Deliverable D3.2
5G-PPP security enablers open specifications (v1.0)

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Executive summary

This document describes the open specifications of 5G Security enablers planned to compose the first software release (i.e. v1.0) of 5G-ENSURE Project due in September 2016 (M11). The enablers' open specifications are presented per security areas in scope of the project, namely: Authentication, Authorization and Accounting (AAA), Privacy, Trust, Security Monitoring, and Network management & virtualisation isolation. For each of these categories the open specifications of all enablers planned in the project's Technical Roadmap for v1.0 and having features for v1.0 are detailed following the same template. Overall, this deliverable paves the way towards the development and demonstration of the first set of 5G-ENSURE security enablers as planned for v1.0 in the project's Technical Roadmap (i.e. D3.1). It is also a valuable input to both works on the 5G Security architecture and 5G Security testbed, since it provides the details regarding security enablers necessary in order to understand their mapping to 5G security architectural components, as well as their integration, testing, demonstration, and assessment on the 5G security testbed.

Foreword

5G-ENSURE belongs to the first group of EU-funded projects which collaboratively develop 5G under the umbrella of the 5G Infrastructure Public Private Partnership (5G-PPP) in the Horizon 2020 Programme. The overall goal of 5G-ENSURE is to deliver strategic impact across technology and business enablement, standardisation and vision for a secure, resilient and viable 5G network. The project covers research & innovation - from technical solutions (5G security architecture and testbed with 5G security enablers) to market validation and stakeholders' engagement - spanning various application domains.

Deliverable D3.2 follows deliverable D3.1 5G-PPP security enablers Technical Roadmap (early vision) that has delivered an early description of 5G security enablers requested to achieve 5G security vision as illustrated in deliverable D2.1 on Use Cases.

Whereas objective of D3.1 was mainly focusing on highlighting 5G Security enablers requested (in terms of their high level product vision) and their scheduling between release one and the next release, D3.2 clearly focuses on providing the open specifications of enablers planned to be software released (through their planned features) for the first release (i.e. v1.0 due at M11).

As such, D3.2 details the open specifications of each of the enablers whose features are planned for the first software release (v1.0).

The 5G-ENSURE security enablers' open specifications are public and royalty free (see Open specification legal notice in Annex A) in order to enable anyone interested to come up with its own "compliant" implementation.

D3.2 will be followed by deliverable D3.3 "5G-PPP Security enablers software release (v1.0)" and deliverable D3.4 "5G-PPP Security enablers documentation (v1.0)" due both at M11, that are respectively devoted to a software release of the 5G Security enablers v1.0 with their planned features (i.e. reference implementations following open specifications) and their accompanying documentation (e.g. installation and administration guide, user & programmer guide, unit testing plan).

This deliverable is also an important input to other technical Work packages of the project to feed into their work. Especially WP2 for what concerns the on-going work on 5G security architecture, since enablers specified in D3.2 would form some of the main building blocks of this architecture, but also WP4, as it is responsible for the instigation of a 5G security testbed where these enablers can be hosted and assessed.

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Abbreviations

3GPP	3rd Generation Partnership Project
AAA	Authentication, Authorization and Accounting
AKA	Authentication and Key Agreement
AMF	Authentication Management Field
API	Application Programming Interface
ASME	Access Stratum Mobile Equipment
AUTN	Authentication Token
AV	Authentication Vector
AVP	Attribute-Value Pair
B-TID	Bootstrapping Transaction Identifier
BSF	Bootstrapping Server Function
BYOI	Bring-your-own-identity
CEP	Complex Event Processing
CK	Ciphering Key
DH	Diffie-Hellman
EPS	Evolved Packet System
GBA	Generic Bootstrapping Architecture
GUSS	GBA User Security Settings
HE	Home Environment
HLR	Home Location Register
HMAC	Hashed Message Authentication Code
HSS	Home Subscriber Server
IDS	Intrusion Detection System
IK	Integrity Key
IoT	Internet-of-Things
IPS	Intrusion Protection System
JSON	JavaScript Object Notation
KDF	Key Derivation Function
LTE	Long Term Evolution
MAC	Message Authentication Code
ME	Mobile Equipment
MITM	Man-In-The-Middle
MME	Mobility Management Entity
MTC	Machine-Type Communication
NAF	Network Application Function
PFS	Perfect Forward Secrecy
PLMN	Public Land Mobile Network
RAND	Random bit string
RES	Response
SDN	Software Defined Network
SGSN	Serving GPRS Support Node
SIEM	Security Information and Event Management
SN	Serving Network
UE	User Equipment
eUICC	Embedded Universal Integrated Circuit Card
UICC	Universal Integrated Circuit Card
UMTS	Universal Mobile Telecommunications System
USIM	Universal Subscriber Identity Module

vGBA	Vertical GBA
VLR	Visitor Location Register
XRES	Expected User Response

1 Introduction

This document describes the open specifications of 5G Security enablers planned to compose the first software release (i.e. v1.0) of 5G-ENSURE Project due in September 2016 (M11). As such this document mainly focuses on enablers identified in the project's Technical Roadmap (D3.1) and having features for v1.0. As for enablers planned for v1.0 but with no feature planned, the open specifications would be given in the context of the next release of this deliverable with the exception of the Basic AAA enabler where open specs were assessed as good enough to be here reported. The enablers' open specifications are presented per security areas in scope of the project, namely: Authentication, Authorization and Accounting (AAA), Privacy, Trust, Security Monitoring, and Network management & virtualisation isolation. For each of these categories the open specifications of the enablers planned in the Technical Roadmap for v1.0 and having features for v1.0 are detailed following same template.

The table below summarizes the 5G-ENSURE technical roadmap for R1 (or v1.0) as described in D3.1. It shows the 5G security enablers in scope providing their (code) name, the category to which they belong to (i.e. AAA, Privacy, Trust, Security Monitoring, Network management & virtualization isolation), as well as the features planned for their 1st software release. The enablers for R1 (v1.0) and having features are those whose open specifications are given in this deliverable, with the exception of basic AAA whose early open specification is also here provided.

Table 1: 5G-ENSURE Technical Roadmap for R1

Category	**5G-ENSURE security enablers**	**Features planned for 1st sw release (R1)**
AAA	*Basic AAA enabler*	*A pre-study is required in the time frame of R1, however, due to lack of resources, an implementation is not feasible for the same release. Prototyping can potentially be done for R2.*
	Internet of things (IoT)	Group authentication
	Fine-grained Authorization	Basic Authorization in Satellite systems
		Basic distributed authorization Enforcement for RCDs
	Federative authentication and identification enabler	*none*
Privacy	Privacy Enhanced Identity Protection	Encryption of Long Term Identifiers **(**IMSI public-key based encryption**)**
	End-to-end encryption	*none*
	Device identifier(s) privacy	Enhanced privacy for network attachment protocols
	SIM-based anonymization	*none*
	Privacy policy analysis	*none*
Trust	Trust Builder[2]	5G Asset model

[2] The features planned for this enabler in R1 have changed. Please see the status section of the Trust Builder specification for more information.

Category	**5G-ENSURE security enablers**	**Features planned for 1st sw release (R1)**
		5G Threat knowledgebase v1
	Trust Metric Enabler	Trust metric based network domain security policy management
	VNF Certification	VNF Trustworthiness Evaluation
Security Monitoring	System Security State Repository	Deployment model ontology
	Security Monitor for 5G Micro-Segments	Complex Event Processing Framework for Security Monitoring and Inferencing
	Satellite Network Monitoring	Pseudo real-time monitoring
		Threat detection
	Generic Collector Interface	Log and Event Processing
	Proactive Security Analysis and Remediation	5G specific vulnerability schema
		5G specific vulnerability schema implementation
		PulSAR interface with Generic Collector
		first study of a scenario based threat management
Network management & virtualization isolation	*Anti-Fingerprinting*	*Controller-Switch-Interaction Imitator* *This enabler has already been developed and evaluated. See the technical report publicly available at http://arxiv.org/abs/1512.06585, which has been accepted for publication at the IEEE Transactions on Forensics and Information Securit). Its open specification is not included in this deliverable, since no further evaluation of its features is planned in R1.*
	Access Control Mechanisms	Southbound Reference Monitor
	Component-Interaction Audits	Basic OpenFlow Compliance Checker
	Bootstrapping Trust	Integrity Attestation of Virtual Network Components
	Micro Segmentation	Dynamic Arrangement of Micro-Segments

Each of the enablers' Open Specification encompasses a range of information including, amongst others, the description of the enabler (e.g. scope, behaviour and intended use), definition of terms to assist the understanding of the specification, legal notice that applies, architectural sketch depicting components and their main interactions, preliminary description of the API that the enabler will support when it applies, to the description of non-functional features.

This document is organized as follows:

- Section 1 is a general introduction.
- Section 2 is devoted to the AAA category of enablers.
- Section 3 is devoted to Privacy category of enablers.
- Section 4 is devoted to Trust category of enablers.
- Section 5 is devoted to Security monitoring category of enablers.
- Section 6 is devoted to Network Management & Virtualization category of enablers.
- Section 7 concludes the document, while References are provided at the end.

The category descriptions of Sections 2-6 provide the open specification of each of the enablers planned to be software released for v1, this in accordance with features as per Technical Roadmap.

Overall, this deliverable paves the way towards the development of the first set of 5G-ENSURE security enablers as planned for v1.0 in the project's Technical Roadmap (i.e. D3.1). It is also a valuable input to both work on 5G Security architecture and 5G Security testbed, since it provides all the details regarding the security enablers necessary for their subsequent mapping to 5G security architectural components, as well as for their testing/demonstration/assessment on the testbed.

2 AAA Security Enablers open specifications

2.1 Internet-of-Things: Open specifications

2.1.1 Preface

Internet-of-things (IoT) is expected to be an essential use case and business area in 5G. This security enabler provides important new features, with their specification, to the existing AKA protocol that is directly aimed at enabling IoT.

The main feature in this enabler is the group-based authentication [3], which is planned for release 1. The development of all features, including those for release 2 of the enabler, has begun, namely: authentication of USIM-less devices; authentication support for BYOI; vertical GBA; and group-based authentication. These features are introduced in the Overview, Basic Concepts and Main interactions. The main feature, group-based authentication, is explained in detail.

Moreover, the open specification introduces an additional feature, vertical Generic Bootstrapping Architecture (GBA), which was not part of the 5G-PPP security enablers' technical roadmap (early vision). This feature has been added to support additional requirements coming from the use case 3.2 from deliverable D2.1.

2.1.2 Status

The IoT enabler is currently under development. The API and detailed open specification below are only given in view of the feature in scope of release 1.

The group authentication enabler includes an initial proposal of the protocol's message exchange and the additions and modifications of the information elements. The specification of specific functions is preliminary.

2.1.3 Copyright

2.1.4 Legal notice

The Legal notice that applies to these specifications is given in Annex A.

2.1.5 Terms and definitions

A group is formed by one or more members that share similar features. Examples of common features include members that do the same task, members located in the same geographical area, or members belonging to the same owner. A group may also share a macro feature that is derived by a combination of single features.

An inverted hash tree [1] is a data structure in which a node is linked to at most two successors (children), and the value of each node is computed using a family of hash functions h_*. The value of the root is given, while the value associated with any other node is derived from the hash value of its parent (Figure 1). Since two siblings use two different hash functions, they get two different hash values. In particular, we consider two hash functions $h_0$and h_1, and recursively assign the value of each node n_{ij} located at i^{th} position and j^{th} level as follows.

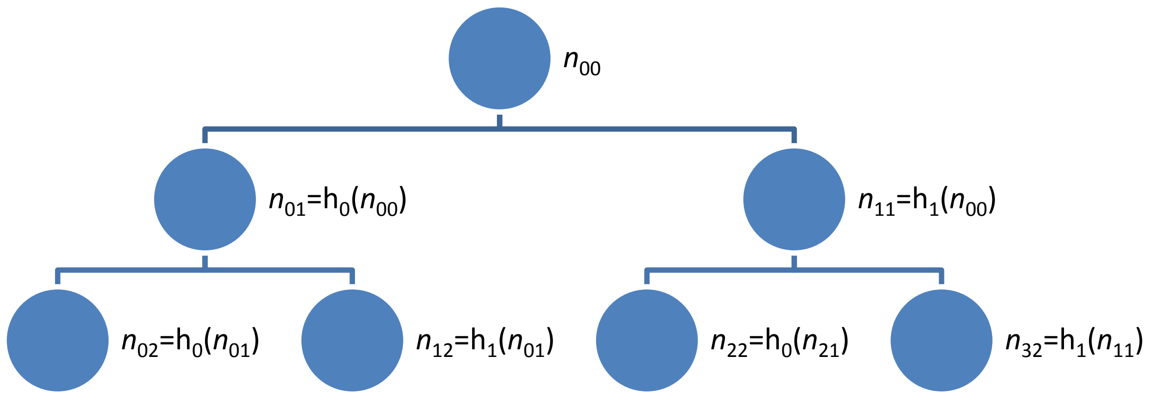

Figure 1: Example of an inverted hash tree of level 2

2.1.6 Overview

The IoT Enabler consists of four main features: support for authenticating USIM-less devices; enabling authentication based on 3rd party identities, i.e. bring-your-own-identity (BYOI); vertical GBA; and introduced support for group-based authentication, aimed at resource constrained devices. As mentioned above, all features will be introduced in the first chapters, while group-based authentication will be described in detail, as it is scheduled for release 1.

An important aspect of IoT, in the context of 5G, is to be able to use non-USIM/SIM based authentication schemes in a 3GPP network. The feature *authentication of USIM-less* devices looks into the adaptions to the AAA framework needed to introduce such a features in the authentication schemes in a 3GPP network, including aspects of identifying which algorithm to use in the AKA as well as which AAA server to contact.

A similar adaption to authentication in 5G, with the expected boom of devices, is the *group-based authentication* feature, which introduces an extension of the current EPS-AKA, mainly aimed at resource constrained devices. The goal of the group-based AKA protocol is to make it more suitable for massive deployment scenarios by reducing the signaling between the serving and home network.

Thirdly, the *vertical Generic Bootstrapping Architecture (GBA)* feature optimizes the use of GBA (3GPP TS 33.220) for resource constrained devices by having the device implicitly perform the GBA bootstrapping during authentication to the network, in the network attach. Thus, the device does not have to perform the HTTP Digest AKA negotiation with the BSF to bootstrap its GBA credentials. Once attached to the 3GPP core the device can set-up a secure connection, e.g. perform GBA based HTTP Digest authentication, to a NAF without additional signaling to the BSF. The solution is called vertical GBA (vGBA) as the keys generated during AKA are re-used at different layers in the stack. The solution is described using the nodes of 4G networks, as 5G network nodes are yet to be specified.

With 5G's expected "as a service" approach, the IoT enabler will also introduce a framework for enabling an organization to reuse an existing AAA infrastructure to authorize 5G access via a MNO. The access stratum may be provided by either the MNO or the organization itself, it is however assumed that the organization is unable, or find it undesirable, to provide a full core network. From a high level, the setup is technically similar to a Mobile Virtual Network Operator (MVNO) providing networks services via a MNOs network. However, from a trust perspective, it introduces entirely new aspects as the organization may not abide by the same rules and regulations as classical operator. It is thus possible that the organization may need to adopt to additional regulatory frameworks, but this is outside the technical scope of the enabler. A new entity, the Industrial Automation Control (IAC), which is functionally similar to an MME, is introduced in the operator network in order for the operator to distinguish between roaming agreements with other MNOs and other external organizations.

2.1.7 Basic concepts

Relevant LTE/EPS signaling entities and interfaces during roaming

The interfaces between a UE and the eNB is denoted Uu, the interface between an eNB and a MME is denoted S1-MME. The interface between the MME and the HSS is denoted S6a. In a classical roaming scenario, the MME and eNB are provided by a visited network, the MME will request authentication data from the HSS located in the home network of the subscriber.

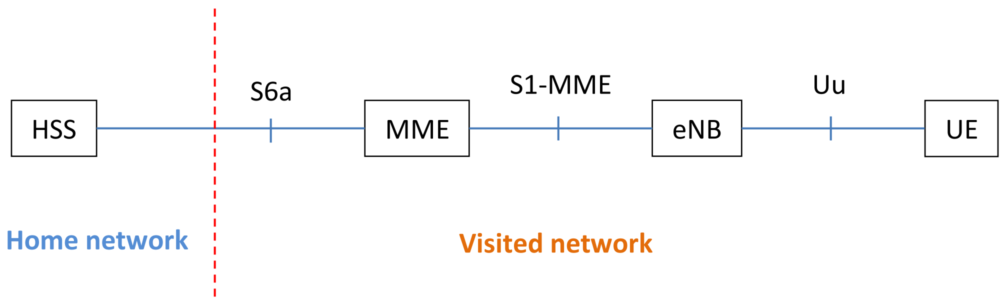

Figure 2: Signalling entities and interfaces during roaming

The authentication vector on the S6a reference point

When a UE attaches to the 3GPP core network it performs the AKA exchange for mutual authentication and key agreement with the network. The AKA is performed between the UE and the MME, which fetches authentication vectors (AV) from the HSS over the S6a reference point.

Generic Bootstrapping Architecture

GBA is a way of using the 3GPP subscription credentials for authenticating the UE and getting keys to a service (Network Application Function, NAF). To achieve this, the UE first bootstraps with the Bootstrapping Server Function (BSF), a bootstrapping entity in the 3GPP core, using the 3GPP credentials and the HTTP Digest AKA protocol. The BSF fetches AVs from the HSS over the Zh reference point, in a similar way as the MME over the S6a reference point. After bootstrapping, the UE can, e.g. using HTTP Digest, authenticate to the service (NAF) based on the bootstrapping context with the BSF. The BSF provides the NAF with a service specific key that the NAF can use for authentication of the UE and securing further communication of the session.

Group-based AKA

The functional goal of a group-based AKA protocol is to authenticate a group of devices efficiently, minimizing the cost of repeated message exchanges and communication delays. More specifically, a group-based AKA protocol aims to reduce the signalling between the mobility management entity (MME) and home subscriber server (HSS) when a large group of machine-type communication (MTC) devices with similar features requires network access simultaneously.

2.1.8 Main interactions

2.1.8.1 Use cases

A 5G PLMN is expected to support a much wider range of devices than previous generations. Additionally, slicing technology will also enable compartmentalization of devices that could potentially be classified into different security categories. It is expected that the USIM is unsuitable for certain categories, e.g. IoT and resource-constrained devices, which will be addressed by the *authentication of USIM-less devices* feature that looks into the integration of non-USIM based AKA procedure into the 5G system.

Similarly, group-based authentication aims to increase the capacity for massive deployments of MTC devices in 5G. At large events, e.g. sporting events, we envision that 5G connected sensors and tracking devices will be deployed at a massive scale. We foresee that the existing EPS-AKA is not sufficiently efficient to handle the massive simultaneous authentication requests that these devices will incur. This is especially important in the case of device subscriptions in a roaming setup. With the group-based authentication approach, the signalling between the MTC devices and their HSS are significantly reduced, enabling the serving network to handle almost all of the signalling independently from the home network, and reducing the latency drastically.

The MTC is preconfigured with the necessary group terms, such as the group ID. The pre-configuration can be performed via non-3GPP access. The identity of the MTC is stored in the USIM, fulfilling the requirements of securing the identities against attacks such as cloning.

We imagine that the configuration of the groups will be performed using an application programming interface (API) to access the network. It allows for an automated approach for submitting the MTC identities that should belong to the specific group.

To further enhance 5G for resource-constrained devices, the enabler will introduce vertical GBA. The basic use case for vertical GBA is that a constrained UE wishes to use some GBA enabled service(s). Constrained devices are in many cases constrained especially regarding power supply and might be operating solely on battery power. To optimize the performance of these types of devices, reducing the amount of signalling required by the device is an important step for improving the lifetime of the device. With vGBA, the UE does not have to perform an explicit GBA bootstrapping with the BSF, thus using vGBA reduces the amount of signalling needed for authentication to GBA enabled services (NAFs), using the pre-generated GBA credentials.

Finally, the use case for BYOI is to attract enterprises that already have a deployed AAA infrastructure to use 5G. By establishing a contract with a MNO, the enterprise can allow their devices to perform roaming and utilize other aspects of a PLMNO.

2.1.8.2 Components and interaction overview

Authentication of non-USIM based devices

Non-USIM based AKA procedures will impact the AKA protocol as well as the identification protocols utilized by the current 3GPP standards, e.g., in a certificate public key pair based authentication system the standard IMSI may not necessarily be an identifier that is used to identify the subscription.

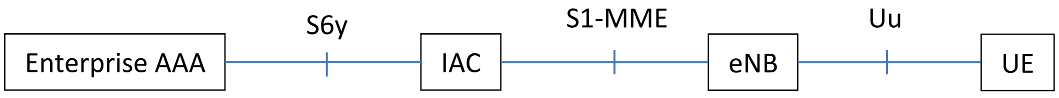

Figure 3: Network deployment considered for non-USIM based devices

In the considered solution, it is assumed that there will be no support for negotiation of authentication methods, the subscription will be associated with an identifier that maps uniquely to a provided ID. The ID provider may either be the MNO, that utilize HSS for AKA procedures, or an enterprise that has deployed an Enterprise AAA for the AKA procedures. It is also assumed that the identifier uniquely determines the AKA protocols to be used. A UE may support several AKA protocols and multiple ID providers, e.g., both towards a HSS and an Enterprise AAA. In such a situation it is assumed that the UE selects which AKA protocol to use, e.g., based on the selected slice ID.

Authentication support for BYOI

As illustrated by the uses cases 1.2 and 1.3 in [2], different levels of enterprise network deployment can be imagined. In all cases, the enterprise is assumed to operate its own AAA. In some scenarios, the organization own and operate their own base stations. However, this is similar to the Home eNodeBs already supported in LTE/EPS and should, as such, not introduce new aspects, beyond the currently defined Home eNB technical solutions. The deployment considered is summarized in figure 4.

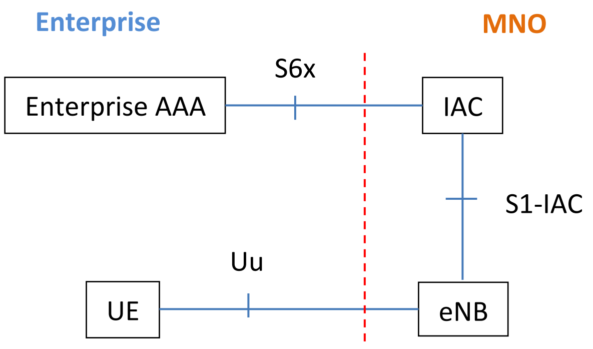

Figure 4: Network deployment where Enterprise operates an AAA

The main difference compared to classical roaming, is that the IAC may require some form of security assurance from the UE and Enterprise AAA during the AKA procedure: this could be in the form of a remote attestation procedure, where the device attests to its current security state; or could just be a classification of the security level of the algorithms used that can be used to assess which slice the UE is allowed to utilize. Alternatively, or in addition, a contractual agreement (with liabilities) between the MNO and the Enterprise could stipulate requirements on secure storage/processing of the credentials in the UE.

Vertical GBA

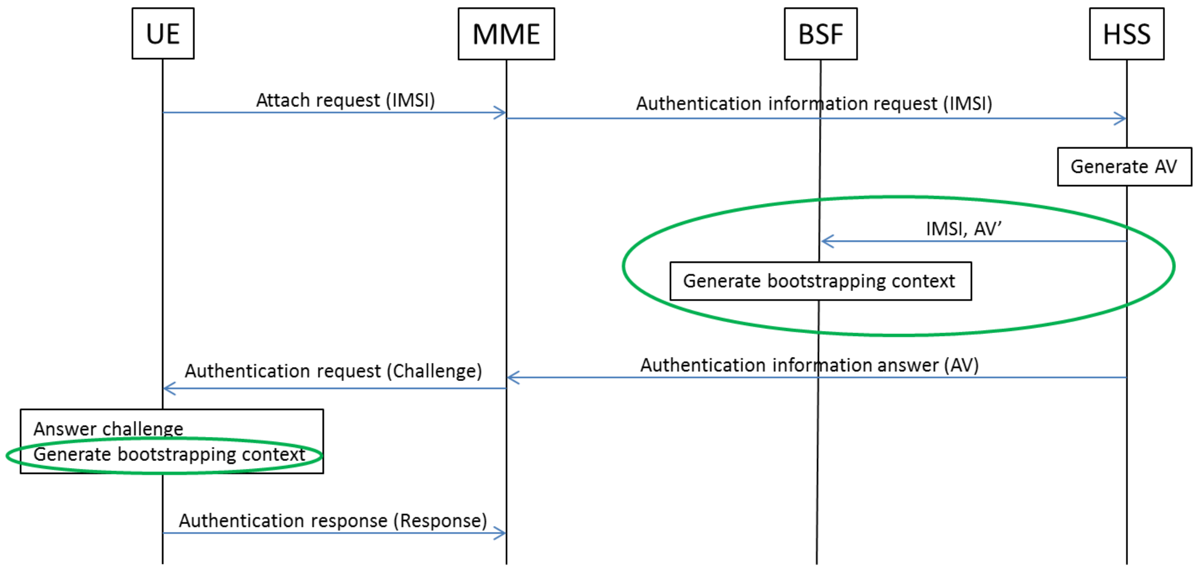
UE
MME
BSF
HSS
Attach request (IMSI)
Authentication information request (IMSI)
Generate AV
IMSI, AV'
Generate bootstrapping context
Authentication request (Challenge)
Authentication information answer (AV)
Answer challenge
Generate bootstrapping context
Authentication response (Response)

Figure 5: vGBA bootstrapping during AKA

Figure 5 shows the modified AKA flow when vGBA is used. During AKA the UE generates the GBA bootstrapping context and associated credentials. The HSS provides the BSF with a subset of the AV (AV'), which is used by the BSF for generating the corresponding bootstrapping context to match a successful GBA bootstrapping end-result.

Group-based authentication

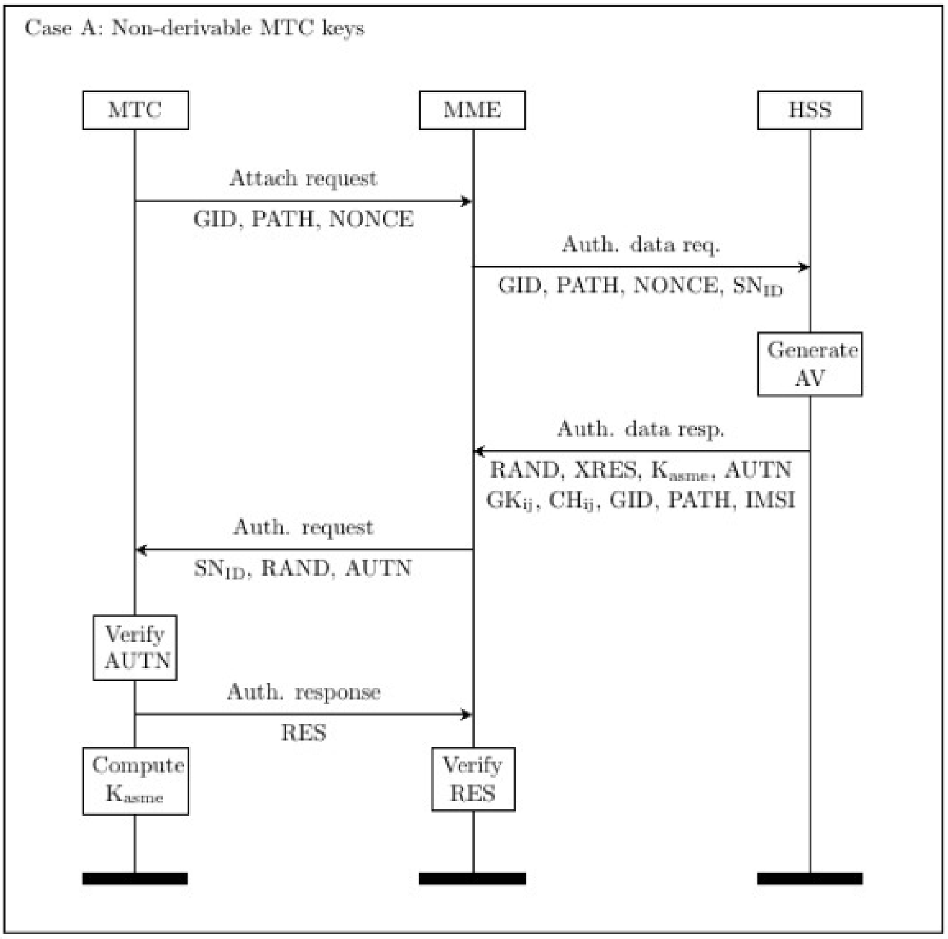

Figure 6: The message sequence chart of group-based authentication when the MME cannot derive the keys for the MTC

The underlying idea of the proposed group-based AKA is to associate each MTC device to a value of the leaf node of an inverted hash tree. The tree is generated by the HSS, which reveal a sub-root node to the MME so that it can authenticate the (sub)group of all MTC descendants. This allows the HSS to control the trade-off between security and efficiency dynamically. Additionally, no shared credentials exist in the group.

Two cases can be distinguished in the proposed protocol: Case A, in which the MME cannot derive the keys for the MTC without signalling with the HSS; Case B, in which the MME can derive such keys.

Case A: Figure 6 provides an overview of the initial *Attach Request* from an MTC device for a specific group, thus requiring the MME to retrieve the group elements from the HSS. The protocol follows the message exchange as specified for EPS-AKA, with additional terms included for the group-based authentication, which are addressed for the MME.

The MTC initiates the protocol by issuing the *Attach Request*, containing the additional terms necessary to specify the group it belongs to, and its position in the inverted hash tree. If the MME is unable to derive keys associated with the MTC device (e.g. the request sent by the first MTC of a specific group), it requests authentication vectors from the HSS via an *Authentication Data Request*.

The HSS will verify that the group id and path is valid and generates and send the authentication vector, including the new terms intended for the MME to enable group-based authentication for future attach requests. Specifically, the HSS decides which sub-root node of the inverted hash tree is sent to the MME.

After receiving the *Authentication Data Response* from the HSS, the MME will continue the message exchange as specified in EPS-AKA. The MME will be able to derive keys for future authentication requests, based on the additional terms provided in the authentication data response from the HSS. This is covered by Case B.

Shall an MTC device crash during the protocol run, it can reattempt the authentication procedure using the classic AKA procedure.

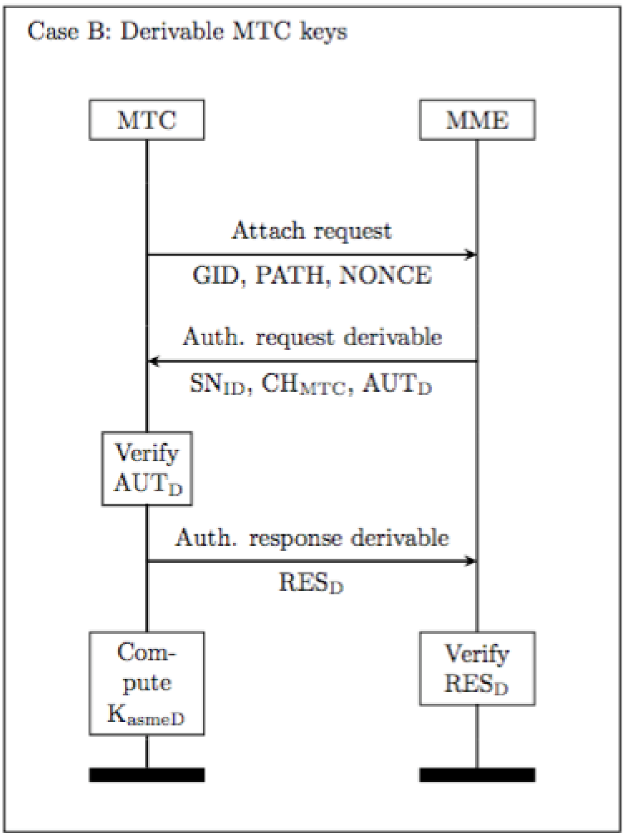

Figure 7: The message sequence chart of group-based authentication when the MME can derive the keys for the MTC

Case B: Figure 7 provides an overview of the succeeding AKA protocol runs for the same group. The MME has stored the necessary terms from the Authentication Data Response as in Figure 6, and can derive keys for the remaining MTC devices. The protocol is executed solely within the serving network, without the need to interact with the HSS of the group members home network.

2.1.9 Architectural drivers

In the following chapters, the specification will solely cover the release 1 feature of the enabler, group-based authentication.

2.1.9.1 High-Level functional requirements

The main goal of the group-based authentication extension is to make the EPS-AKA protocol more suitable for massive deployment scenarios. This is achieved by removing the existing 1-to-1 correlation between the number of MTC devices and the number of messages in the authentication signaling to the HSS, located in the subscriber's home environment. A group can be defined by an arbitrary attribute.

The group(s) are defined in the HSS, thus in this release the members of a group must be subscribers of the same (virtual) operator, as the HSS must know the individual identity of each MTC device. Additionally, the feature requires provisioning of the group ID, the assigned path of the binary tree, and the obfuscated value given to each MTC. The provisioning procedure is out of scope in the current release.

With a configured group in the HSS, only the first authentication request, independent of the actual MTC device that requests it, is sent to the HSS. The HSS will thereafter send the necessary terms to the MME to enable group-based authentication for the succeeding authentication requests.

The group-based authentication feature requires a universal integrated circuit card (UICC or (e)UICC) based authentication in this release to provide a strong identification of the MTC device. To prevent cloning of shared credentials, the feature is built with independent secrets for each MTC device, configured by the HSS. Furthermore, the feature provides properties of perfect forward secrecy (PFS) to prohibit future, or past, members of a group of being able to decipher data exchanged when they were not part of the specific group. The feature is compliant with lawful interception requirements since all members of a group can be uniquely identified.

2.1.9.2 Quality attributes

A product implementing one or several of the features described in enabler should be evaluated primarily based on the following quality attributes:

*Security:

- Confidentiality
- Integrity
- Non-repudiation
- Accountability
- Authenticity

*Compatibility:

- Co-existence
- Interoperability

2.1.9.3 Technical constraints

Since the group is configured in the HSS, all members in a specific group must have a subscription from the same HSS. Furthermore, the key provisioning for each MTC device that should be part of a group is out of scope for this release, hence it must be preconfigured manually at this stage of research. Additionally, the API access for configuring the group(s) to the core network is out of scope.

2.1.9.4 Business constraints

No known business constraint exists.

2.1.10 Detailed specifications

2.1.10.1 Introduction

In this section, key concepts regarding the group-based authentication protocol and the new terms used are introduced.

The proposed group-based extension to the AKA protocol use the same cryptographic primitives that already exist in EPS-AKA, e.g. hash and MAC functions, no new primitives are added. However, new terms are introduced in the protocol to support this feature, see Table 2.

In the message exchange between the MTC device and MME, the initial message of the protocol is the *Attach Request*. Depending on whether the MME has earlier authenticated an MTC of the same group as the *Attack Request* or not, the second run of the protocol may differ. In Case A (see Figure 6), the MME contacts the HSS to retrieve the necessary information. The response from the HSS, namely the authentication vector, is returned to the MME as specified in EPS-AKA, however with additional elements for group-based authentication support. The new elements are stored in the MME.

In Case B (see Figure 7), the MME does not need to contact the HSS to authenticate the MTC.

Term	**Description**
GID	Group identifier
PATH	The path assigned to the MTC. Each MTC is assigned with the same path in both trees.
NONCE	Random number
GKij	The (sub)group key assigned to the i^th of GK tree at j^th level.
CHij	The challenge key assigned to the i^th of CH tree at j^th level.
GK_{MTC}	The key associated to the MTC. It is the hash value of the leaf of the GK tree at PATH.
CH_{MTC}	The challenge key associated the MTC. It is the hash value of the leaf of the CH tree at PATH.
O_{MTC}	The obfuscated value that hides the key associated to the MTC
AUT_D	The authentication parameter in the group authentication
RES_D	The response parameter in the group authentication
K_{asmeD}	The session key generated in the group authentication

Table 2: New terms introduced by the group-based authentication protocol

2.1.10.2 Conformance

An implementation to be reported as conformant should comply with the open specifications here stated for the enabler.

2.1.10.3 API specifications

The group-based authentication protocol will introduce functionality adjustments, modifications as well as new content in the EPS that will need specification. A high-level description of the new aspects and elements introduced in the main entities which perform AKA will be presented first, thereafter the modifications to the AKA signaling will be presented.

2.1.10.3.1 New functions, messages and commands

In this section the new functions, messages and USIM commands are introduced in the UE, MME and HSS respectively.

2.1.10.3.1.1 UE, USIM application & UICC commands

The USIM application is responsible for interaction between the mobile equipment (ME) and the Universal Integrated Circuit Card (UICC). The ME and USIM combined is denoted user equipment (UE). The UICC is responsible for storing security critical data. The group-based authentication protocol introduces four new elements, which must be supported by the USIM application with regards to the secure storage in the UICC. The purpose of these elements is defined in Table 2.

- GID
- PATH
- NONCE
- O_{MTC}

Additionally, the UE must support new commands in order to perform the group-based authentication protocol.

- A key derivation and authentication command in the USIM, which produce the session key K_{asmeD}, authenticates the token AUT_D to enable authentication of the network, and produce the response RES_D. See Table 2 for a description of the terms.
- A random generator command for producing the NONCE value.

Moreover, the UICC must provide functionality to update and read additional elementary files (EFs). For read operations of GID; PATH; O_{MTC} the output value should be the value variable. For update operations of GID; PATH; $O_{MTC}$the output should be success/failure.

2.1.10.3.1.2 Mobility Management Entity (MME)

The group-based authentication protocol introduces five new elements to the MME to enable session handling, processing and authentication.

- GID
- PATH
- NONCE

- GKij
- Chij

Additionally, the MME requires two new functions in order to perform the group-based authentication protocol.

- A function to produce K_{asmeD} and RES_D , described in Table 2, to enable the MME to authenticate the UE.
- A function for generating the authentication token AUT_D used in Case B (figure 7), of the group-based authentication protocol.

2.1.10.3.1.3 Home Subscriber Server (HSS)

The group-based authentication protocol introduces 5 new elements to the HSS. The purposes of these elements are described in Table 2.

- GID
- PATH
- NONCE
- GKij
- Chij

Additionally, the HSS requires a function for fetching or generating Chij, GKij elements depending on GID and PATH.

2.1.10.3.2 Signalling

There are five messages included in the group-authentication protocol: attach request, authentication data request, authentication data response, authentication request derivable, and authentication response derivable. These can be seen in Figure 6 and Figure 7.

These messages closely correspond to the five message exchanges in the current EPS AKA procedure. In order to perform the group-authentication protocol, the network is required to support additional elements, which are added to the existing AKA messages. Additionally, the protocol requires a new message in scenario Case B.

2.1.10.3.2.1 UE – MME

The signalling between the UE and the MME in Case B requires a new message denoted *Authentication Request Derivable*, sent from the MME to the UE, see Figure 7. The *Authentication Request Derivable* is sent as a response of the *Attach request*; in case the specific device is initiating its first authentication request.

The UE responds with *Authentication Response Derivable*, containing $RES_{D,}$ see Table 2 for explanation of RES_D. The Authentication Response Derivable is similar to the *Authentication Response* in EPS-AKA, which contain *RES*.

2.1.10.3.2.2 MME - HSS

The signalling methods between the MME and HSS, specified in the S6a interface, contain the authentication information request (AIR) and the authentication information answer (AIA) message. The group-based authentication protocol appends two attribute value pairs (AVPs) to these message.

The *Requested-group-authentication-info* include the Nonce and Path, which are added as information elements to the AIR.

The *Group-response-vector* include the GKij, CHij, and IMSI, which are appended as an option in the existing Authentication Info information element.

2.1.11 Re-utilised Technologies/Specifications

The software prototype for group-based authentication is built using the Open Air Interface as foundation.

2.1.12 References

[1] Page, T, “The application of hash chains and hash structures to cryptography,” Technical report Royal Holloway, University of London, 2009.

[2] 5G-Ensure Consortium, *Deliverable 2.1 Use Cases,* [Online]. Available: http://www.5gensure.eu/sites/default/files/Deliverables/5G-ENSURE_D2.1-UseCases.pdf, 2016.

[3] Giustolisi R., Gehrmann, C., Svensson M., “Lightweight 5G Group-Based Authentication”, Technical report, to appear.

2.1.13 Acknowledgements

We would like to thank Markus Ahlström and Simon Holmberg for their contribution and excellent work with the API specifications.

2.2 Fine-grained authorization: Open specifications

2.2.1 Preface

This section describes the open specification of the Fine-grained authorization enabler focusing on authorization for two areas, which are expected to be strongly involved in 5G.

First, in addition to the authentication focus brought by the IoT enabler, this enabler will research new methods to provide distributed authorization, suitable in resource-constrained environments. The goal of the enablers is to make 5G fully ready for Identity and Access Management (IAM) of IoT devices.

The second area is based on requirements from 5G satellite business needs and 5G-ENSURE use cases. The goal is to provide an integrated satellite and terrestrial approach, compared to the diverse methods existing today, to provide secure fine-grained access control to satellite resources (i.e. network element and services).

Please, consult as well the "5G-ENSURE_D3.1 5G-PPP security enablers technical roadmap (early vision)" [9] document and the website on http://www.5gensure.eu/ in order to understand the complete context of the 5G-ENSURE project.

2.2.2 Status

A prototype of the enabler is currently being developed.

2.2.3 Copyright

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2.2.4 Legal notice

The Legal notice that applies to these specifications is given in Annex A.

2.2.5 Terms and definitions

This section comprises a summary of terms and definitions used during the later sections.

- **ABAC (attribute-based access control):** an **access control** paradigm whereby access rights are granted according to a combination of attributes of any type (**user**, **resource**, **environment**, etc.).
- **Access:** Performing an **action**.
- **Access control:** Controlling access in accordance with a **policy** or **policy set**.
- **Action:** An operation on a **resource**.
- **Attribute:** Characteristic of a **subject**, **resource**, **action** or **environment** that may be referenced in a **predicate** or **target**.
- **Environment:** The set of **attributes** that are relevant to an **authorization decision** and are independent of a particular **subject**, **resource** or **action**.
- **PAP (policy administration point):** The system entity that creates a policy or policy set.

- **PDP (policy decision point):** component which computes **access decisions** by evaluating the applicable **access control policies**; one of the main functions of the **PDP** is to mediate or deconflict **policies**.
- **PEP (policy enforcement point):** component which enforces **policy decisions** in response to a request from a **subject** requesting **access** to a protected **resource**; the **access control** decisions are made by the **PDP**.
- **PIP (policy information point):** the system entity that acts as a source of **attribute** values (e.g. LDAP).
- **Policy:** A set of **rules**, an identifier for the **rule-combining algorithm** and (optionally) a set of **obligations** or **advice**. May be a component of a **policy set**.
- **RBAC (role-based access control):** an **access control** paradigm whereby access rights are granted according to roles and privileges.
- **RCD (resource-constrained device):** a device which has very few resources to run.
- **Resource:** Data, service or system component.
- **Subject:** An actor whose **attributes** may be referenced by a **predicate**.

For a summary of terms and definitions managed, please refer to “INCITS 359-2012” standard [1] and XACML v3.0 standard [5] section 1.1.1.

2.2.6 Overview

2.2.6.1 Target Use for R1

The enabler provides an AAA solution suitable for an environment of resource-constrained devices and satellite resources, relying on ABAC and/or RBAC policies. It consists of:

- a AAA service, based on 5G AAA credentials, able to provide a secured and standalone proof of the rights granted to a given client over a given device or satellite resource;
- a module for resource-constrained devices, able to ensure the validity and the enforcement of the proof towards a performed request, without requiring more external communication;
- a module for satellite resources, able to ensure the validity and the enforcement of the proof towards a performed request.

We assume that a trust relationship has been pre-established between the owner/provider of the enabler and the devices. The enabler scope does not include the security of the communication channels of the different components. The access control of the enabler administration API is also out of the enabler open specification scope.

2.2.6.2 Target Use for R2

The next release is expected to support policies for decision per user, resource and action, and access control based on dynamically changing parameters.

Also, in the satellite context, the next release is expected to integrate the authentication and authorization mechanism with the Satellite system.

Finally, in the resource-constrained context, the next release is expected to provide the final version of PEP and PDP embedded on the RCD, and the Authentication server delivering a self-sufficient security token allowing decentralized authentication and authorization, compatible with RCDs in terms of performance.

2.2.7 Basic concepts

2.2.7.1 OAuth2concepts

OAuth2 is an authorization protocol which enables a third-party application to obtain limited access to a resource over HTTP, through a prior authorization from the resource owner. OAuth2 defines 4 distinct roles [3]:

- **Resource owner**: an entity capable of granting access to a protected resource. In the enabler context, it refers to a RCD owner who can define its access rights.
- **Resource server**: the server hosting the protected resources, capable of accepting and responding to protected resource requests using access tokens. In the enabler context, it refers to the RCD itself, with the access token enforcement module.
- **Client**: an application making protected resource requests. In the enabler context, it refers to the user who performs a request toward a protected RCD.
- **Authorization server**: the server issuing authorization to the client to access protected resources. In the enabler context, it refers to the enabler AAA service.

In OAuth2, the authorization server grants rights by delivering access tokens. Access tokens are credentials, representing specific scopes of access rights and duration of access, understood by the resource server. They can have different formats, structures, methods of utilization (e.g. cryptographic properties) according to resource server requirements. The token scope is a parameter which is used to limit token access rights.

OAuth2 also specifies a few different usage flows. An applicable one in the enabler context is the *Client Credentials Grant* flow, illustrated in Figure 8. The client can simply request an access token using its credentials when requesting access to the protected resource. This flow is suitable for the cases in which the client is the resource owner, or is already by other means authorized to access the resource, which is applicable in the enabler context through the access control policies.

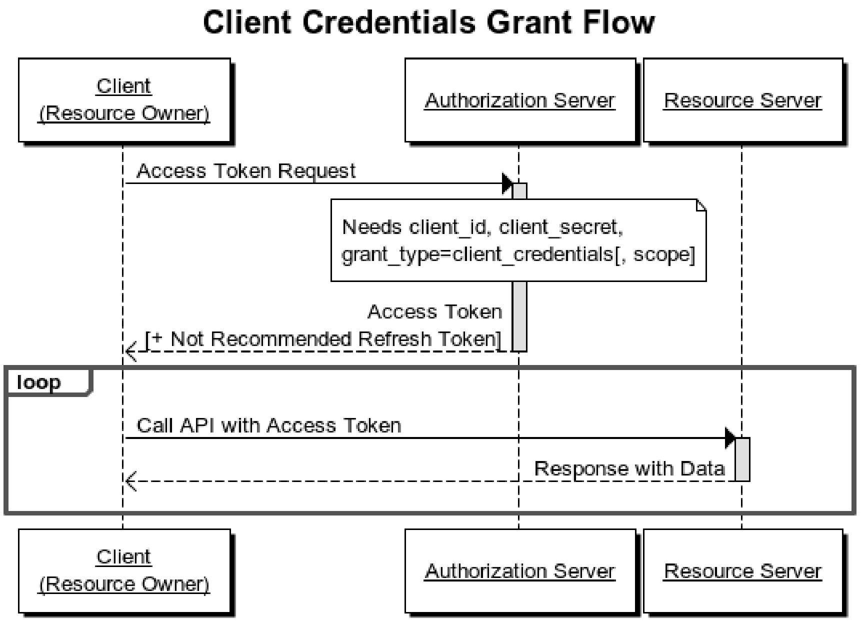
Client Credentials Grant Flow
Client (Resource Owner)
Authorization Server
Resource Server
Access Token Request
Needs client_id, client_secret, grant_type=client_credentials[, scope]
Access Token [+ Not Recommended Refresh Token]
loop
Call API with Access Token
Response with Data
Client (Resource Owner)
Authorization Server
Resource Server

Figure 8: OAuth2 Client Credentials Grant flow

Another applicable flow is the *Authorization Code Grant* flow, illustrated in Figure 9. This flow is suitable in cases where a resource owner can explicitly grant a client an access to its protected resources. The client must get an authorization code in order to access the resource that it requests from the authorization server. The server responds with a redirection URI that the resource owner must reach to log in and then explicitly grant the requested access. The client can then exchange this authorization code against an access token usable with the resource server.

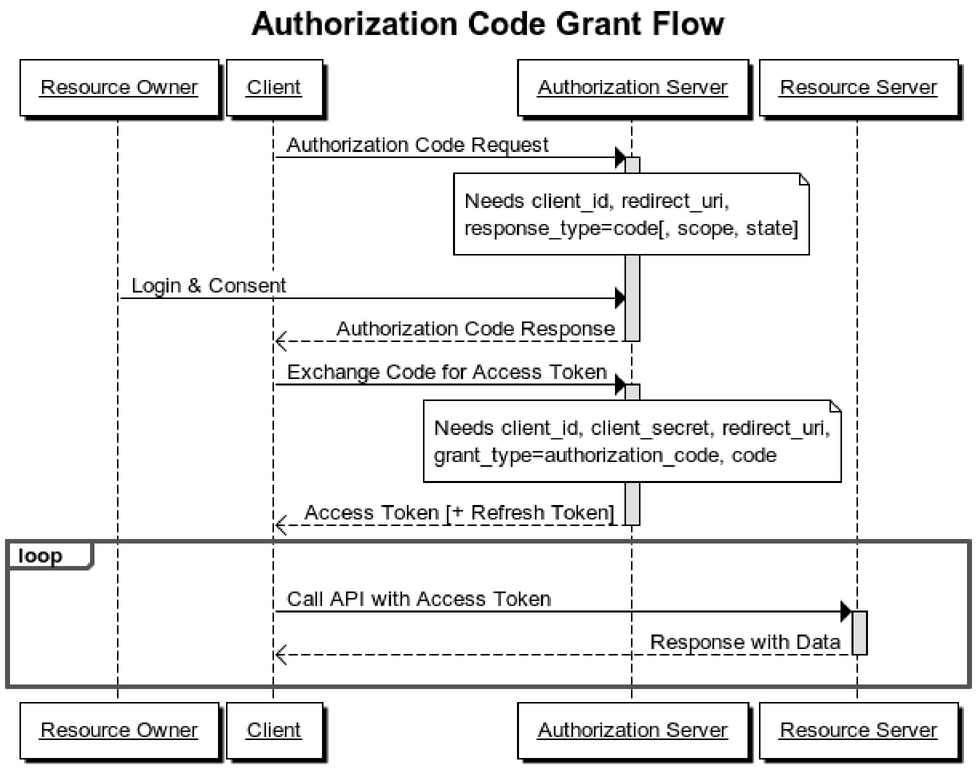
Authorization Code Grant Flow
Resource Owner
Client
Authorization Server
Resource Server
Authorization Code Request
Needs client_id, redirect_uri, response_type=code[, scope, state]
Login & Consent
Authorization Code Response
Exchange Code for Access Token
Needs client_id, client_secret, redirect_uri, grant_type=authorization_code, code
Access Token [+ Refresh Token]
loop
Call API with Access Token
Response with Data

Figure 9: OAuth2 Authorization Code Grant flow

OpenID Connect is an authentication standard based on OAuth2, specifying how to perform authentication through OAuth2, using Authorization Code Grant flow. In this context, the client is a service requiring a user identity; the protected resource is the user identity, obviously owned by the user, which will authenticate to the authorization server in order to provide the client a proof of his identity. The usability of OpenID Connect in the enabler context will be studied for the enabler second release.

2.2.7.2 RBAC concepts
RBAC is an access control method for controlling user access applying roles and permissions. Roles are created for various operations. The permissions to perform certain operations are assigned to specific roles. Subjects are assigned particular roles, and through those role assignments acquire the permissions to perform particular operations.

Three primary rules are defined for RBAC:

- Role assignment: A subject can exercise permission only if the subject has selected or been assigned a role.
- Role authorization: A subject's active role must be authorized for the subject. With rule 1 above, this rule ensures that users can take on only roles for which they are authorized.
- Permission authorization: A subject can exercise permission only if the permission is authorized for the subject's active role. With rules 1 and 2, this rule ensures that users can exercise only permissions for which they are authorized.

2.2.7.3 ABAC concepts

ABAC[2] is an access control method where subject requests to perform operations on objects are granted or denied based on assigned attributes of the subject, assigned attributes of the object, environment conditions, and a set of policies that are specified in terms of those attributes and conditions.

When an access request is made, attributes and access control rules are evaluated by the ABAC mechanism to provide an access control decision. In its basic form, the ABAC mechanism illustrated in Figure 10 contains both a Policy Decision Point and a Policy Enforcement Point.

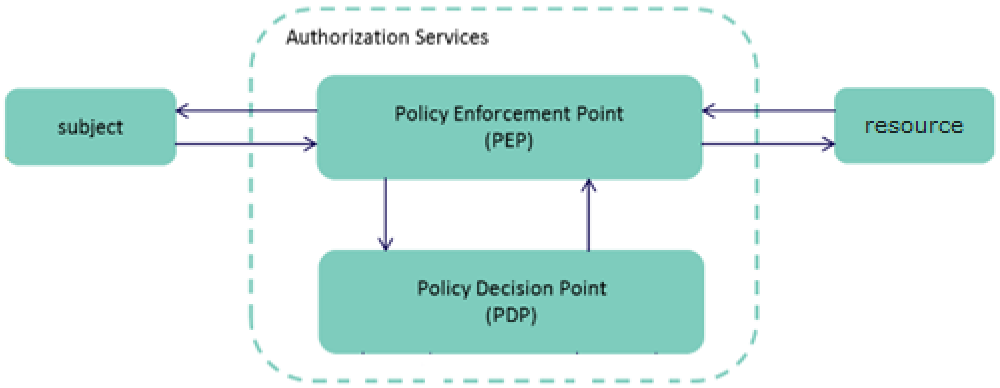

Figure 10: Basic ABAC core mechanism

The PEP takes place in front of the protected object in order to filter subject request attempts, in accordance with the access control policy. For each incoming subject request, the PEP builds an authorization request toward the PDP, assigning different attributes according to information extractable from the subject request. The PDP is charged to evaluate the access control policy with assigned attributes and decide whether the subject request is conforming or not.

However, in the resource-constrained context, the objective is to make PEP and PDP independent and break their direct communication link. To do this, the PDP should perform a partial evaluation of the policy based on the authenticated subject information, then return a remaining attributes combination, usable as an access token scope, in order to let the PEP know about the subject access rights.

In the satellite context, the ABAC core mechanism is extended with two entities:

- The Policy Administration Point (PAP), which manage the access control policies. Basically it is an interface to write/edit/delete policies and makes them available to the PDP.

- The Policy Information Point (PIP), which acts as a source of attribute values using LDAP. Basically if there are missing attributes in the request which is sent by PEP, PIP would find them for the PDP to evaluate the policy.

2.2.7.4 XACML concepts

XACML (eXtensible Access Control Markup Language) is an OASIS standard [5] specification of an ABAC language based on XML.

We can summarize it in three parts:

- **Policy language**: XACML defines a XML data model for defining authorization policies, as well as the logic to follow to evaluate them in a given access request context. *Rule*, *Policy* (set of *Rules*), and *PolicySet* (set of *Policy* elements) constitute the main elements of the model. In short, a rule consists of a condition on the access request attributes, and a decision – *Permit* or *Deny* - to apply if the condition holds true for the request. A *Policy* (resp. *PolicySet*) combines multiple *Rules* (resp. *Policies*) and therefore multiple decisions together in various ways (defined in the standard) to make the final decision.
- **Request-Response protocol**: The XACML standard also defines a XML/JSON data model for the authorization decision request (XACML *Request*) that a PEP (described later) creates with all the necessary access request attributes and sends to the PDP API for evaluation; and the resulting response (XACML *Response*) that contains the final decision (Permit or Deny).
- **Architecture framework**: The XACML standard also defines a high-level architecture, re-using the ABAC concepts described in 2.2.7.3.

2.2.8 Main interactions

2.2.8.1 Use cases

2.2.8.1.1 Authorization in resource-constrained devices

This enabler covers the use case 4.1: Authorization in Resource-Constrained Devices Supported by 5G Network defined in D2.1 [8].

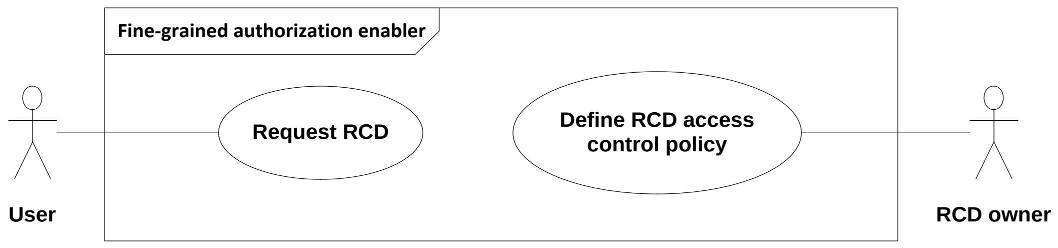
Fine-grained authorization enabler
Request RCD
Define RCD access control policy
User
RCD owner

Figure 11 : Authorization in resource-constrained devices Use cases diagram

Figure 11 shows a generic use cases diagram for the enabler. The user (Alice in D2.1) can perform an authenticated request towards a RCD (a sensor in D2.1). The details of the authentication and verification are not part of the use case but will be taken into account and described in the sections below. In the same way, the RCD owner (sensors' owner in D2.1) can define the security policies which will be enforced in front of its RCD and condition the user access.

2.2.8.1.2 Authorization in satellite systems Use case

This enabler covers the use case 1.3 “Satellite Identity Management for 5G Access” defined in D2.1 [8].

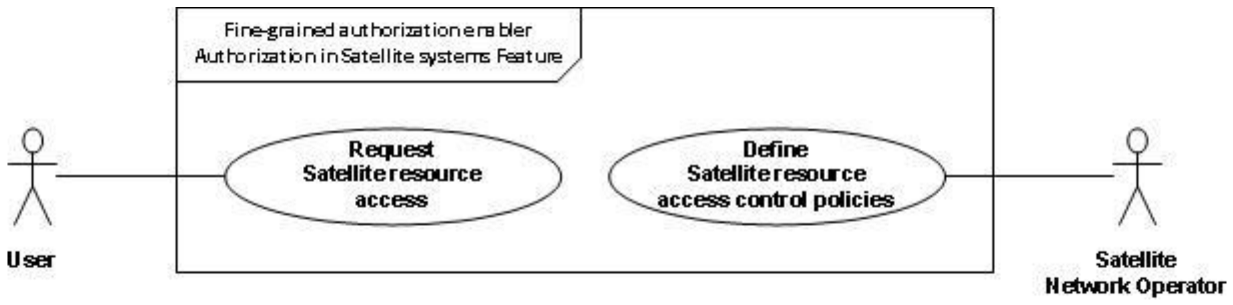
Fine-grained authorization enabler
Authorization in Satellite systems Feature
Request Satellite resource access
Define Satellite resource access control policies
User
Satellite Network Operator

Figure 12 : Authorization in satellite systems Use cases diagram

Figure 12 shows a generic use cases diagram for the enabler. The user (Bob in D2.1) can perform an access request towards a satellite resource. The details of the authentication and verification are not part of the use case but will be taken into account and described in the sections below. In the same way, the satellite resource owner (Satellite Network Operator in D2.1) can define the access control policies which will be enforced in front of the satellite resources and condition the user access.

2.2.8.2 Components and interaction overview

2.2.8.2.1 Authorization in resource-constrained devices feature

Figure 13 shows a static view of the different components implementing the enabler and their links. The different APIs exposed by the enabler are described in section 2.2.10.3.

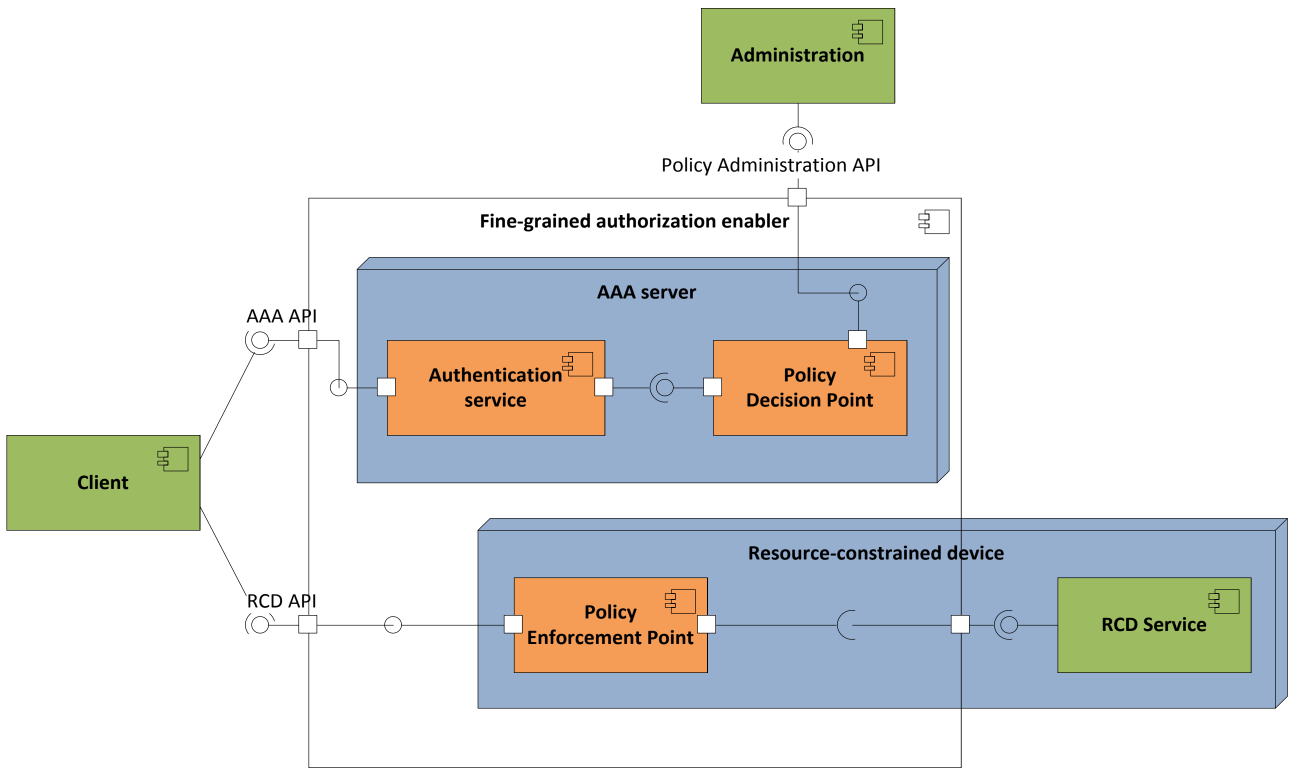

Figure 13: Authorization in resource-constrained devices Components diagram

A client can address the PEP in order to request a RCD, as well as an Authentication service in order to get an access token which will be used to grant the RCD request. The Authentication service is linked to the PDP in order to define a scope for the token, for evaluation by the PEP. Contrary to the common ABAC architecture described in section 2.2.7.3, the PDP and the PEP are not linked together, the information they usually need to share will be part of the token. The dynamic flow of RCD requesting use case is detailed on Figure 14.

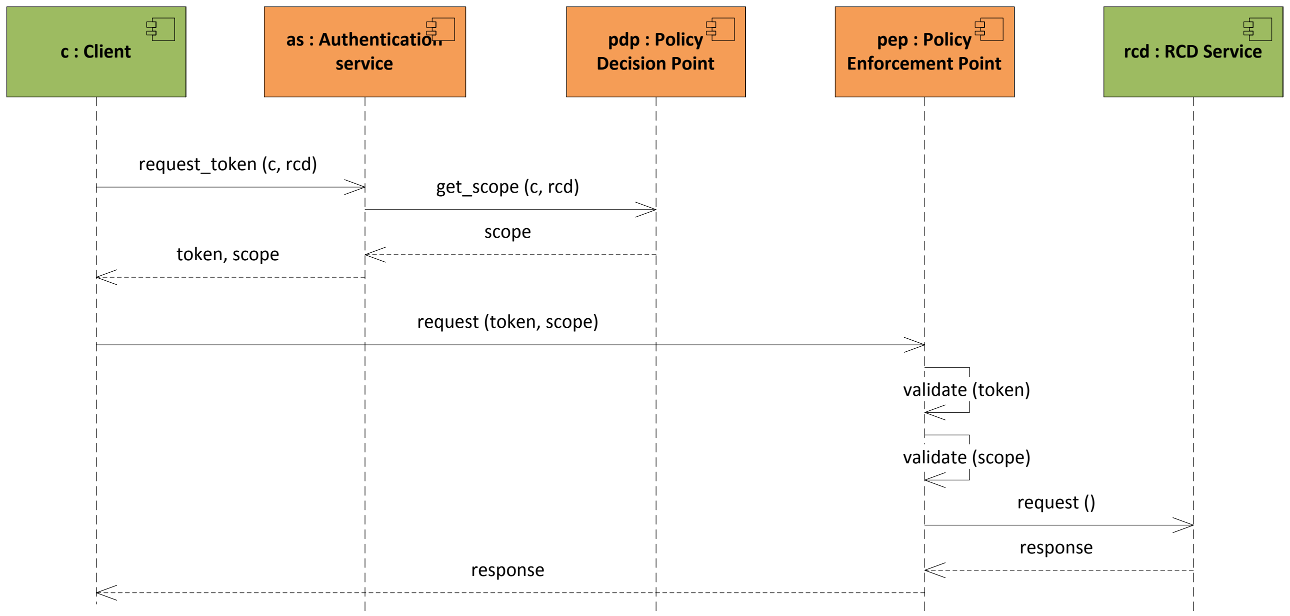

Figure 14 : Use case "Request RCD" sequence diagram

Moreover, an administration API is exposed by the PDP component in order to let the RCD owner define his own access control policies through any administration component. The dynamic flow of the RCD access control policy definition use case is detailed on Figure 15.

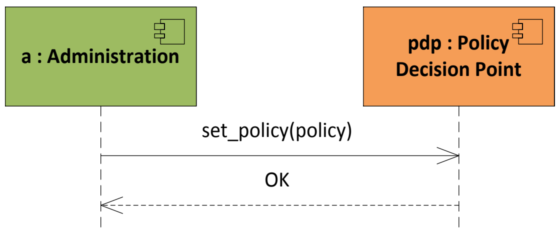

Figure 15: Use case "Define RCD access control policy" sequence diagram

2.2.8.2.2 Authorization in satellite systems feature

A geosynchronous satellite imposes a delay between messages: a radio signal takes approximately 0.25 of a second to reach and return from the satellite. Addressing this constraint involves optimizing the number of messages interchanged (e.g. in authorization functionality) with the satellite device. Therefore, this feature is related to satellite systems, but may also relate to other systems (e.g. RCD).

Figure 16 shows a static view of the different components implementing the enabler and their links. The different APIs are described in section 2.2.10.5.

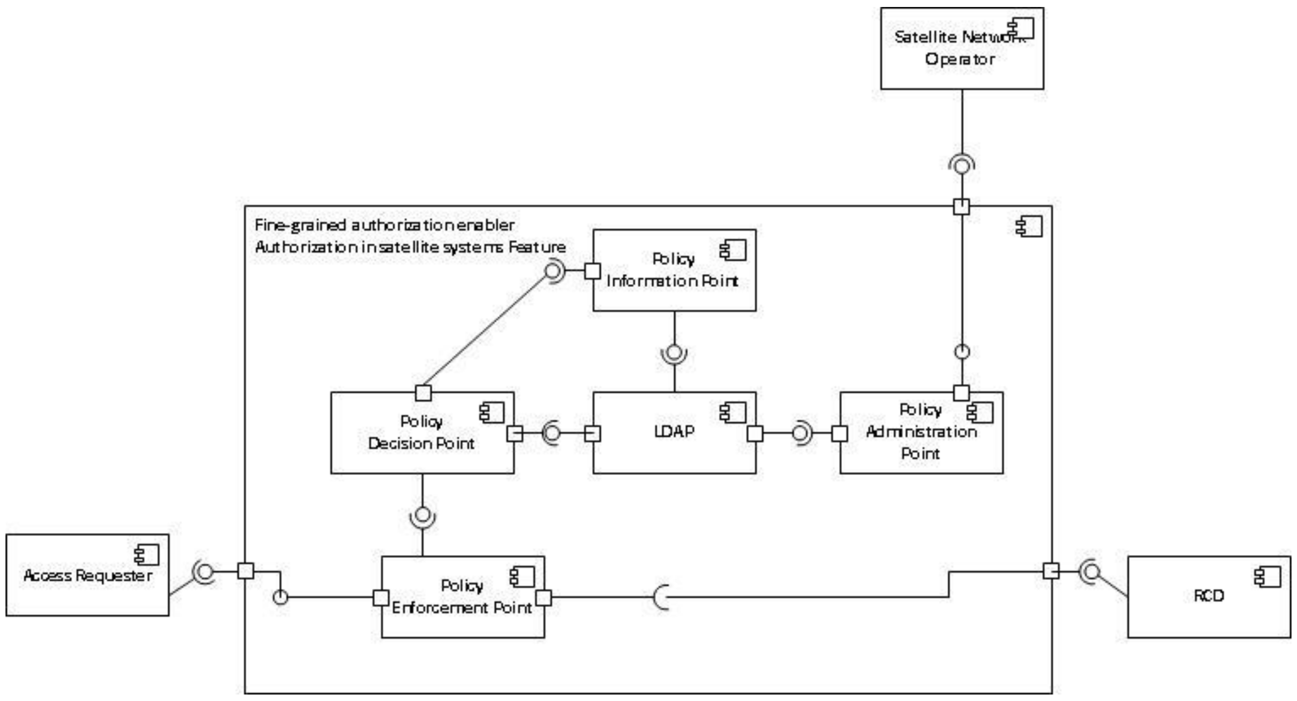
Satellite Network Operator
Fine-grained authorization enabler
Authorization in satellite systems Feature
Policy Information Point
Policy Decision Point
LDAP
Policy Administration Point
Access Requester
Policy Enforcement Point
RCD

Figure 16: Authorization in satellite systems Components diagram

An administration API is exposed by the PAP component in order to let the satellite resource owner define his own access control policies through any administration component.

A client can address the PEP in order to request a satellite resource, as well as an Authentication service in order to get an access token which will be used to grant the satellite resource request. The Authentication service is linked to the PDP in order to define a scope for the token, for evaluation by the PEP. Unless the common ABAC architecture described in section 2.2.7.3, the PDP and the PEP are not linked together, the information they usually need to share will be part of the token. The dynamic flow of satellite resource requesting use case is detailed on Figure 17.

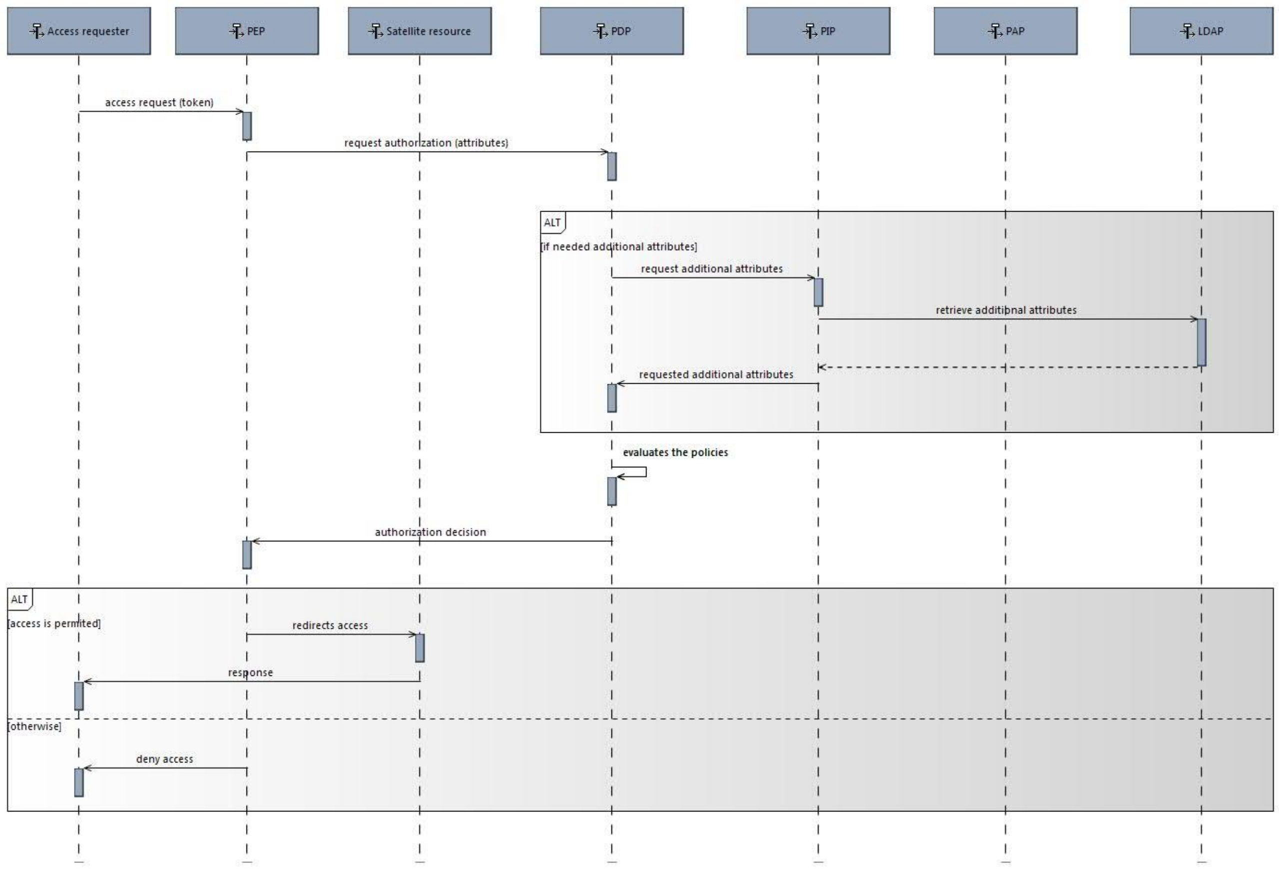

Figure 17 : Use case "Request satellite resource access" sequence diagram

2.2.9 Architectural drivers

The enabler shall provide a method for flexible definition of the access control policies.

2.2.9.1 High-Level functional requirements

The high-level functional requirements are:

- The user shall be authenticated using 5G credentials to access a RCD or a satellite resource.
- The enabler shall deliver a token to an authenticated user, containing a proof of its access rights.
- The enabler shall ensure that any access to the RCD must be authenticated.
- The enabler shall provide a method to define access control policies.
- The enabler shall provide authorized access to the RCD or to the satellite resources according to the access control policy defined by its owner.
- The information contained in the token shall be sufficient for the PEP module to enforce a decision, in order to limit external information researches.

2.2.9.2 Quality attributes

Compliance with standards: XACML v3.0, OAuth 2.0, JWT
Fault tolerance: minimized dependency on the AAA central server; if it is temporarily unavailable, the PEP should still authorize already delivered tokens (for a limited duration)
Resource-utilization: minimized bandwidth consumption by cutting the PEP-PDP connection link, minimized CPU and memory consumption for the PEP to fit in a RCD

Integrity/Non-repudiation/Authenticity: token information must be signed by Authentication service, and are authenticatable end-to-end.

2.2.9.3 Technical constraints

In the resource-constrained context, the PEP module should be deployable on a RCD with 900MHz CPU and 1GB RAM.

2.2.9.4 Business constraints

None.

2.2.10 Detailed specifications

2.2.10.1 Introduction

This specification defines the Fine-grained authorization API, which provides fine-grained authorization access to RCD and satellite resources based on defined access control policies.

The API follows the REST design principles and complies with XACML 3.0.

Fine-grained authorization enabler is currently being developed. Below is a preliminary API specification of the enabler.

2.2.10.2 Conformance

An implementation that conforms to this open specification shall implement fully the architecture described.

All the interfaces described are mandatory and must be implemented in order to be compliant with.

The usage of LDAP as a source of attribute values is optional.

2.2.10.3 Authorization in resource-constrained devices API specifications

2.2.10.3.1 AAA API

The AAA API is compliant with OAuth 2.0 standard API. According to the Client Credentials Grant flow, the only interesting OAuth2 endpoint is the token endpoint. Since the client authentication is used as authorization grant, no additional authorization request is needed.

Method Name	*request_token*	
Method Definition/Description	Request the OAuth2 token endpoint in order to get an access token. Note that the client must authenticate in any way to call this method.	
Method input attributes		
Name	***Type***	***Description***
grant_type	String	Must be set to “client_credentials”.
Method output attributes		
Name	***Type***	***Description***
token	JWT-encoded JSON	A JWT-encoded OAuth2 access token, containing the following fields: • *access_token*: an access token identifier

		• *token_type*: the access token type • *expires_in*: the lifetime in seconds of the access token • *scope*: the scope of the token, containing the access rights granted to the client. The scope should be defined by the PDP, according to the access control policy.

2.2.10.3.2 Policy Administration API

The Policy Administration API is a RESTful HTTP API defined as below:

Method Name	*set_policy*	
Method Definition/Description	Add a XACML PolicySet.	
Method input attributes		
Name	***Type***	***Description***
Policy	PolicySet	A XACML PolicySet
Method output attributes		
Name	***Type***	***Description***
policyUID	String	PolicySet unique identifier (PolicySet UID). This is the identifier allocated by the Service Provider for the PolicySet resource. Note that this is different from the XACML PolicySetId in at least two ways: 1. It is allocated by the Service Provider whereas the XACML PolicySetId is defined by the Service Consumer. 2. It identifies the XACML PolicySetId AND Version. In other words, you can have two different resources with the same PolicySetId but different Versions (therefore different PolicySet UIDs).

Method Name	*get_policy*	
Method Definition/Description	Get a deployed XACML PolicySet.	
Method input attributes		
Name	***Type***	***Description***
policyUID	String	The PolicySet UID (see *set_policy* return)
Method output attributes		

Name	*Type*	*Description*
Policy	PolicySet	The XACML PolicySet matching the UID. None if no PolicySet match the UID.

Method Name	*delete_policy*	
Method Definition/Description	Delete a deployed XACML PolicySet	
Method input attributes		
Name	***Type***	***Description***
policyUID	String	The PolicySet UID (see *set_policy* return)
Method output attributes		
Name	***Type***	***Description***
--	--	--

2.2.10.3.3 RCD API

The RCD API exposed by the enabler is a replication of the one exposed by the RCD Service, with in addition the expectation of an access token. The way this token is expected strongly depends on the protected RCD Service API and must be specific to each one. If the RCD Service is over HTTP, the common way is using an additional HTTP header.

2.2.10.4 Examples

2.2.10.4.1 AAA API

2.2.10.4.1.1 request_token

```
POST .../token HTTP/1.1
Host: server.example.com
Authorization: Basic czZCaGRSa3F0MzpnWDFmQmF0M2JW
Content-Type: application/x-www-form-urlencoded

grant_type=client_credentials
```

```
HTTP/1.1 200 OK
Content-Type: application/jwt;charset=UTF-8
Cache-Control: no-store
Pragma: no-cache

eyJhbGciOiJIUzI1NiIsInR5cCI6IkpXVCJ9.eyJhY2Nlc3NfdG9rZW4iOiIyWW90bkZaRkVqcj
F6Q3NpY01XcEFBIiwidG9rZW5fdHlwZSI6ImV4YW1wbGUiLCJleHBpcmVzX2luIjozNjAwLCJle
GFtcGxlX3BhcmFtZXRlciI6ImV4YW1wbGVfdmFsdWUifQ.5lpcvJ8zZnElXY0nsSNC_0AcuMm-
Q0WMgnSxwv8gj5A
```

2.2.10.4.2 Policy Administration API

2.2.10.4.2.1 set_policy

```
POST .../policies HTTP/1.1
Host: server.example.com
Content-Type: application/xml

<PolicySet xmlns="urn:oasis:names:tc:xacml:3.0:core:schema:wd-17" ... />
```

```
HTTP/1.1 200 OK
```

2.2.10.4.2.2 get_policy

```
GET.../policies/{policyUID} HTTP/1.1
Host: server.example.com
```

```
HTTP/1.1 200 OK
Content-Type: application/xml;charset=UTF-8

<PolicySet xmlns="urn:oasis:names:tc:xacml:3.0:core:schema:wd-17" ... />
```

2.2.10.4.2.3 delete_policy

```
DELETE.../policies/{policyUID} HTTP/1.1
Host: server.example.com
```

```
HTTP/1.1 200 OK
```

2.2.10.5 Authorization in satellite systems API specifications

2.2.10.5.1 Define an access control policy

Add a new XACML policy to the PAP policies repository

Request:

- Method: POST
- URI: /pap/policy
- Content-type: application/xml
- Body: XACML policy

Response:

- HTTP status code:
  - 201 when success
  - 400 when error
- Body: None

2.2.10.5.2 Retrieve an access control policy

Get a XACML policy from the PAP policies repository

Request:

- Method: GET
- URL: /pap/policies/{policyID}
  - Parameter policyID

Response:

- HTTP status code:
  - 200 when success
  - 404 when not found
- Content-type: application/xml
- Body: XACML policy

2.2.10.5.3 Request resource access

Request RCD or satellite resource access

Request:

- Method: POST
- URL: /pdp/authorize
- Authorization: {access token}
- Content-type: application/json
- Body: {"userName":<username>,"action":<action>,"resource":<resource>}

Response:

- HTTP status code:
  - 200 when allow access
  - 401 when deny access
- Redirects the request to the satellite resource

2.2.11 Re-utilised Technologies/Specifications

The Fine-grained authorization enabler is based on RESTful design principles. The technologies and specifications used in this enabler are:

- RESTful web services
- Java API for RESTful Web Services - JAX-RS 2.0
- HTTP/1.1
- JSON and/or XML data serialization formats
- The Authentication Server relies on OAuth 2.0 standard
- The AAA API can re-use an existing OAuth 2.0 standard implementation

- In order to manage self-contained tokens, the encoding of the returned token by the Authentication Server uses the standard JSON Web Token (JWT) format
- The Policy Decision Point relies on OASIS XACML v3.0 specification and re-utilises FIWARE Access Control Generic Enabler as well as the Policy Administration API re-utilises the FIWARE Authorization PDP API Specification
- LDAPJIRA issue tracking product
- SVN software versioning and revision control system
- Gitsoftware version control system
- Melody Advance system engineering modelling tool
- Thales Control continuous integration tool based on Jenkins and Sonar

2.2.12 References

[1] INCITS 359-2012 - Role Based Access Control standard by InterNational Committee for Information Technology Standards (formerly NCITS)

[2] Guide to Attribute Based Access Control (ABAC) Definition and Considerations – NIST Special Publication 800-162 http://nvlpubs.nist.gov/nistpubs/specialpublications/NIST.sp.800-162.pdf

[3] RFC 6749 - The OAuth 2.0 Authorization Frameworkhttps://tools.ietf.org/html/rfc6749

[4] RFC 7519 – JSON Web Token (JWT) https://tools.ietf.org/html/rfc7519

[5] eXtensible Access Control Markup Language (XACML) Version 3.0 – OASIS Standard http://docs.oasis-open.org/xacml/3.0/xacml-3.0-core-spec-os-en.pdf

[6] ISO 25010 – CD 25010.2, Software engineering-Software product Quality Requirements and Evaluation (SQuaRE)Quality model

[7] Using XACML Policies as OAuth Scope – Hal Lockhart http://www.openliberty.org/wiki/uploads/3/38/XACML_as_OAuth_Scope.pdf

[8] 5G-Ensure Consortium, Deliverable 2.1 Use Cases. Available online athttp://www.5gensure.eu/sites/default/files/Deliverables/5G-ENSURE_D2.1-UseCases.pdf, 2016.

[9] 5G-Ensure Consortium, Deliverable 3.1 5G-PPP security enablers technical roadmap. Available online at http://www.5gensure.eu/sites/default/files/Deliverables/5G-ENSURE_D2.1-UseCases.pdf.

2.3 Basic AAA: Open specifications

2.3.1 Preface

5G brings a wide range of new requirements to the mobile networks. The AAA algorithms from earlier generations will likely remain in a similar form also. This enabler studies potential improvements of AAA while assuming most properties are reused from previous generations.

2.3.2 Status

The Basic AAA security enabler has no features planned to be released in release 1 (v1), and all features are in various states of research at this moment. The trusted interconnect feature is currently in a too premature state to be incorporated into this release. Nevertheless, to reflect on the progress of the development, a preliminary open specification is presented, to indicate what is expected for release 2. The final open specifications, with the features announced, will be delivered in release 2.

2.3.3 Copyright

Perfect Forward Secrecy - Copyright © TBD by Ericsson AB

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2.3.4 Legal notice

The Legal notice that applies to these specifications is given in Annex A.

2.3.5 Terms and definitions

Authentication, Authorization and Accounting	
Authentication and Key Agreement	Protocol that establishes mutual authentication and a shared key used for further protection of the communication
Authentication Management Field	An input parameter of the AKA' authentication algorithms. (in 4 hex digits)
Access Stratum Mobile Equipment	Notation used to indicate that it is a key shared between the Access Stratum (MME) and the ME (should really be UE as it could be on USIM)
Authentication Vector	Set of quadruplets {XRES,CK,IK,AK} user for mutual authentication of network and UE, and for key establishment
Ciphering Key	Key used for confidentiality protection of information
Evolved Packet Core	Is a framework for an evolution or migration of the 3GPP system to a higher-data-rate, lower-latency, packet-optimized system that supports, multiple RATs (From TR21.905 v13.0.0 [1])
Evolved Packet System	Is an evolution of the 3G UMTS characterized by higher-data-rate, lower-latency, packet-optimized system that supports multiple RATs. The Evolved Packet System comprises the Evolved Packet Core together with the evolved radio access network (E-UTRA and E-UTRAN). (From TR21.905 v13.0.0 [1])
EvolvedUTRA/EvolvedUTRAN	Evolved UTRA is an evolution of the 3G UMTS radio-access technology/network towards a high-data-rate, low-latency

	and packet-optimized radio-access technology.
Home Environment	Responsible for overall provision and control of the Personal Service Environment of its subscribers (From TR21.905 v13.0.0 [1])
Hashed Message Authentication Code	Integrity check calculated by using hash functions with a secret key as input as well as the message.
Home Subscriber Server	Server managing subscription related information including keys and functions for producing authentication vectors
Integrity Key	Key used for integrity protection of information
Long Term Evolution	Name of the 3GPP project for E-UTRAN, has since been adopted as the name for E-UTRAN. Does not include EPS.
Message Authentication Code	A secret key dependent checksum that is used to verify the authenticity and integrity of data
Mobile Equipment	The mobile device excluding the USIM/UICC
Man-In-The-Middle	An attack where a man in the middle can establish connections with both communicating parties without either end point being aware that data is relayed between an entity in between.
Public Land Mobile Network	A network that provides communication services according to the specifications to mobile users in a geographical area
Serving GPRS Support Node	A node responsible for the delivery of data packets from and to the UEs within its geographical service area. Its tasks include packet routing and transfer, mobility management, logical link management, and authentication and charging functions.
Serving Network	The serving network provides the user with access to the services of home environment (From TR21.905 v13.0.0 [1])
User Equipment	ME+USIM
Universal Mobile Telecommunications System	An umbrella term for the third generation radio technologies developed within 3GPP
Universal Subscriber Identity Module	An application residing on the UICC used for accessing services provided by mobile networks, which the application is able to register on with the appropriate security (from TR21.905 v13.0.0 [1])
Visitor Location Register	A database that contains information about roaming subscribers within a locations area.

2.3.6 Overview

The Basic AAA enabler builds on the assumption that the AAA framework utilized by 4G to a large degree is inherited also into 5G. The enabler looks into three areas of new functionality or improvements, namely AAA aspects of trusted micro-segmentation in 5G networks; Perfect Forwards Secrecy for the AKA protocol; Trusted interconnect and authorization. The features will be described independently in the document.

AAA aspects of trusted micro-segmentation in 5G networks

Micro-segments are virtualized, isolated parts of the 5G network, meant to provide customizable security to subscribers, which can be hospitals, factories, and Industrial Internet and Internet of Things (IoT) based companies. Micro-segmentation aims to provide a more homogeneous and smaller environment to manage by security monitoring. By means of this, better accuracy can be achieved for e.g. anomaly detection. The AAA method in micro-segments depends on the needed security level, which is determined by the micro-segment subscriber. One possible authentication method could be Extensible Authentication Protocol over LAN (EAPoL).

Perfect Forward Secrecy

This feature introduces perfect forward secrecy into the AKA protocol to ensure that a compromised key does not affect the secrecy of messages protected by other keys established as a result of previous or future AKA runs. The aim is to only modify the necessary parts of the current AKA protocol and reuse properties, such as mutual authentication.

2.3.7 Basic concepts

2.3.7.1 Perfect Forward Secrecy

Perfect forward secrecy is a property of a protocol which ensures that a key leakage does not compromise sessions using successor keys, or future sessions using newly established keys, i.e., only the session encrypted/integrity protected with the affected key can be attacked.

2.3.7.2 UMTS / LTE AKA procedure

On a high level, AKA works as in Figure 18

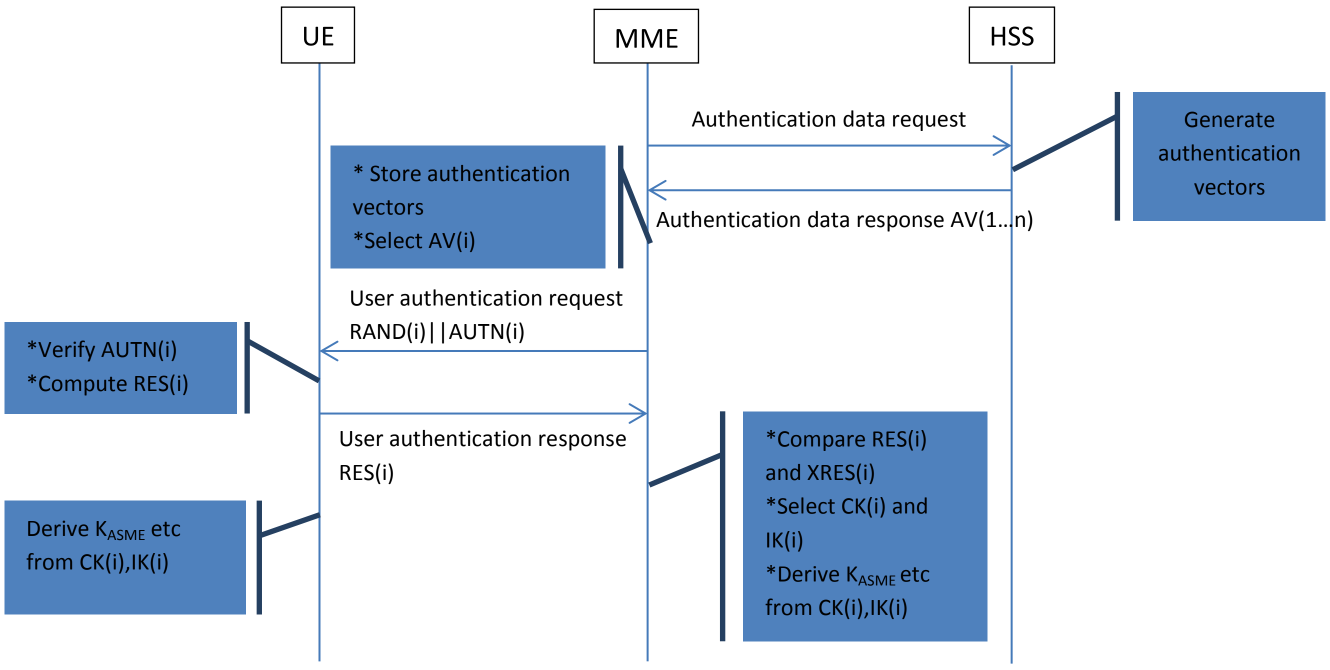

UE
MME
HSS
Authentication data request
Generate authentication vectors
* Store authentication vectors *Select AV(i)
Authentication data response AV(1…n)
User authentication request RAND(i)||AUTN(i)
*Verify AUTN(i) *Compute RES(i)
User authentication response RES(i)
*Compare RES(i) and XRES(i) *Select CK(i) and IK(i) *Derive K_ASME etc from CK(i),IK(i)
Derive K_ASME etc from CK(i),IK(i)

Figure 18: AKA procedure

AUTN is a parameter composed of different fields: AMF, MAC and a sequence number indication (SQN, possibly encrypted by an anonymity key AK). The MAC is a Message Authentication Code that protects RAND, SQN and AMF from being forged by a 3rd party through the cryptographic functions implemented by the USIM as shown in Figure 19. The keys CK and IK are used directly for ciphering /integrity protection in 3G and are used indirectly for these purposes in 4G/LTE by deriving ciphering/integrity keys from CK and IK.

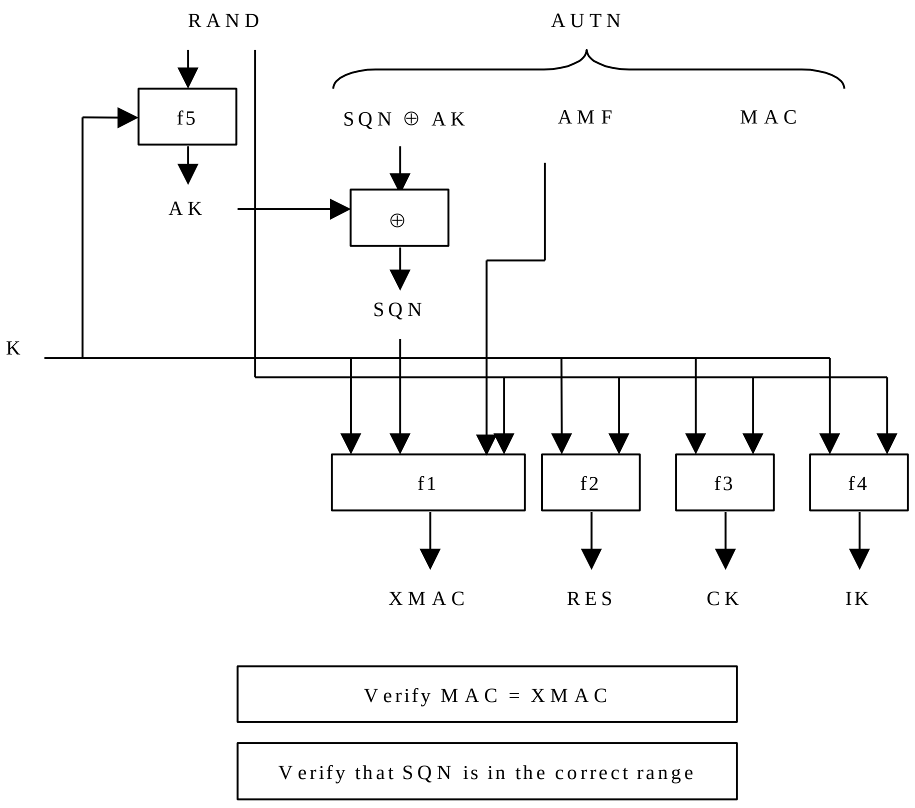


Figure 19: USIM AKA calculations

2.3.7.3 Diffie-Hellman key exchange protocol

The original protocol is based on the multiplicative groups of integers module a prime number *p*, the generator element *g* is primitive root modulo *p*. Both parties each randomly generates a secret value, the UE generates value x, and the network generates value y. The UE calculates g^y (which does not need to be kept secret) and sends the result to the network, the network calculates g^x and sends to the UE, see Figure 20.

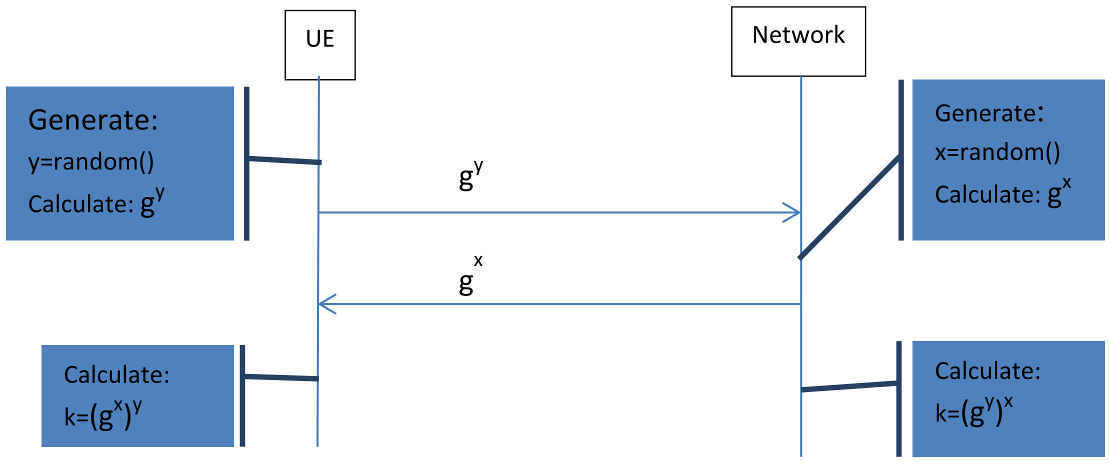


Figure 20: Diffie-Hellman key exchange procedure

The UE and the network can then each calculate the shared secret key as $k=(g^x)^y=(g^y)^x$. For an adversary with knowledge of g^x and g^y it is believed difficult to derive g^{xy}.

2.3.8 Main interactions

2.3.8.1 Use cases

AAA aspects of trusted micro-segmentation in 5G networks

Once a micro-segment has been created, nodes can be added to the micro-segment. Before adding nodes to the micro-segment, they need to be authenticated by the micro-segment AAA entity and subsequently authorized to use the micro-segment. As mentioned earlier, the AAA methods in micro-segmentation depend on the used application or the requirements of the micro-segmentation subscriber. The AAA method is thus fully customizable.

An example of a new AAA policy could be the setting of more detailed requirements on the authentication of users. Also, preventing users or group of users from the use of a micro-segment is another possible action.

Perfect Forward Secrecy

In this use case, a subscriber and a MNO want to reduce the security effect of any compromised keys shared between the subscriber and the operator. Current AKA procedures suffer from the fact that a comprompise of the long term keys stored in HSS/USIM can lead to all future, and past messages, sent with keys derived from the compromised key can be decrypted. It is proposed that the key agreement protocol is updated to use the Diffie-Hellman key exchange protocol instead to ensure that a compromised key only affect sessions in which that particular key is used. To prevent man-in-the-middle attacks on the Diffie Hellman protocol, the authentication aspects of the AKA procedure are reused.

2.3.8.2 Components and interaction overview

AAA aspects of trusted micro-segmentation in 5G networks

Each micro-segment could have its own AAA entity, but the AAA functionality of a micro-segment should not add to the overall complexity. This component would be a virtualized resource or function, i.e., Network Function Virtualization (NFV) would be used. It is for further study how to bootstrap the micro-segment AAA entities.

Perfect forward secrecy

The Diffie-Hellman protocols in general requires transportation of parameters that are much larger than the parameters of the AKA protocol (RAND, RES, etc). Even if it is possible to increase the number of bits signaled over the air interface, it would be desirable to maintain the standardized USIM-ME interface, which implies a bottleneck for the size of the protocol parameters which falls below the level where DH offers strong security. RAND is currently 128 bits, and to reach a security matching the 128-bit strength of AKA:

- DH parameters of at least 256-bits are need for elliptic curve variants of DH
- around 3000-bits for standard discrete log DH modulo a prime, p
- around 6000-bits for supersingular isogeny DH, out of which it is sufficient to transfer roughly 3000 bits (this variant is believed to be quantum computer immune).

Another aspect to consider is that DH is sensitive to a man-in-the-middle (MITM) attacks, as a result, a mechanism to authenticate the DH parameters is necessary.

The RAND information element can be used to carry a DH value when sent from the network to UE: RAND = g^x. The result is likely to be substantially larger than the current size of 128-bits. To maintain the USIM-ME interface, we propose to compress RAND, e.g. by cryptographic hashing: RAND' = H(RAND) = H(g^x), where H denotes taking the 128 LSB of SHA256, i.e., H(x)=$\text{TRUNC}_{128\text{-LSB}}$(SHA256(x)). H is applied in the ME, before inputting RAND' to the USIM. As a consequence, the AKA MAC-field will be computed in dependency of RAND', but through the use of H, it will in effect still be computed in dependency of g^x. Therefore, the authenticity of the DH value g^x is ensured between the AuC/HSS and the USIM, which prevents MITM attacks, in particular between the serving network and UE.

The UE will need to compute a response DH-value of the form g^y, which is computed from a (pseudo) randomly generated value, y, in the UE. Again, to thwart MITM attacks, this value must be authenticated. To this end, however, we propose to use RES and add a standard MAC, i.e., by computing RES' = MAC(RES , g^y), and thus the UE responding with RES', g^y. It is proposed that the MAC function is based on HMAC.

Note that the AuC/HSS needs to generate the authentication vectors sent to the serving network accordingly, i.e. compute parameters: RAND' = H(g^x), before inputting it to the f-functions, etc.

Note: In principle, the HSS does not need to send CK, IK (or keys derived therefrom) to the MME as part of Authentication Vectors (AV) since the resulting shared key will be based on g^{xy} which is not known to the HSS at time of AV generation. However, in EPS/LTE keys are "bound" to the access network through inclusion of a PLMN identifier in the derivation of the K_{ASME} key from CK, IK. Since the HSS as noted does not know g^{xy} at the point when AVs are generated, a binding to PLMN ID could be achieved by including the PLMN ID in derivation of some further key from CK, IK and including that derived key in the AV.

Also the MME would need updates, i.e. given XRES in the AV from the HSS, it would compute XRES' = MAC(XRES, g^y) before verifying subscriber authenticity, and it would need to derive KASME as KDF(g^{xy}), where KDF denotes the key derivation function as defined in TS 33.401 [2] (accompanied by some newly chosen string S). The UE would compute KASME similarly. The updated AKA procedure is shown in Figure 21.

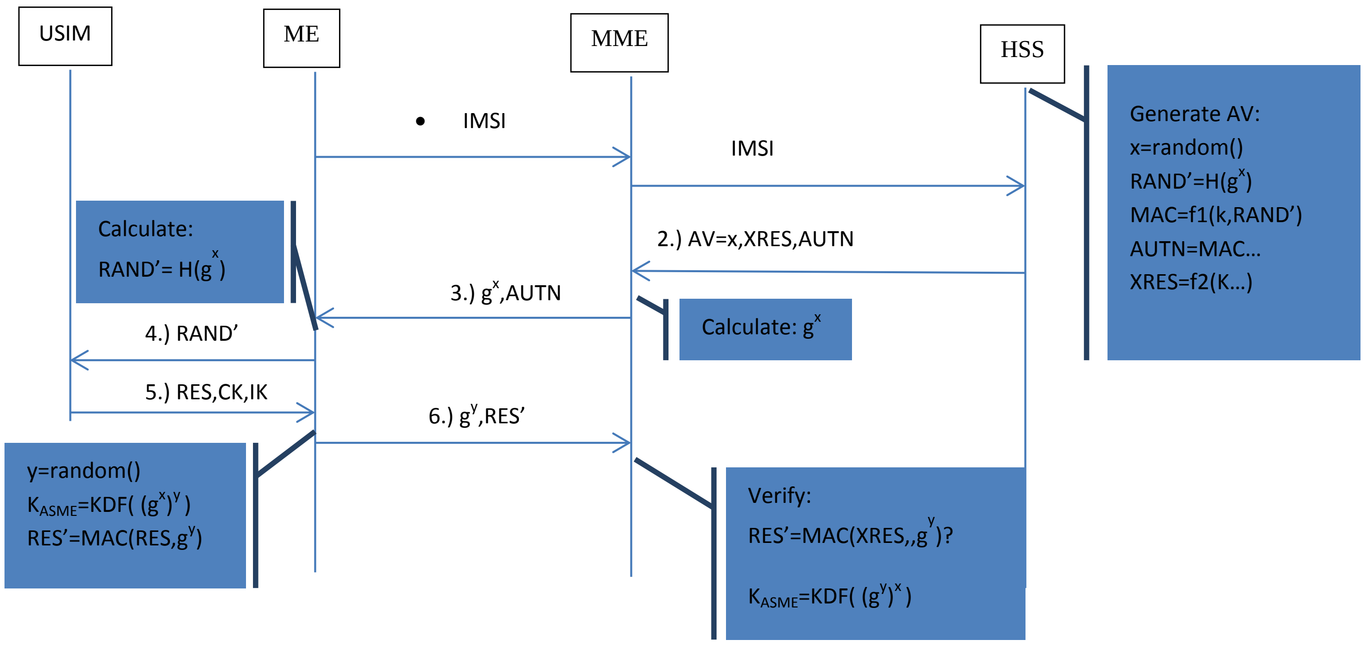


Figure 21: Adding PFS to the USIM AKA procedure

2.3.9 Architectural drivers

2.3.9.1 High-Level functional requirements

AAA aspects of trusted micro-segmentation in 5G networks

In general, the AAA methods of a micro-segment should not add to the complexity of the whole system. The authentication protocol of micro-segments depends on the needed security level, which is adjustable. For example, if the application or service requires strong authentication, Extensible Authentication Protocol over LAN (EAPoL) may be used.

Micro-segments may support and require particular authentication mechanisms. For example, if the mobile device has been authenticated strongly to the mobile network by the use of USIM, it can be authorized to use the micro-segment. However, if lighter authentication methods have been used in the mobile network, the device may need to be re-authenticated using a stronger or a second-factor mechanism to authorize use of the micro-segment.

Perfect Forward Secrecy

The AKA procedure shall provide perfect forward secrecy, i.e., a compromised long term keys shall not affect keys established during other AKA procedures.

2.3.9.2 Quality attributes

A product implementing one or several of the features described in enabler should be evaluated primarily based on the following quality attributes:

- Security:
    - Confidentiality
    - Integrity
    - Non-repudiation
    - Accountability
    - Authenticity
- Compatibility
    - Co-existence
    - Interoperability
- Performance efficiency
    - Time Behavior
    - Resource Utilization

2.3.9.3 Technical constraints

The enabler is scheduled for release 2 and is currently in a research phase, thus there are no known technical constraints at this stage.

2.3.9.4 Business constraints

No known business constraints.

2.3.10 Detailed specifications

2.3.10.1 Introduction

In this section, detailed information about the required updates to the 3GPP specifications to implement the suggested AAA enhancements are provided.

2.3.10.2 Conformance

An implementation to be reported as conformant should comply with the open specifications here stated for the enabler.

2.3.10.3 API specifications

Perfect Forward Secrecy

For the interface between the MME and the HSS, i.e., S6a, a new Authentication-Info needs to be defined, as documented by TS29.272 [3]

```
5G-Vector ::= <AVP header: 14xx 10415>

              [ Item-Number ]

              { x }

              { XRES }

              { AUTN }

              *[AVP]
```

In addition, the NAS AUTHENTICATION REQEST message needs to be updated according to Table 3 (see TS24.008 v13.5.0 [4] section 9.2.2 for original values).

Table 3: 3GPP TS 24.008: AUTHENTICATION REQUEST message content

IEI	Information element	Type/Reference	Presence	Format	Length
	Mobility management protocol discriminator	Protocol discriminator TS24.008 section 10.2	M	V	½
	Skip Indicator	Skip Indicator TS24.008 section 10.3.1	M	V	½
	Authentication Request message type	Message type TS24.008 section 10.4	M	V	1
	Ciphering key sequence Number	Ciphering key sequence number TS24.008 section 10.5.1.2	M	V	½
	Spare half octet	Spare half octet TS24.008 section 10.5.1.8	M	V	½
NEW	Authentication element is replaced by: gx (Diffie-Hellman parameter used for key establishment)		M	V	32
20	Authentication Parameter AUTN	Auth. parameter AUTN TS24.008 section 10.5.3.1.1	O	TLV	18

The AUTHENTICATION RESPONSE message can be kept the same, although the content of the authentication response parameter (and extension) is derived differently compared to 3G and 4G.

Note: This feature is backward compatible with USIM, the IMSI cannot indicate whether the ME supports it or not. It is for further study if is shall be mandated for all 5G accesses, or if we need some “classmark” too, to indicate ME support.

2.3.11 References

[1] 3GPP, *TR 21.905* Vocabulary for 3GPP Specifications*.*

[2]3GPP, *TS 33.401 ;* 3GPP System Architecture Evolution (SAE);Security architecture; *v13.2.0*

[3] 3GPP, *TS 29.272;* Evolved Packet System (EPS); Mobility Management Entity (MME); Serving GPRS Support Node(SGSN) related interaces based on Diameter protocol*; v13.5.1.*

[4]3GPP, *TS24.008;* Mobile radio interface Layer 3 specification; Core Network Protocols*; v13.5.0.*

3 Privacy Enablers open specifications

This section contains the open specifications of v1.0 of the two Privacy enablers due at Release 1: the Encryption of Long Term Identifiers component from the enabler Privacy Enhanced Identity Protection and the enabler Device Identifier(s) Privacy.

3.1 Privacy Enhanced Identity Protection Enabler Open specifications

3.1.1 Preface

This enabler aims to provide protection against subscriber's identity disclosure in 5G networks to unauthorized parties. The main goal is to offer stronger protection of user identity than in current 3G and 4G networks. The fundamental idea behind this enabler can be summarized in several simple concepts: 5G true user identities shall not be transferred in clear text over the network; unique dynamic (pseudo) random pseudonyms should be used during all normal operations. If a true identity (e.g., the IMSI) has to be sent from the UE to the network, it should be sent encrypted.

The final version of the present enabler will implement the following (full) set of features/components as enumerated in D3.1 [2]: Encryption of Long Term Identifiers and Pseudorandom dynamic pseudonyms. The present open specification relates only to the first version of the enabler to be released and the feature planned for that version, namely: Encryption of long term identifiers. Long term identifiers are also known as IMSIs (International Mobile Subscriber Identifiers).

3.1.2 Status

The version 1.0 of this component is currently under development.

3.1.3 Copyright

Privacy Enhanced Identity Protection - Copyright © 2015-2017 by Telecom Italia S.p.A.

Copyright © 2015-2017 by 5G-ENSURE Consortium (http://www.5gensure.eu/)

3.1.4 Legal notice

The Legal notice that applies to these specifications is given in Annex A.

3.1.5 Terms and definitions

ABE - Attribute Base Encryption	In an ABE system, users' keys and ciphertexts are labelled with sets of descriptive attributes and a particular key can decrypt a particular ciphertext only if there is a match between the attributes of the ciphertext and the user's key.
AKA - Authentication and Key-agreement	The 3rd generation Authentication and Key Agreement mechanism, specified for Universal Mobile Telecommunications System (UMTS) in TS33.102.
EAP - Extensible Authentication Protocol	The Extensible Authentication Protocol Method is defined in RFC 3748.
EAP-AKA, EAP-AKA'	The Extensible Authentication Protocol Authentication Key Agreement method is defined in RFC 4187, while EAP-AKA' is defined in RFC 5448.
EAP-SIM	The Extensible Authentication Protocol Method for Global System for Mobile Communications (GSM) Subscriber Identity Modules (EAP-SIM) is defined in RFC 4186.
KP-ABE	In a Key Policy ABEcryptosystem, ciphertexts are labelled with sets of attributes and private keys are associated with access structures that control which ciphertexts a key is able to decrypt. The attributes are specific to each system implementation and enable users to selectively share their encrypted data at a fine-grained level.

3.1.6 Overview

The main end user privacy issues in 5G networks may arise because of the exposure of long term identifiers. The main authentication methods/protocols used at present (e.g., AKA, EAP-AKA, EAP-AKA') rely on symmetric key encryption, and there are unavoidable situations where they use the IMSI in order to correctly identify the subscriber requesting network connectivity. Therefore, in situations where no shared keys are yet available, long time identifiers are exchanged in clear text and are exposed to the whole range of IMSI sniffing attacks, and, subsequently to user tracking attacks. Active IMSI catchers can defeat subscriber identity protection even after shared keys have been established. For increased user privacy, 5G networks should offer security mechanisms able to defeat or totally avoid such exposure.

Public key-based encryption of long term identifiers is the straightforward protection method in such cases. In order to avoid the setting up of a full PKI and the management of millions (if not billions) of private/public key pairs (one pair per subscriber), the present enabler proposes the use of a public key-based encryption algorithm of IMSIs contained in messages sent by the UE to the serving network, for example inside LTE Attach Request messages, Identity Response or EAP-Response/Identity messages. In all other situations IMSI pseudonyms should be used instead of the long term identifiers.

An example of a network architecture where the enabler's component is meant to be integrated is illustrated in Figure 22. It refers to the access authentication procedure for non-3GPP access to the 5G core network. It is based on the use of a modified version of EAP-AKA (RFC 4187) [6] today defined for the EPS network in the 3GPP document [8]. The main actors are:

- the UE which possess a valid 5G network subscription, therefore a SIM and the corresponding IMSI andimplements the modified version of EAP-AKA as specified herein
- the access point (AP)
- the authentication server (AuS). It comprises a3GPP AAA server which implements the modified version of EAP-AKA authentication, as well as the HSS server where the authentication vectors are generated for the authentication procedure.

Fundamentally, the modification of the EAP-AKA (we may call it EAP-AKA-p, where p stays for privacy) consists in always encrypting the identifier (the username portion of NAI, see RFC4282, RFC 4187) sent inside the EAP-Response/Identity messages (at the UE side) using the proposed cryptographic scheme and always decrypting the encrypted identifiers at the authenticating server side with the corresponding private key. It is intrinsic in the scheme that the AAA server should always perform decryption, and afterwards, when the plain text identifier is obtained, performs the normal unmodified AKA procedure for the subscriber.

In order for the server to recognize that an encrypted identifier (encrypted IMSI) is used we may employ the byte that prepends the permanent user identifier described in "Section 4.1.1.6 Format of the Permanent Username". This byte is set to "0" for normal IMSIs in EAP-AKA.

For example, a permanent username derived from the IMSI 295023820005424 would be encoded as the ASCII string "0295023820005424" and the EAP server MAY use the leading "0" as a hint to try EAP-AKA as the first authentication method during method negotiation, rather than using, for example, EAP-SIM. For EAP-SIM this byte is set to "1".

In order to indicate to the server the use of modified EAP-AKA (we may call it EAP-AKA-p) with an encrypted IMSI we can use other unallocated values for this byte, like for example “2”. This will always lead to an identifier decryption at server side prior to any other processing.

The encryption function is deployed on UE, while the decryption function is deployed on AuS. An additional system, a trusted authority entity (TA) is required and is responsible with the initialization of the cryptographic system and the generation of cryptographic material (the public key, the private keys and the attributes and the corresponding access structures required for encryption and decryption). The functions will be described in detail in the following sections.

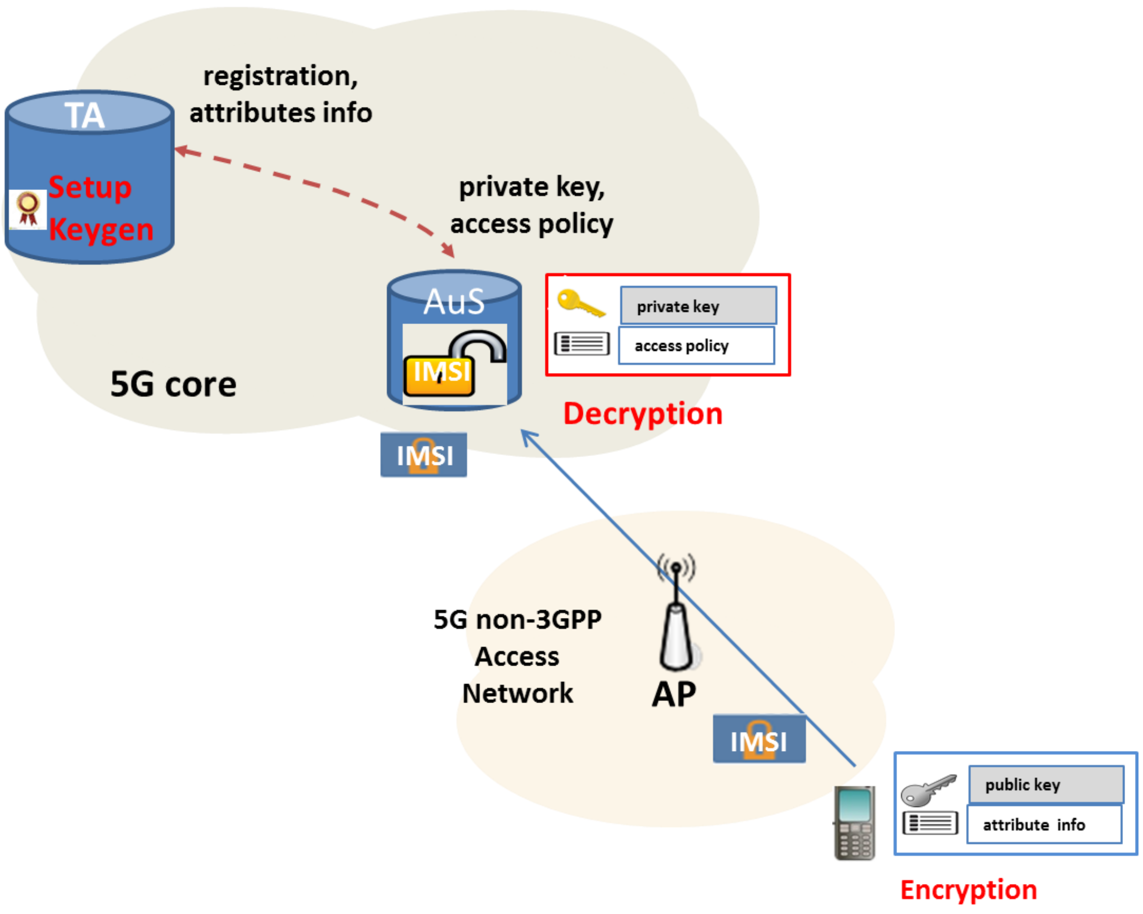


Figure 22: Architecture overview.

3.1.7 Basic concepts

Public key cryptography can be used in order to avoid sending long term identifiers in clear text over the network in situations where the user is not known/authenticated to the network. For example, the user equipment UE can encrypt the IMSI with the public key of the network, such as only the authorized network entity in possession of the corresponding private key can decrypt the identifier. This setting will avoid IMSI sniffing attacks if the attacker does not know the private key. This configuration does not scale well when the user changes its location to another network appertaining to a different administration domain (e.g., in roaming scenarios), where a different private/public key pair is in place and user has to be provisioned again the public key of the network certified by a trusted authority.

Attribute Based Encryption is a type of public key based cryptosystem which may enable the encryption of data by a single public key and decryption by different secret private keys according to access policies. Access policies are expressed as access structures in terms of attributes and can be built in the private decryption keys (key-policy ABE [1]) or in the ciphertext (ciphertext-policy ABE [9]). In KP-ABE the attribute or the set of attributes is built in the ciphertext and the access policies in private decryption keys of the authorized entities.

The present enabler consists in a cryptographic library that implements the KP-ABE encryption scheme described in [1] to encrypt and decrypt a given IMSI. The library also provides the setup and key generation functions.

The algorithms implemented by the library are briefly described below with reference to the components illustrated in Figure 24.

- **Setup**: runs on a trusted authority server TA which is also responsible for the generation of private keys to trusted entities (e.g., network elements like authentication servers) based on the user access policy. At the cryptographic system initialization time, TA generates a public parameter (public key) and a master key. The latter is only known by the TA server.
- **Keygen:** runs on the TA server. An entity entitled to perform decryption (e.g., a network element like an authentication server) requests the provisioning of the decryption key (the private key) by presenting an access policy over an attribute or a set of attributes. The randomized key generation algorithm takes as input the public parameters (public key), the master key and the access policy. It outputs the authentication server's private key which is able to decrypt all IMSIs encrypted under the attributes that satisfy the access policy.
- **Encryption**: runs on the client components, e.g., on the UE devices. The randomized encryption algorithm takes as input the user identity (i.e., the IMSI) to be encrypted, an attribute or set of attributes, and the public key. It outputs the ciphertext, i.e., the encrypted IMSI. In this way only the authentication servers which have the decrypted key generated with the correct access policy (that matches the encryption attributes) will be able to decrypt the ciphertext.
- **Decryption:** the decryption algorithm runs on an authorized network element (i.e., the authentication server). It takes as input the ciphertext, which was encrypted under the set of attributes, the public key parameter and the private key for access control. The output is the IMSI in clear text if the attributes included in the ciphertext satisfy the access policy.

The present enabler will provide a C library (`libkpabe`) containing all the functions required to perform all the cryptographic operations described above. The library is developed by making use of some mathematics and cryptographic libraries that implement basic functionalities required by ABE systems.

3.1.8 Main interactions

3.1.8.1 Use cases

The use case chosen for the implementation of the current enabler refers to a non-3GPP access network which uses the EAP-SIM/EAP-AKA authentication protocol.

To complete the authentication, the UE sends an EAP Response/Identity message. The UE send its identity complying with Network Access Identifier (NAI) format specified in [5]. NAI contains either a pseudonym allocated to the UE in a previous run of the authentication procedure or, in the case of first authentication, the IMSI. In this case the IMSI or NAI is encrypted with the encryption function of the enabler.

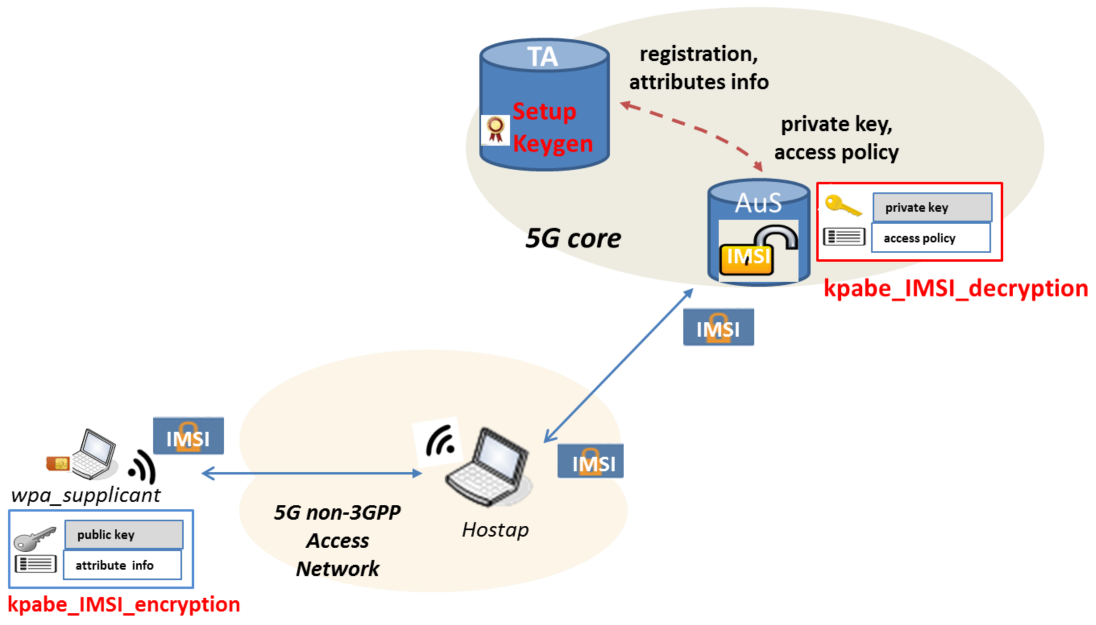


Figure 23: Use case architecture.

The IMSI is encrypted on the client using the `kpabe_imsi_encryption()` function from the `libkpabe` library. Specifically, the encryption function is integrated in the wpa_supplicant (see Figure 23) that is the component residing on the client side that implements the EAP-AKA/SIM authentication protocol.

The IMSI is decrypted by the authentication server (AuS in Figure 23) using the `kpabe_imsi_decryption()` function from the `libkpabe` library.

All cryptographic material (the public key and all authorized private keys) is provided by TA using the functions `kpabe_sys_setup()` (run only once) and `kpabe_entity_keygen()` (run all times a private key is required). These are also functions implemented in the `libkpabe` library.

A use case diagram is provided in Figure 24. The main actors which use the system are the network administrator and the normal network user. The network administrator runs the Setup and Keygen algorithms on TA and provides the private key and the access policy to AuS and the public key to the network user together with the access network attribute(s). The user, who has a valid subscription and therefore a SIM and the corresponding IMSI; saves the public key and the attribute and issues the network connection requests for which EAP-SIM authentication is required. The KP-ABE algorithms are implemented on the user's device (wpa_supplicant) and AuS, therefore during the EAP-SIM authentication exchange the long term identity of the user is transferred encrypted.

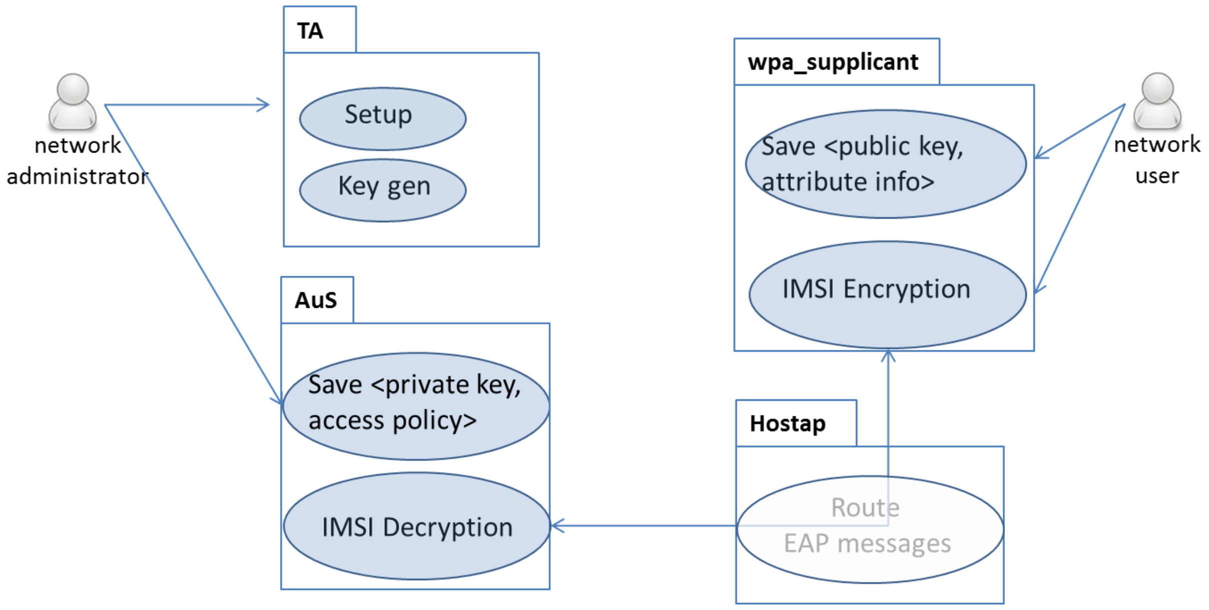


Figure 24: Use case diagram.

3.1.8.2 Components and interaction overview

The enabler implementation corresponds to a simple client server architecture, to be subsequently contextualized in the network that uses the encryption scheme. For the use case example from Figure 23, the main components are the client (the UE or wireless device), the server (the AuS) and a trusted authority entity (TA).

Prior to EAP authentication there must be some (secure) OOB interactions between the TA and AuS and then the UE for the setup and the key generation procedure and public key provisioning. In Figure 24 these interactions corresponds to the dashed lines between TA and AuS and TA (or AuS) and the UE (wpa_supplicant).

- The EAP authentication is triggered by the access point AP (hostap) by sending the EAP Request/Identity message to the UE requesting network connection.
- The UE sends an EAP Response/Identity message inserting its identity complying with Network Access Identifier (NAI) format specified in TS 23.003 [8]. NAI contains the user IMSI that is first encrypted with *kpabe_imsi_encryption* function.
- The AP (implemented by the HostAP component), based on the realm part of the NAI, routes the EAP Response/Identity messages to the correct AuS as described in [3].
- The AuS decrypt the username part of the NAI using the *kpabe_imsi_decryption*function and retrieves the user IMSI in clear. The IMSI is the used to identify the user in the HSS. The authentication procedure then follows as defined in [8].

The messages which transfer encrypted IMSIs are represented by the bold arrows in Figure 25.

The Response/Identity message and EAP Response/GSM Subscriber Identity message. The specific libpkabe functions called for each interaction that require encryption and decryption are also indicated Figure 25

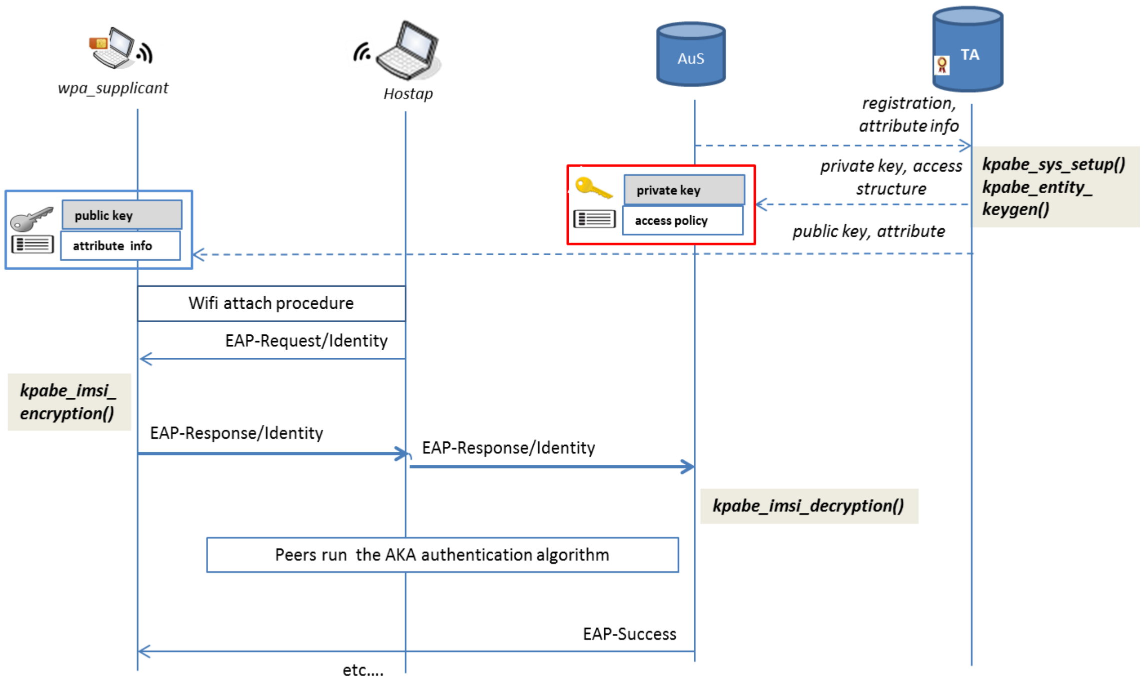


Figure 25: Interactions between components.

In our example implementation the AuS component has both the AAA/EAP server and HSS/AuC authentication functionalities. The EAP server and the HSS server are processes on the same Linux box and communicate through a UNIX socket. The EAP server receives from the client (the wpa_supplicant) the username containing a byte code set to “2”, for indicating EAP-AKA-p, concatenated with the encrypted IMSI The EAP server initiates the EAP-AKA authentication procedure, by sending the authentication request to the HSS server, containing the encrypted IMSI and the Encryption flag (Eflag) set to true indicating that for this user the IMSI is encrypted (see Figure 26). The HSS controls the Eflag and calls the kpabe decryption function for obtaining the IMSI in clear text. From now on the EAP-AKA proceeds in the traditional way, the HSS computes the authentication data for the IMSI and sends it to the EAP server in order to authenticate the user.

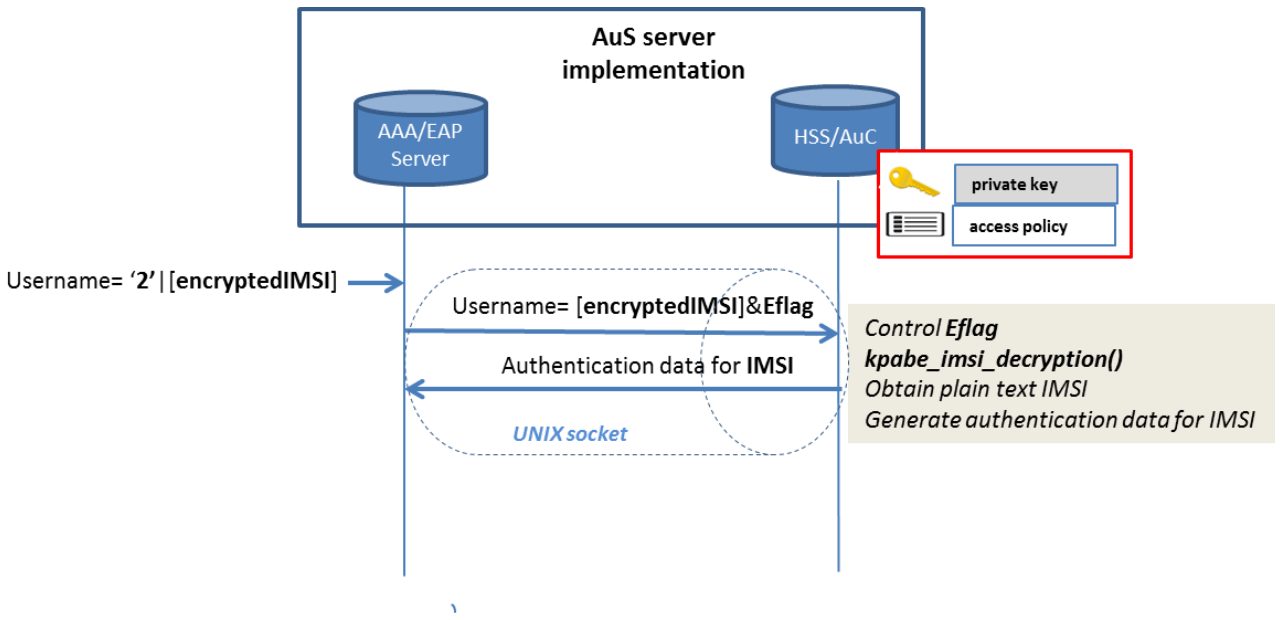

AuS server implementation
AAA/EAP Server
HSS/AuC
private key
access policy
Username= '2'|[encryptedIMSI]
Username= [encryptedIMSI]&Eflag
Authentication data for IMSI
UNIX socket
Control Eflag
kpabe_imsi_decryption()
Obtain plain text IMSI
Generate authentication data for IMSI

Figure 26: AuS implementation details.

3.1.9 Architectural drivers

3.1.9.1 High-Level functional requirements

The high level requirement of the enabler is the randomized encryption of the long term identifiers, i.e., IMSIs, therefore the enabler must implement the encryption of the long time identifier with random encryption and in such way that only the authorized network entities can perform the decryption and obtain the identifier in clear text. The enabler should also provide means to generate the keys used by the actors of the crypto system.
The requirements are so split on the system components:

- At the client side (the wpa_supplicant) the function implemented is the encryption of the long term identifier (IMSI) with random encryption using the network AAA server's public key and the corresponding attribute.
- At the authentication server (AuS) side the function implemented is the decryption of the long term identifier (IMSI) by means of the private key corresponding to the access policy that is matched by the attribute.

An additional system, the TA (trusted authority) entity provides the initialization phase of the system and implements the private keys generation procedure.

3.1.9.2 Quality attributes

A product implementing one or several of the features described in this enabler should be evaluated primarily based on the following quality attributes: performance efficiency, security (confidentiality) and maintainability.

3.1.9.3 Technical constraints

The implementation of libkpabe is based on the use of PBC (Pairing-Based Cryptography) library, a free C library (released under the GNU Lesser General Public License) built on the GMP library that performs the mathematical operations underlying pairing-based cryptosystems. This library works on evolved OSes like the Linux OS, and could work on smartphone OSes, like Android OS. Nevertheless, to the best of our knowledge, an implementation does not exist on a SIM/UICC at the present time.

For the same reason, more research is needed to understand if an implementation is possible on a Resource Constrained Devices like IoT sensor devices. This is out of the scope for the present enabler.

3.1.9.4 Business constraints

The scheme can be applied in a stand-alone manner by an MNO. If the same protection is required for roaming, the network operators could agree on a common key and attribute management infrastructure.

3.1.10 Detailed specifications

3.1.10.1 Introduction

This section contains the detailed specification of the crypto library `libkpabe` which can be used on all client and server components of the adopting network in order to protect long time identifiers by means of the KP-ABE cryptographic scheme described in [1].

3.1.10.2 Conformance

For an implementation to be conformant it should implement specifications as stated herein.

3.1.10.3 Library specifications

The cryptographic functions are provided by the C library `libkpabe` which can be linked dynamically, and which is developed and tested on Linux Ubuntu systems.

The library provides the following main functions: `kpabe_sys_setup()`, `kpabe_entity_keygen()`, `kpabe_imsi_encryption()`, `kpabe_imsi_decryption()`.

3.1.10.3.1 The setup function

```
gboolean kpabe_sys_setup(gchar* msk_key_path, gchar* pub_key_path, gchar** allattrs);
```

The function generatesthe global kpabe system parameters, a public key, and a master secret keyfor use with `kpabe_entity_keygen()`, `kpabe_imsi_encryption()`, and `kpabe_imsi_decryption()`.

Attributes are any string of letters, digits and underscores, and they must begin with a letter.The keywords “and”, “or” and “of” are reserved for the policy languageand may not be used for an attribute.

Output is written to the files indicated by their complete file system path "`pub_key_path`" and "`msk_key_path`".

Input parameters:

`pub_key_path`	Local path to the public key output file name
`msk_key_path`	Local path to the master key output file name
`allattrs`	An array of strings containing the universe of attributes

Output parameter:

A boolean indicating if the key generation was successful or not.

3.1.10.3.2 The key generation function

```
gboolean kpabe_entity_keygen(gchar* prv_key_path, gchar* msk_key_path,
                             gchar* pub_key_path, gchar* policy)
```

The functions generates a private key to an authorized entity under the decryption policy "policy" using the public key and the master key stored in the corresponding files indicated by their complete path. The private key will be written to the output file indicated by its complete path.

Input parameters:

`pub_key_path`Local path to the public key file

`msk_key_path`Local path to the master key file

`policy` The string with the private key's access policy

Output parameter:

A boolean indicating if the key generation was successful or not.

3.1.10.3.3 The encryption function

```
gbooleankpabe_imsi_encryption(gchar*pub_key_path,uint8_t*imsi,size_timsi_len,
                              gchar**attrs,uint8_t**beimsi);
```

The function encrypts the target IMSI using the provided set of attributes and the public key file.

Input parameters:

`pub_key_path`Local path to the public key file

`imsi`Plain IMSI string

`imsi_len`Length of the plain IMSI string

`attrs`List of attributes

`beimsi`Used to return the ciphered IMSI's base64 encoded bytes.

Output parameter:

A boolean indicating if the encryption was successful or not.

3.1.10.3.4 The decryption function

```
gbooleankpabe_imsi_decryption(gchar*pub_key_path,gchar*prv_key_path,
                              constuint8_t*beimsi,uint8_t**imsi);
```

The function decrypts the target base64-encoded ciphered IMSI using the provided public key and private key files. The decryption is performed on the base 64 ciphered IMSI.

Input parameters:

`pub_key_path`Local path to the public key file `prv_key_path`Local path to the private key file

`beimsi`Ciphered IMSI's base64 encoded bytes

`imsi`Used to return the plain value of the deciphered IMSI.

Output parameter:

A boolean indicating if the decryption was successful or not.

3.1.10.3.5 Auxiliary functions

```
voidparse_attrs(char*attrs_string,gchar***attrs);
```

The function Parses attributes string from the wpa_supplicant configuration file.It strips leading and trailing whitespaces from each attribute token.

Input parameters:

`attr_string`	Attributes string to be parsed
`attrs`	Array of strings used to return the list of parsed attributes.

Output parameter:

None.

3.1.10.4 Examples

An example on where and how the functions of the library are effectively used is given by our system demo implementation depicted in Figure 23.

3.1.11 Re-utilised Technologies/Specifications

Our implementation used the following C libraries: the PBC (Pairing Based Cryptogrphy) library [4], GMP, the GNU Multiple Precision Arithmetic library [10], libcelia - a static linux library implementing primitive kpabe operations [11], and kpabe [12].

3.1.12 References

[1] Goyal, Pandey, Sahai, Waters, Attribute Based Encryption for Fine Grained Control of Encrypted Data, https://eprint.iacr.org/2006/309.pdf

[2] 5G ENSURE Deliverable D3.1, “5G-PPP security enablers technical roadmap (early vision)”

[3] ETSI, ”UMTS, LTE, 3G Security - WLAN Interworking security” http://www.etsi.org/deliver/etsi_ts/133200_133299/133234/13.00.00_60/ts_133234v130000p.pdf

[4] The PBC Library, https://crypto.stanford.edu/pbc/

[5] ETSI - TS 23.003, “Numbering Addressing Identification”, http://www.etsi.org/deliver/etsi_ts/123000_123099/123003/13.05.00_60/ts_123003v130500p.pdf

[6] IETF, EAP-AKA (RFC 4187) , https://tools.ietf.org/html/rfc4187

[7] IETF, EAP-AKA' (RFC 5448), https://tools.ietf.org/html/rfc5448

[8] 3GPP TS 33.402, "3GPP System Architecture Evolution (SAE); Security aspects of non-3GPP accesses", http://www.etsi.org/deliver/etsi_ts/133400_133499/133402/13.00.00_60/ts_133402v130000p.pdf

[9] Bethencourt, Sahai, Waters, "Ciphertext-Policy Attribute-Based Encryption", https://www.cs.utexas.edu/~bwaters/publications/papers/cp-abe.pdf

[10] The GMP library, the GNU Multiple Precision Arithmetic library, https://gmplib.org/

[11] Libcelia, https://github.com/gustybear/libcelia

[12] kpabe, https://github.com/gustybear/kpabe

3.2 Device Identifier Privacy Open specifications

3.2.1 Preface

3.2.2 Status

The version 1.0 of this enabler is currently under development.

3.2.3 Copyright

The copyright will be attributed to existing source code authors and those authors who contribute to the development of the enabler code, which currently includes the University of Oxford ([UOXF]).

Copyright © 2015-2017 by 5G-ENSURE Consortium (http://www.5gensure.eu/).

3.2.4 Legal notice

The Legal notice that applies to these specifications is given in Annex A.

3.2.5 Terms and definitions

This section comprises a summary of terms and definitions used by this enabler.

DHCP	Dynamic Host Configuration Protocol [1][2]
DNA	Detection of Network Attachment protocol [3]
ARP	Address Resolution Protocol[4]
ACD	Address Conflict Detection [5]
SSID	Service Set Identifier – a human readable identifier for a Wireless LAN
MAC	Media Access Control address

3.2.6 Overview

This enabler aims to utilise state-of-the art obfuscation techniques on the user's device, offering *Privacy Enhanced Attachment,* which provides protection against device identity (and also potentially subscriber identity) disclosure and unauthorized device/user tracking. The main focus is to offer improved privacy protection of the identifiers for devices, over IP-based networks, to access 5G services such as via GAN/UMA, or for application level interactions. Additionally it provides enhanced device identity privacy for access to third party Internet-based resources when utilising 5G-based authentication schemes (e.g. EAP-AKA for WiFi).

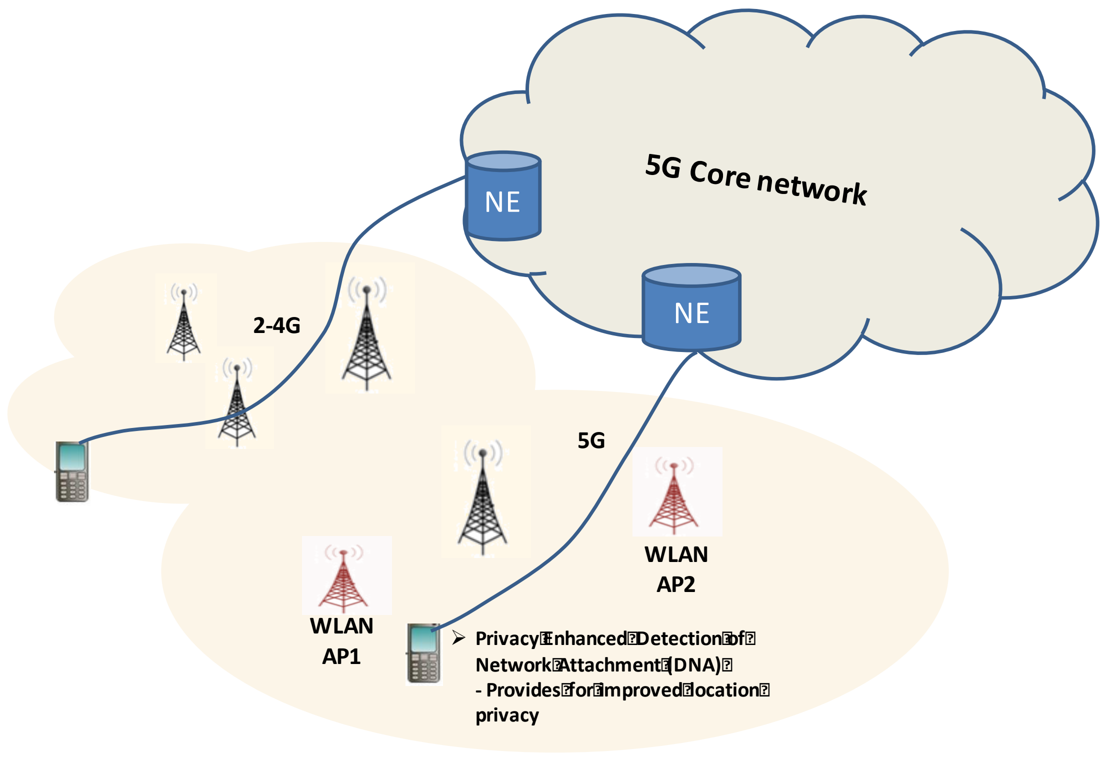

5G Core network
NE
NE
2-4G
5G
WLAN AP2
WLAN AP1
➢ Privacy Enhanced Detection of Network Attachment (DNA)
- Provides for improved location privacy

Figure 27: Privacy Enhanced Attachment

3.2.6.1 *Target features for R1*

The enabler aims to enhance location privacy as a device roams from one IP-based network to the next, primarily in the context of 5G non-3GPP access. It provides for enhanced privacy with respect to the leakage of identifiers for previous points of attachment. Specifically, we introduce two new mechanisms to protect the privacy of the device.

- **Randomised ordering**: This mechanism will provide for randomisation of candidate link layer (MAC) addresses so as to enhance the location privacy with respect to the time-based analysis of the device's movement patterns.
- **Dummy addresses**: This mechanism will allow for the introduction of dummy MAC addresses into the attachment phase to enhance location privacy with respect to location identification and time-based analysis of the device.

3.2.6.2 *Target features for R2*

The next release aims to enhance the mechanisms developed in R1. Specifically, we are considering approaches which could provide a pre-analysis phase of the address anonymity metrics which would allow for dynamically optimised choice of address randomisation and dummy addresses.

3.2.7 Basic concepts

3.2.7.1 Dynamic Host Configuration Protocol (DHCP) concepts

When a device has connected at the link-layer then it will begin the process of configuring an Internet Protocol address. If the device is set up to automatically obtain an address this is typically achieved using the Dynamic Host Configuration Protocol (DHCP) which is specified for both IPv4 [1] and IPv6 [2].

The mode of operation of DHCP depends on whether the device has determined if it has connected to a new network, in which case it enters the INIT state and attempts to obtain a new address, or if the device has determined it has reconnected to a previous network, then the DHCP client enters the INIT-REBOOT state and attempts to reuse an unexpired lease. The problem is that with mobile devices there are a limited number of cases where one can be sure whether a device is on a new or existing network. With WiFi a device can ascertain the SSID of the network which can help in determining whether it has been previously visited. Furthermore, if the device has a stored WiFi security association then it can be reasonably sure this is indeed a previously visited network. Thus most devices will default to using the INIT state. However, as we see in the next section if a device makes use of the DNA protocol it can potentially omit the full INIT state transition and utilise an expedited INIT-REBOOT phase.

On connecting to the network, in the INIT state, a node will broadcast a DHCPDISCOVER packet which elicits a DHCPOFFER from the DHCP server, containing an offered IP address. The device then generates a DHCPREQUEST containing the offered address, which the server should acknowledge with a DHCPACK. Once the request is acknowledged the device should perform an Address Conflict Detection (ACD) [5] before it attempts to use its requested address. ACD basically consists of sending out a series of 'ARP Probes' for its own address to check if another node is using this address. If no responses are seen then the node follows this up with a series of 'ARP Announcements' claiming the address, after which it starts using the address.

If a node determines it is on the same link as before then it will initiate the INIT-REBOOT state and attempt to reuse an existing unexpired DHCP lease by sending out a DHCPREQUEST for it. Once the server confirms it with a DHCPACK then the node can start using the address, without having to perform ACD. However most mobile devices do not employ INIT-REBOOT directly [4] as there aren't any reliable ways to ascertain whether the device has reconnected to the same network.

3.2.7.2 Detection of Network Attachment (DNA) concepts

Although most devices employ DHCP to obtain an IP address the protocol can take up to seven seconds to complete the address assignment operation (when the protocol incurs the full range of specified delays due to conflict detection or collisions etc). In a number of cases this time can be significantly reduced by employing an enhancement protocol known as Detection of Network Attachment (DNA) [5], which is widely deployed in Apple devices running iOS and OSX, and also in Google devices running ChromeOS. Specifically, DNA speeds up the connection re-establishment to networks that the device has previously visited for which the device has a pre-existing DHCP lease. It does this by verifying that it has reattached to a known network for which it can quickly reuse an existing lease without the need to perform address conflict detection.

3.2.8 Main interactions

3.2.8.1 Use cases

Here we detail the use case diagram in Figure 28 which provides an overview of the basic use case and entities involved in the enabler.

The steps involved are for the device to perform a privacy-enhanced IP address request and then for the system to provide an IP address. This is based upon DHCP services but the privacy services are provided at the attachment phase before a DHCP request is made.

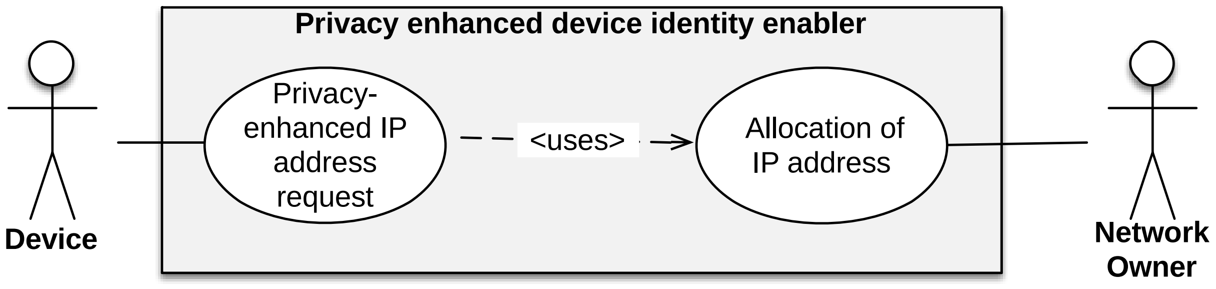

Privacy enhanced device identity enabler
Privacy-enhanced IP address request
<uses>
Allocation of IP address
Device
Network Owner

Figure 28: Use case diagram

3.2.8.2 Components and interaction overview

The basic components are detailed below in Figure 29, with the enabler components highlighted. The enabler operates within the system DHCP services and provides for privacy-enhanced operation.

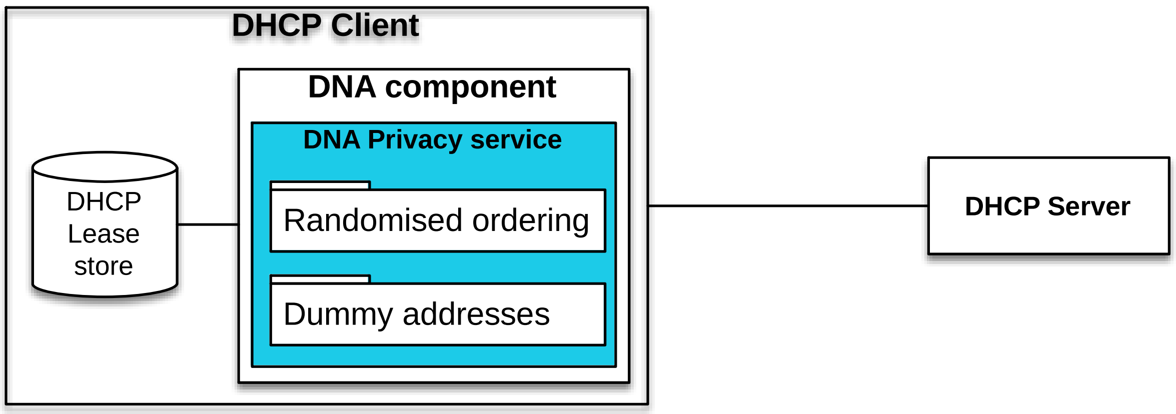


Figure 29: Device identifier privacy component overview

The DHCP client initiates a protocol exchange for each new connection and stores any unexpired leases in the DHCP lease store. On attachment to a new network when the client has active leases in the DHCP lease store the Detection of Network Attachment (DNA) protocol is enacted.

The sequence of events concerning the DNA privacy service are detailed by the sequence diagram in Figure 30. The protocol operates by utilising stored information about prior unexpired DHCP leases that have not been released back to the DHCP server. In particular, for each lease the MAC and IP addresses of the router, and the assigned IP of the client may be used to perform a 'reachability test'. This test is performed by a device once it has connected at the link-layer, provided it has a suitable set of candidate leases and is not prohibited by the configuration of authenticated DHCP. When used on WiFi networks some systems, including iOS and OSX, attempt to use the SSID of the current network to filter candidate leases.

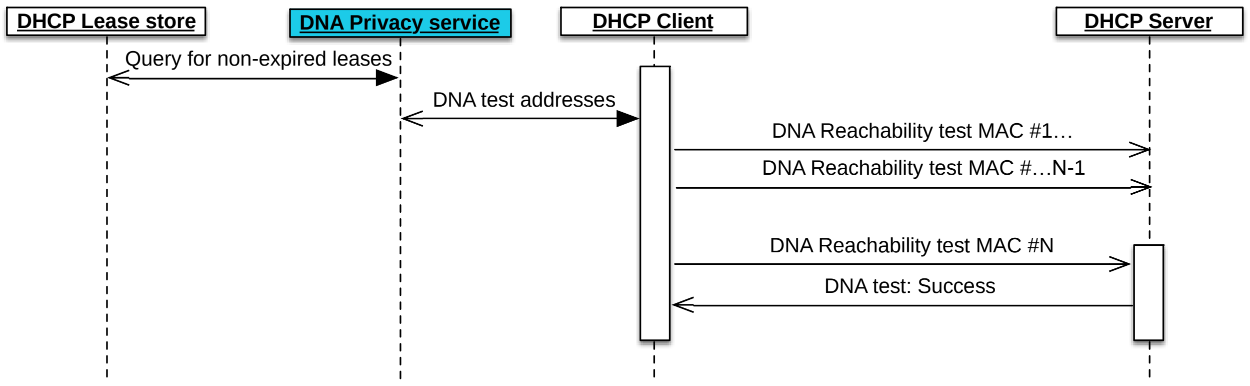

DHCP Lease store
DNA Privacy service
DHCP Client
DHCP Server
Query for non-expired leases
DNA test addresses
DNA Reachability test MAC #1…
DNA Reachability test MAC #…N-1
DNA Reachability test MAC #N
DNA test: Success

Figure 30: Device identifier privacy sequence diagram

The reachability test takes the form of a unicast ARP request packet, sent by the client, directed at the router's MAC address with the ARP's target protocol address set to the router's IPv4 address, and the sender protocol address field to its own candidate IPv4 address. The client includes its MAC address in the sender hardware address field and sets the target hardware address field to the null address. If a valid ARP Reply is received, the MAC address in the sender hardware address field in the ARP Reply is matched against the target hardware address field in the ARP Request, and the IPv4 address in the sender protocol address field of the ARP Reply is matched against the target protocol address field in the ARP Request. If a match is found, then the host continues to use that IPv4 address, subject to the conditions of the matching stored DHCP lease.

3.2.9 Architectural drivers

3.2.9.1 High-Level functional requirements

The high-level functional requirements are:

- The user shall have attached to previous networks
- The user shall be attaching to IP based network
- The enabler shall provide for privacy-enhanced attachment
- The enabler shall provide for improved location privacy

3.2.9.2 Quality attributes

Compatibility: The privacy enhanced version of the DNA protocol aims to maintain compatibility with the standard version.

Security: The enabler aims to provide location privacy improvements for the device.

3.2.9.3 Technical constraints

The device needs to be capable of running POSIX compliant, preferably Linux, system which supports the use of a DHCP client.

3.2.9.4 Business constraints

None.

3.2.10 Detailed specifications

3.2.10.1 Introduction

This enabler aims to enhance location privacy as a device roams from one Internet-based network to the next, primarily in the context of non-3GPP 5G access. It provides for enhanced privacy with respect to the leakage of identifiers for previous points of attachment. Specifically, we introduce two new mechanisms to protect the privacy of the device.

- **Randomised ordering**: This mechanism will provide for randomised delivery of candidate link layer addresses in the DNA reachability tests so as to enhance the location privacy with respect to the time-based analysis of the device’s movement patterns.
- **Dummy addresses**: This mechanism will allow for the introduction of dummy addresses into the DNA reachability tests to enhance location privacy with respect to location identification and time-based analysis of the device’s movement patterns.

3.2.10.2 Conformance

For an implementation to be conformant it should implement specifications as stated herein.

3.2.10.3 API specifications

There is no specific API for the enabler as it operates within the confines of an existing DHCP client and thus provides no external API interfaces.

3.2.10.4 Enabler component specifications

3.2.10.4.1 Randomised ordering component specifications

The ordering of the DNA requests can be quite revealing in terms of deriving the path a device has taken. This presents a privacy issue in terms of potentially deriving a user’s previous locations and a time ordered path taken between those previous locations. Thus we propose that for each DNA reachability tests the ordering of the leases used should be randomised so as to reduce the potential likelihood that ordering information may be derived regarding the device’s path. Clearly, in some situations, where other data is available, such as timing and location information, this approach may provide limited benefits. However, we consider that in most cases this change would enhance privacy and should not increase the time to connection, since the original ordering would only be potentially beneficial if a person was to retrace their steps.

3.2.10.4.2 Dummy addresses component specifications

Another way to enhance the user’s privacy for DNA is to inject dummy MAC addresses into the protocol. This has benefits in terms of adding noise to any path-based inferences and also to obscure potential derivation of locations. Two physically adjacent MAC addresses are typically sufficiently to derive a user’s location from a location provider such as Google. For each new point of attachment we recommend that nodes inject a one or two extra reachability tests to dummy MAC addresses, which would have a negligible impact on performance as the device need not wait for a response for these.

The efficacy of such an approach depends upon a number of factors; it depends on how easy it is to discern which MAC addresses are the dummy ones. Firstly, this may be achieved by inspecting the MAC's validity in terms of its compliance to IEEE OUI prefixes and flags. Secondly it may be possible for an adversary to test for geographic proximity by sending the MAC addresses to a location service and deriving a possible path. Thus the choice of random MAC addresses needs careful consideration. We propose a number of potential approaches:

- Random MACs: There are a number of ways in which to generate random MAC addresses which we will explore, such that they comply with IEEE rules.
- MACs from expired leases: Over the lifetime of a device it will typically encounter many different points of attachment some of which could be stored and reused. This approach has the advantage that it is self-contained, but can be limited if a user's attachment points are constrained.
- MAC address location spoofing: Addresses could be specifically chosen from either a location service provider, or from previous DHCP leases, in such a way as to provide a dummy location.

These techniques aim to enhance the privacy of a client device against localised attacks on their location privacy, though they will have limited benefits against a stronger adversary, but in that case there is often other auxiliary information which can reduce the efficacy of other location privacy measures.

3.2.11 Re-utilised Technologies/Specifications

We aim to build upon existing DHCP client implementations to provide for the enabler service.

3.2.11.1 References

[1] R. Droms, "Dynamic Host Configuration Protocol. RFC 2131 (Draft Standard)," IETF, 1997.

[2] R. Droms, J. Bound, B. Volz, T. Lemon, C. Perkins and M. Carney, "Dynamic Host Configuration Protocol for IPv6 (DHCPv6). RFC 3315 (Proposed Standard)," IETF, 2003.

[3] B. Aboba, J. Carlson and S. Cheshire, "Detecting Network Attachment in IPv4 (DNAv4). RFC 4436.," IETF, 2006.

[4] D. Plummer, "Ethernet Address Resolution Protocol: Or converting network protocol addresses to 48.bit Ethernet address for transmission on Ethernet hardware, STD 37, RFC 826," IETF, 1982.

[5] S. Cheshire, "IPv4 Address Conflict Detection. RFC 5227 (Proposed Standard)," IETF, 2008.

[6] I. Papapanagiotou, E. M. Nahum and V. Pappas, "Configuring DHCP leases in the smartphone era," in *ACM Conference on Internet Measurement Conference, IMC '12*, New York, 2012.

3.2.12 Acknowledgements

We would like to acknowledge the work of Joss Wright and the UK EPSRC Being There project (grant EP/L00416X/1).

4 Trust Enablers open specifications

4.1 Trust Builder

4.1.1 Preface

The Trust Builder enabler uses innovative semantic models to provide a way to understand and control threats to a system. The Trust Builder is used primarily when specifying or designing new deployments and shares models with the Secure System State Repository enabler which is a runtime monitoring component.

4.1.2 Status

Since the publication of the 5G-ENSURE roadmap in D3.1, the development schedule for the Trust Builder has been rethought and rearranged in order to provide tangible software for evaluation and feedback at an earlier stage.

The roadmap stated that in the first release (R1) the 5G Asset Model and v1 of the 5G Threat Knowledgebase would be delivered and that in release 2 (R2) the graphical editor for describing systems using the knowledgebase and v2 of the Threat Knowledgebase would be delivered. Instead the roadmap will be as follows:

- R1
    - Graphical editor v1 (software)
    - 5G asset model v1 (ontology)
- R2
    - Graphical editor v2 (software)
    - 5G asset model v2 (ontology)
    - 5G threat knowledgebase (ontology)

This specification therefore focusses on the graphical editor and also describes the modelling approaches which are both in development.

4.1.3 Copyright

4.1.4 Legal notice

The Legal notice that applies to these specifications is given in Annex A.

4.1.5 Terms and definitions

Core Model – the core ontology, defining common vocabulary and relationships used in all higher level models.

Generic Model – an ontology defining the typology of Assets, Threats and Controls (security measures) for a given domain (e.g. 5G networks). In release R1, this will cover only Assets and some types of Controls.

Design-Time System Model – an abstract model of a particular system, described in terms of the relationships between system specific Asset classes. The design time model can then be enriched by specifying which security Controls should be used to protect each type of system asset, and auto-generating a set of system-specific Threat classes describing potential threats to the system.

Runtime System Model – a model using instances of the Assets, Threats and Controls to describe what is known about the current state of an existing system.

4.1.6 Overview

The Core and Generic Models are both used in the Trust Builder and System Security State Repository enablers. The Core Model provides a basic structure which both tools assume will underpin any System model they need to handle. Both tools also load the Generic Model, and use it to generate user interface elements and as a basis for semantic reasoning.

The increased complexity and dynamicity of 5G networks means that modelling and understanding the threats is even more important than in earlier relatively static and well-understood systems. For instance, with NFV, SDN and micro-segmentation there will be new virtual networks (which may be relatively short-lived) created on top of the static physical infrastructure. Design-time decisions will therefore be more frequent and more complex and decision-support tools such as the Trust Builder can play their part.

The Trust Builder enabler provides a way to model the components of 5G networks and their relationships, understand what threats are present and what controls are necessary to mitigate or annul those threats. It thereby supports creation of a Design-Time System Model describing a specific 5G network and/or application, including an automatically generated set of potential threats from which trust and security requirements can be determined.

For instance, when needing to deploy a new slice to support a specific application, a (virtual) network operator will need to define how the various network elements are orchestrated: how to create the required functionality by composing the basic elements defined by the 5G standard. These network slices which will potentially incorporate physical assets of many actors will not be one-size-fits-all solutions and so each different design will need to be analysed to determine what controls (e.g. firewalls) are necessary to mitigate the threats specific to the design. Here the user of the enabler is the (V)MNO and potentially (depending on their business relationship) the customer of the slice.

Trust Builder will be a web application where system designers and other classes of user can create and collaborate on "design-time" system models. Based on the threats and controls encoded in the knowledgebase, Trust Builder will highlight the potential weaknesses in a model and propose controls to address the nascent threats. The design-time system model can then be used as an input to the System Security State Repository to document the intended design of the system (including the necessary controls) and thus carried into the runtime operational phase.

4.1.7 Basic concepts

The Trust Builder makes use of a Core Model and a Generic Model to create a Design-Time System Model. These concepts are further described here.

4.1.7.1 The Core Model

The current Core Model is shown in Figure 31. It includes just the concepts which are common across all domains. In simple terms the model says that assets can be threatened by threats which cause misbehaviour and protected by controls. Furthermore, assets that are related to each other using specific relationship types to form patterns, in which each asset takes a role (such as client or server). Threats apply to patterns and when active cause misbehaviours (i.e. unacceptable behaviour) in the assets forming the pattern they apply to. Control strategies, each comprising of one or more controls located on assets block or mitigate threats. If all controls within a control strategy are present, the control strategy blocks or mitigates a threat.

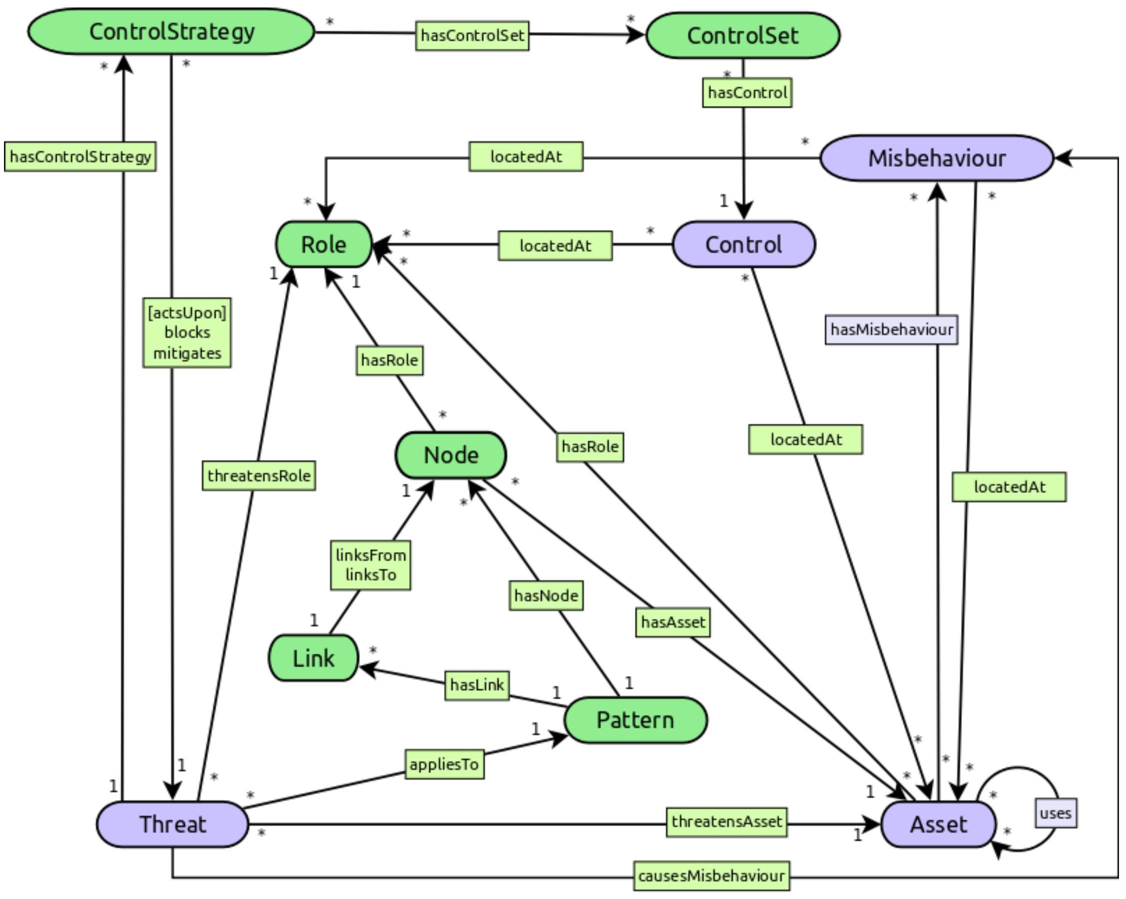


Figure 31: The Core Model.

4.1.7.2 *The Generic Model*

The Generic Model is where the domain-specific knowledge is encoded. In relation to the Trust Builder roadmap, the 5G Asset Model and the 5G Threat Knowledgebase together form the Generic Model. As the content and design of the Asset Model and Threat Knowledgebase are formed it may be necessary to adjust or extend the concepts in the Core Model itself.

The generic model specialises the core model allowing the encoding of the security knowledge. The specialisation is done via sub classing the different core model classes:

- The subclasses of core: Asset form the 5G Asset Model, representing the assets (such as an HSS but also human stakeholders) that will be used by the system designer to express the structure of their system. The assets are categorised by type (e.g. logical asset, host, etc.) and have roles based on their relationships (e.g. client role, service role).
- The 5G Threat Knowledgebase includes several parts:

- The subclasses of core: Threat constitute the threat knowledge base that may compromise the generic assets.
- The subclasses of core: Control constitute the set of controls that can protect Assets and thereby block threat actions or mitigate threat consequences. The ControlStrategy elements describe groups of controls that can counteract specific threats.
- The subclasses of core: Misbehaviour are the set of adverse asset behaviours that could be induced by the threats if they were active (i.e. if the threat action occurs).

In addition, Patterns of Assets will also be defined and the possible Asset relationship types will be encoded.

4.1.7.3 The Design-Time System Model

The purpose of the Trust Builder is to provide a tool to create and analyse Design-Time System Models. In the use cases below, “model” refers to the instances of the Design-Time System Model.

Technically, the Design-Time System Model is created using sub-classes of the assets, threats and controls defined in the Generic Model. More than one item in the Design-Time System Model can have the same super-class, so for instance if there was an MME asset in the Generic Model, there could be two or more MMEs in the Design-Time System Model: each one a different sub-class of the MME class (which is itself a sub-class off core:Asset), and distinguished by their relationships to other assets.

Practically, the user of the Trust Builder will create the Design-Time System Model by dragging and dropping assets from the Generic Model onto a canvas and linking them together using the relationships also defined in the Generic Model.

4.1.8 Main interactions

4.1.8.1 Use cases

The use cases are diagrammed below in Figure 32.

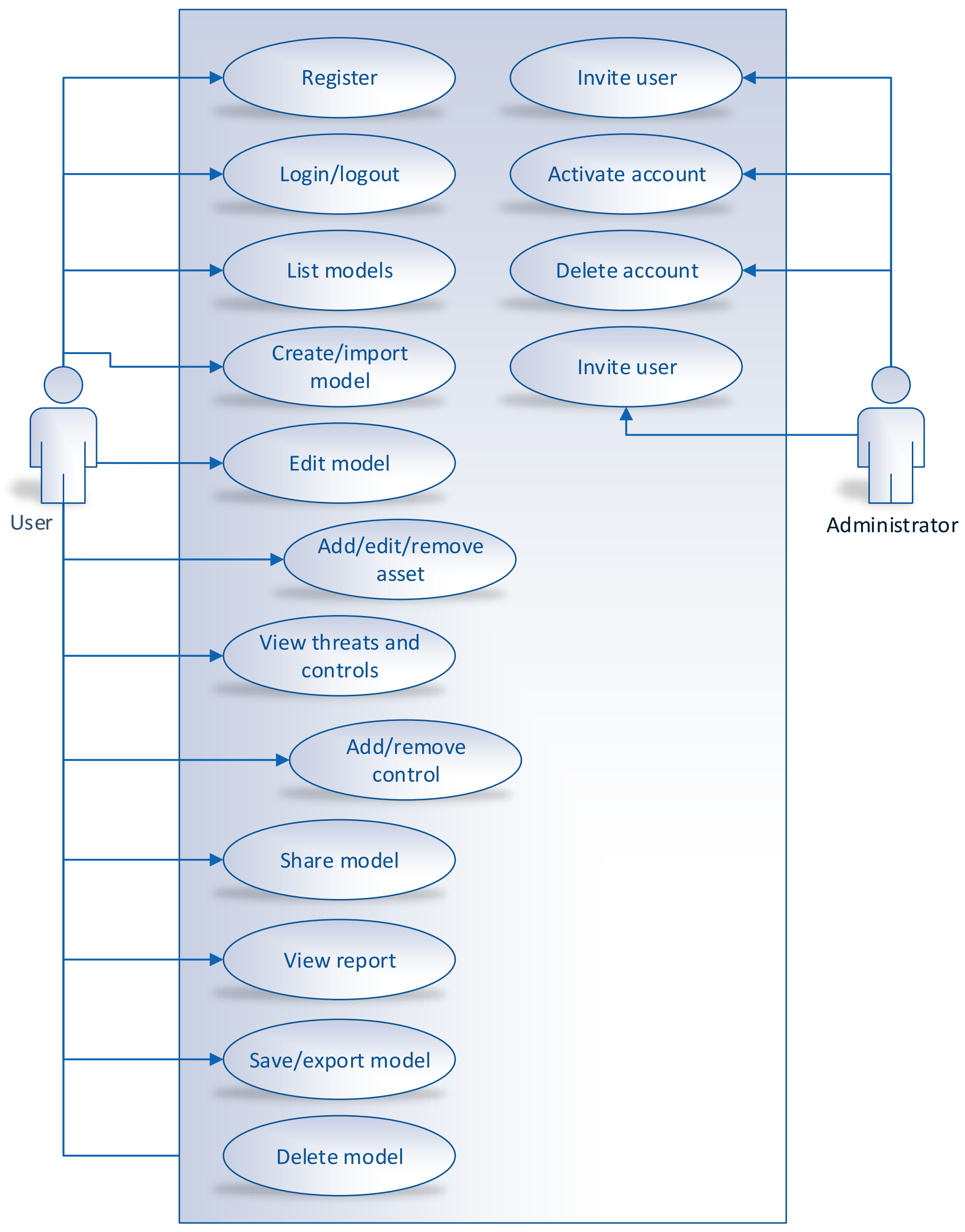


Figure 32: Trust Builder use cases.

4.1.8.1.1 Registration and user account setup

A new user requests an account for the service or is invited by an administrator. After activation by an administrator, the user is provided with credentials for their account. The user account will provide access to the service: an online workspace where the user can create, modify, store and share models. A user account can be deleted by an administrator at any time.

4.1.8.1.2 Login/Logout

The user logs into their account (is authenticated) using a secure connection. On logging in, the user should be informed of when they last logged in. The subsequent use-cases are only available to authenticated users. After using the service, the user should log out to prevent unauthorised access.

4.1.8.1.3 List models

The user can list all models that they have read or read-write access to.

4.1.8.1.4 Share model

A user can choose to share read-only or read-write access to a model with another user. A user can also transfer ownership of a model that they own, choosing whether to retain read-only, read-write or no access rights on the model. Only exactly one user can be the owner of a model at any time. The owner of a model may revoke others' access rights on a model. A user who has access rights to a model may revoke their own rights.

Concurrent access to models will not be implemented, so if more than one user has write access, the model will need to be locked while being edited by a user.

4.1.8.1.5 Copy / Create / Import model

A model can be created by starting with a blank canvas (i.e. "empty" model). Alternatively, an existing model RDF file can be uploaded from disk or an existing model can be duplicated. The user becomes the owner of any model they create.

4.1.8.1.6 Delete model

Models the user owns can be deleted. This will remove the model entirely and remove any access rights to the model for other users.

4.1.8.1.7 Design time model specification and compilation

Application domain experts will create system models by dragging and dropping generic assets from a curated subset of all generic (domain-specific) asset classes onto a canvas and connecting them using predefined relationship types.

Once a system asset model has been created, the editor should automatically:

- determine and add any implicitly created assets and relationships as needed to completely define the relationships of system assets needed to model threats and control strategies;
- determine additional 'inferred' classifications for some of the system-specific asset classes, which are also needed to determine the applicability of some generic model threats;
- generate system-specific threat classes by specialising the generic model classes so they apply to system-specific asset types.

The process of carrying out these steps is known as system model 'compilation'.

4.1.8.1.8 Design time model analysis and refinement

Once a compiled system model is available, the designer would be interested in finding out:

- a complete list of known potential threats to the system (i.e. system specific threat classes generated during the compilation step) and their relationships to system specific asset types;
- a classification of those threat types based on whether they are always, sometimes or never secondary effects;
- a complete list of misbehaviours that could be caused by those threat types (i.e. which types of misbehaviour could be caused in each asset type);

- a list of potential threats to (and/or involving) a selected system asset type, plus the status of each threat (primary, secondary, or either);
- a list of misbehaviours that may be caused in a selected system asset type by the known system threat types;
- a set of relevant control options for blocking or mitigating a selected type of threat;
- the set of threats whose control options include a specific control protecting a specific asset type.

The designer should then be able to select one or more control options for threats they wish to block or mitigate. By selecting a control option, the designer is saying that the corresponding control objectives should be met by the system implementers so that type of threat will be blocked/mitigated. At any stage the designer will be able to query the model to find out the consequences if all the control requirements so far selected by the designer are met:

- Which potential threat types would be blocked or mitigated and which would be left untreated? Which misbehaviours in which asset types should be monitored to detect activity in untreated, unblocked or all types of threats (i.e. which misbehaviours could be caused by those threats)?
- For a selected asset type, which types of controls should be protecting that asset type given the selected control options?
- For a selected asset type, which types of misbehaviours should be monitored to detect activity in untreated or unblocked types of threats?

The trust builder can build on the top of the offered features to format the results of these queries (especially threat types and controls related to system asset types) to provide human readable documentation of the system security (control) requirements, including which threats would be treated by meeting these requirements, and which would remain as residual risks.

4.1.8.1.9 View report

After finishing the modification and refinement of a model, the user can generate a report. This will generate and display a (printable) HTML page, containing information (visual and/or text) about the model and the effects of the controls including but not limited to:

- a picture of the system model graph
- a list of all assets in the system model including information about potential controls
- a list of all threats in the system, possibly grouped by which asset they affect
- a (graphical) overview of controls added to the system and the percentage of threats that would be treated with the controls in effect

4.1.8.1.10 Model import/export

This feature provides a mechanism to import/export models to/from the system. It enables users to download model files to their machine for archive or sharing purposes.

4.1.8.2 Components and interaction overview

The Trust Builder will be a web application using HTML5 and modern client-side JavaScript libraries to provide a rich responsive interface. The web client will communicate with the server side using a secure REST API. Processing of the design-time system model will be performed on the server side and the threats and potential controls communicated back to the client for examination and selection.

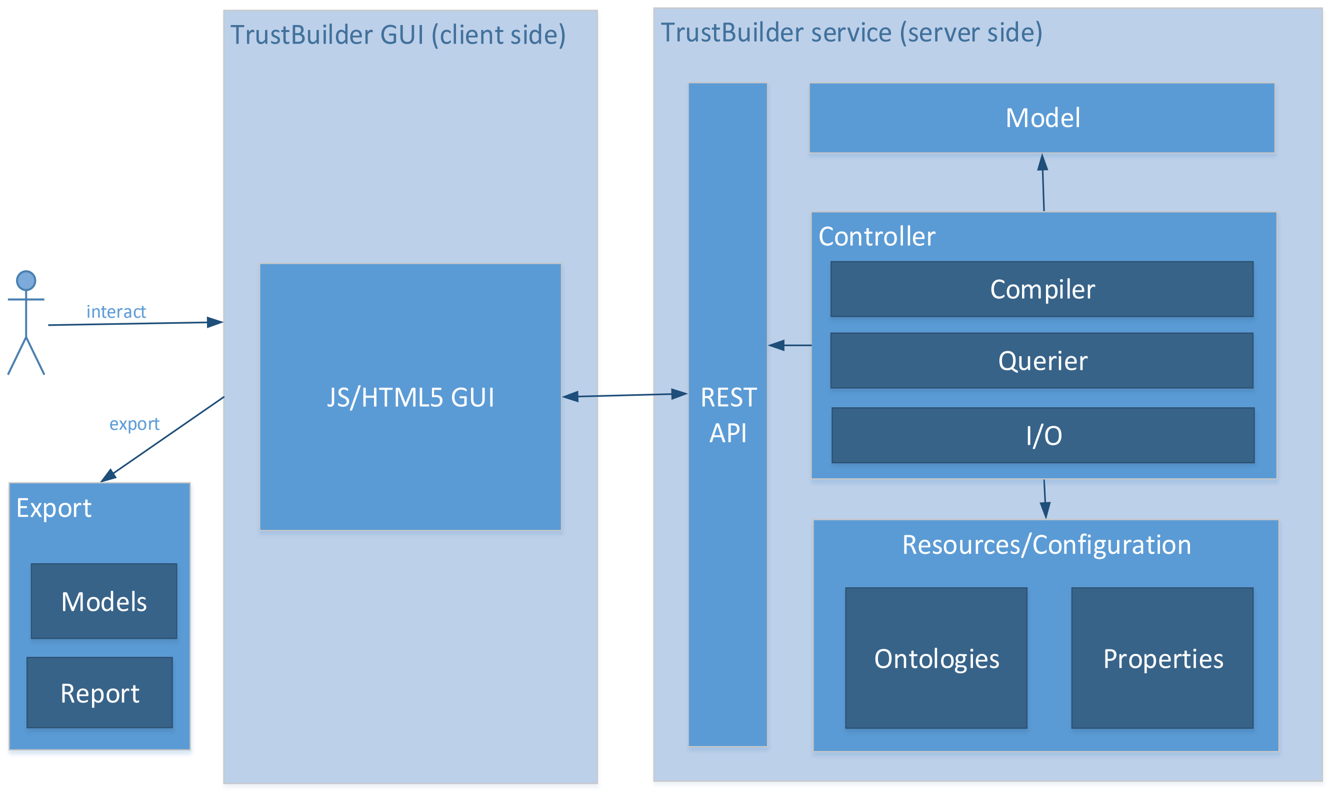


Figure 33: Trust Builder architecture.

4.1.9 Architectural drivers

4.1.9.1 High-Level functional requirements

The high-level functional requirements are covered by the use cases above.

4.1.9.2 Quality attributes

Compatibility: all generated ontologies need to be valid serialized RDF files.

4.1.9.3 Technical constraints

The tool should work in recent main-stream desktop web browsers such as Internet Explorer v11 or later, Firefox, Chrome and Edge.

4.1.9.4 Business constraints

No known business constraint exists.

4.1.10 Detailed specifications

4.1.10.1 Introduction

The Trust Builder enabler provides a way to model the components of 5G networks and their relationships, understand what threats are present and what controls are necessary to mitigate or annul those threats

4.1.10.2 Conformance

For an implementation to be conformant it should implement specifications as stated herein.

4.1.10.3 API specifications

Although the Trust Builder service will provide an API for the web-based client to use, the two parts are closely coupled and alternative clients using the same API are not envisaged. Therefore the detail of the API is not relevant and does not form part of this open specification.

4.1.11 Re-utilised Technologies/Specifications

This enabler builds on the Secure System Designer software from the OPTET project [1]. Aspects of the interface design along with some libraries to be used on the server side of the Trust Builder will be re-used.

4.1.12 References

[1] OPTET Project: www.optet.eu

4.2 Trust Metric Enabler Open specifications

4.2.1 Preface

This section presents 'Trust Metric Enabler'. The enabler is related to two other 5G-ENSURE security enablers, namely 'Micro Segmentation' and 'Security Monitor for 5G Micro-Segments'.

4.2.2 Status

This document provides an open specification of the framework feature that will be implemented for the first release of the enabler. The status of these open specifications is preliminary especially for what concerns API definition.

4.2.3 Copyright

4.2.4 Legal notice

The Legal notice that applies to these specifications is given in Annex A.

4.2.5 Terms and definitions

AP	Access Point
eNodeB	Evolved Node B
EPC	Evolved Packet Core
HSS	Home Subscriber Server
IDS	Intrusion Detection System
Micro-Segment	An isolated and secured segment inside a SDN
Micro-Segment Orchestrator	Entity that automatically arranges, coordinates and manages micro-segments
MME	Mobility Management Entity
MNO	Mobile Network Operator
PGW	Packet Data Network Gateway
RAN	Radio Access Network
SDN	Software Defined Network
SGW	Serving Gateway
UE	User Equipment
VMNO	Virtual MNO
VNF	Virtual Network Function

4.2.6 Overview

The vision of 5G is a flexible and dynamic system in terms of use cases, UEs, RAN technologies and core network services. The complexity of the system will become even more evident if new deployment models, such as third-party and multi-operator deployments, and new third-party APIs, enabling e.g. full configuration control of network functions, will be supported. The goal of Trust Metric Enabler is to reduce the complexity of operating security aware 5G services, provided by MNO or VMNO, specifically in terms of trust. In addition, it facilitates efficient use of 5G network resources by optimizing the used 5G network infrastructure and services based on the third-party service provider requirements.

The Trust Metric enabler provides an abstraction layer for utilizing trust in third-party services (also in other 5G Security Enablers). The third-party service provider may use the enabler to

- Define trust requirements of the provided service
  - 5G system will adapt to these requirements within its capabilities
  - 5G network and 5G Security Enablers may provide dynamic security controls and network management, when available
- Monitor how the trust requirements are met in the e.g. service as a whole, part of the service, specific UE or traffic flow.
- Assign trust levels for unauthenticated UEs e.g. through isolated slices with MAC authentication bypass or Web authentication. Trust level can be zero when UE is not-trusted

The main function of the enabler is to **produce a trust metric value which measures in real-time how the third party service provider's and the network operator's combined trust requirements are met in the 5G system**. The trust metric value is calculated based on the third party service provider's trust model, 5G network operator's trust model and 5G trust measurements. When the result of the calculation is acceptable, the service is enabled, otherwise it is disabled. The enabler has three input and one output categories:

- Inputs: Third-party service provider's trust model, network operator's trust model, trust measurement
- Outputs: Trust metric value

4.2.7 Basic concepts

Trust model

Trust model is used to present a set of security related characteristics related to a specific use case, service or system. It includes the mechanisms necessary to respond to a respective threat profile. A threat profile identifies most likely attacks and vulnerabilities that put a specific environment at risk. Trust model encompasses also trust relationships between entities. If it is possible to bind unique attributes to a unique identity (including non-verified identity) then a trust relationship can be established based on the level of confidence in the binding. The trust relationship enables a framework in which interactions between the entities takes place within predictable boundaries with some confidence. The model may include also definition of a trust domain in which a baseline trustworthiness value can be associated to entities within the domain. Trust model is used here in two main contexts:

1. Third-party service trust model defines a set of requirements that must be met in order to enable good-enough security related to a specific third-party service.
2. Network trust model defines a set of axiomatic characteristic in the current network setup and the additional security capabilities that can be applied. These additional capabilities may adapt and evolve as measured trust changes.

Trust measurement

"Trust measurement is an objective measurement that provides evidence to enable evaluation of trust from a specific point-of-view. The measurement must be aligned with the trust requirements in order to support the evaluation. For each point-of-view different measures must be used, and these measures may change when environment changes. For example, the measurement categories can include

- Application trust; level of end-to-end protection, level of platform protection, level of application protection, measurements of vulnerabilities
- Communication trust; level of transport protection, level of platform protection, QoS measurements, level of implemented security controls, measurements of vulnerabilities
- Identity trust; level of authentication mechanisms, reputation of the peers, transitive trust characteristics

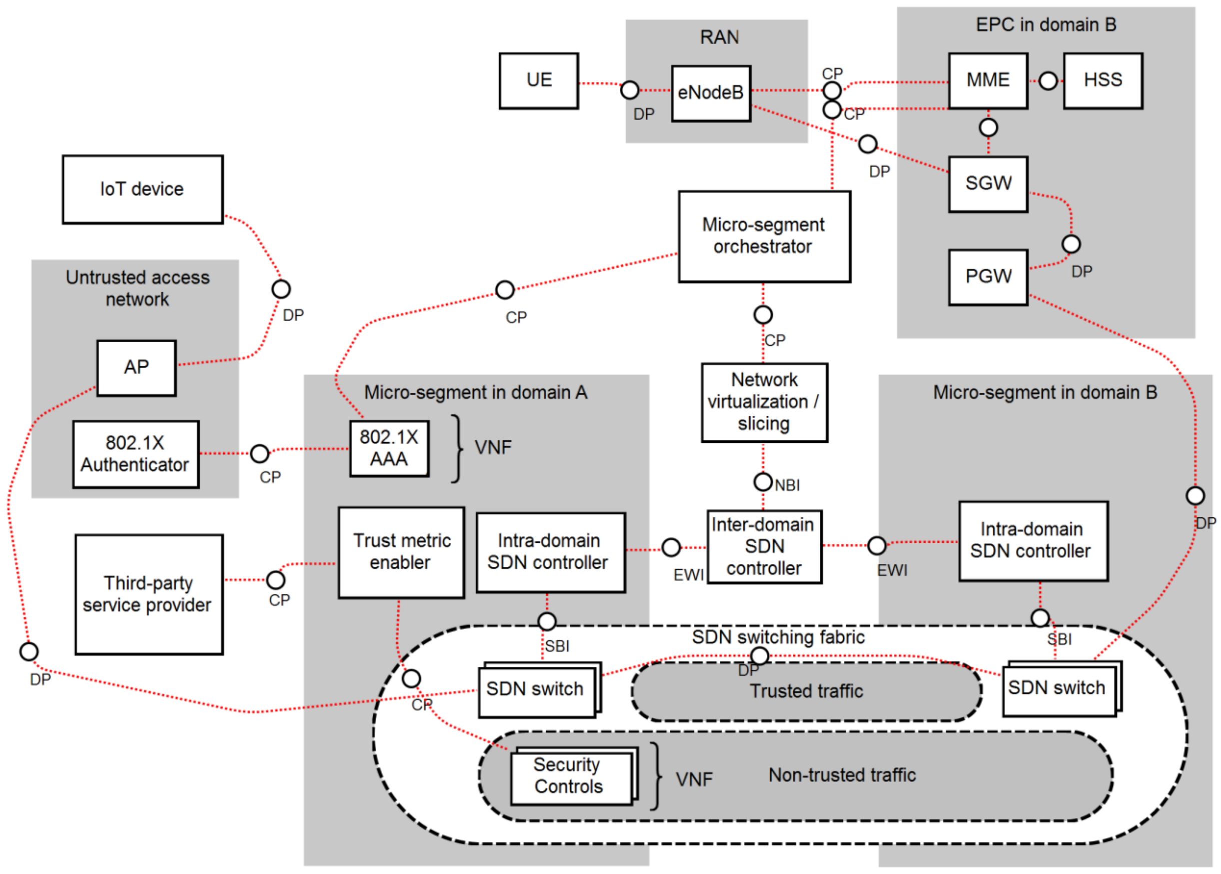
4.2.8 Main interactions

4.2.8.1 Use cases

A component diagram of an example use case is presented in the following figure. In this use case a third-party service provider provides an IoT service to end-user (presented by UE). The service's main value-added characteristics are following

- UE is able to connect directly (i.e. no intermediated servers) to IoT devices
- Untrusted access network can be utilized to connect untrusted IoT devices to the service securely

The service provider utilizes Micro-Segmentation Enabler (presented by Micro-segment orchestrator) which takes care of service isolation, multi-domain support and network management (Micro-segments and segmentation are defined in Chapter 6.4 of this document).



CP = Control plane, DP = Data plane,
NBI = North-bound interface (SDN), SBI = South-bound interface (SDN), EWI = East-west interface (SDN)

Figure 34: Use case example component diagram

The third-party service provider has defined following network requirements, measurements and trust metric mapping in a trust model.

Network requirements

- Isolated micro-segment
  - Allow communication between IoT device and UE (data plane)
- VNFs: 802.1X AAA, IDS (Security controls)
- Minimum data plane protection
  - Transport based hop-by-hop integrity protection
- Traffic flows (data plane)
  - Trusted traffic
    - Allow trusted network access with 802.1X authentication
    - Highest QoS (no additional security controls)
  - Non-trusted traffic
    - Allow
      - untrusted network access with MAC authentication bypass
      - untrusted network access with web authentication
    - Deny end-to-end encrypted traffic (in order IDS to work)
    - Inspected by IDS

Measurements

- Validate network requirements (this measurement is included by default)
- Number of connected IoT Devices and UEs
- Subscribed IDS alerts
    - High severity (i.e. indicates attacks and malware)

Trust metric mapping

- Binary value (0,1)
- Value 0 (trust metric unacceptable)
    - Network requirements are not achieved or validated
    - More than ten IoT devices is connected to a single UE
    - IDS alert with high severity detected
- Value 1 (trust metric acceptable)
    - Otherwise

5G network (Micro-segmentation Enabler) has provided following network capabilities and measurements in a trust model.

Network capabilities

- Generic network capabilities
- Security Enablers
    - Micro-segmentation
    - Trust Metric Enabler
- VNFs (security)
    - IDS, IPS, Firewall

Measurements

- Validation of network capabilities
- Security Enablers
    - Micro-segment network and service statistics
- VNFs
    - IDS and IPS alerts
    - Firewall statistics

The following diagram depicts the activities in this use case.

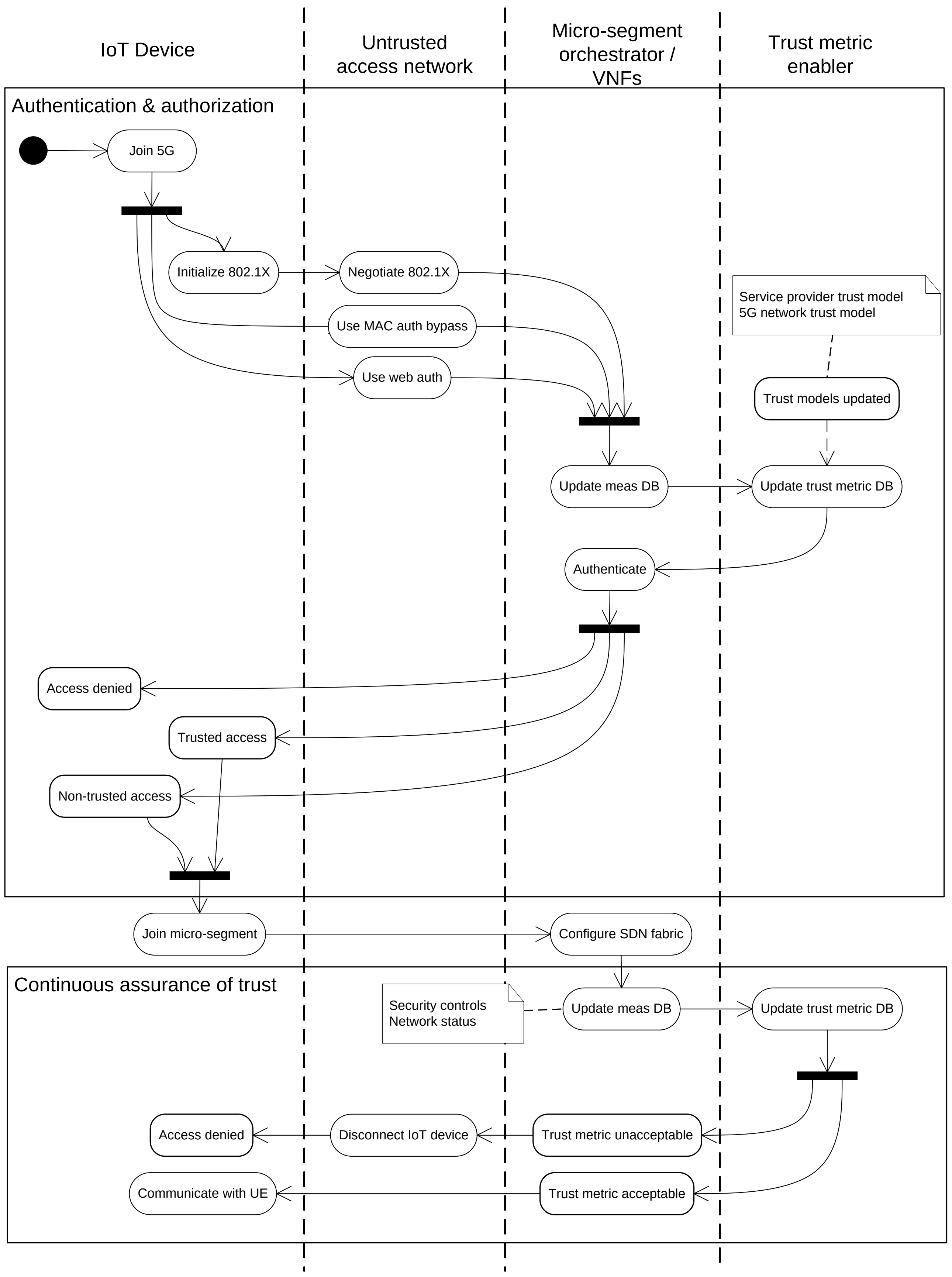


Figure 35: Use case example activity diagram

4.2.8.2 Components and interaction overview

The main components, APIs and interactions are presented in the following figures as discussed previously.

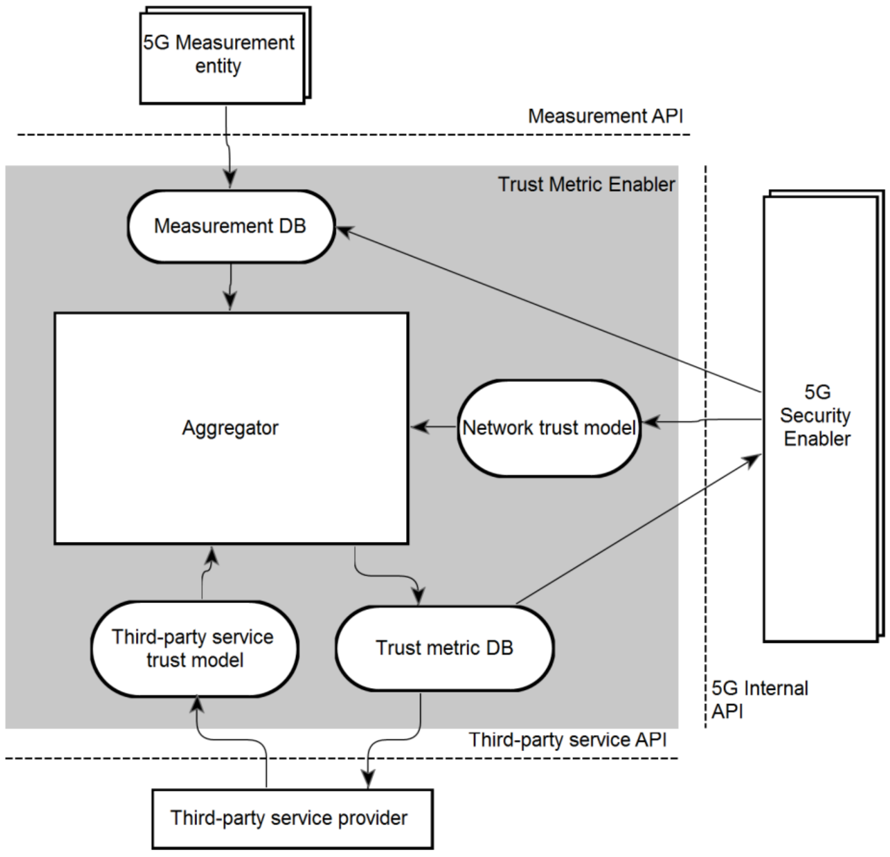


Figure 36: Main component diagram

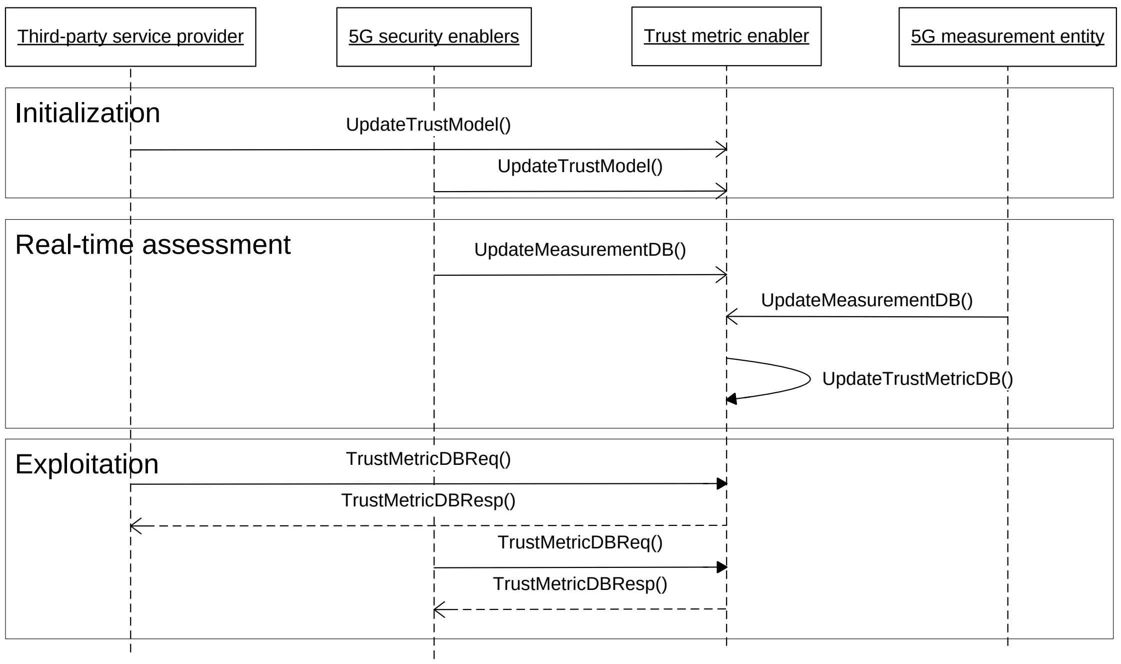


Figure 37: High level interaction sequence diagram

4.2.9 Architectural drivers

4.2.9.1 High-Level functional requirements

Third-party API

5G third-party (standard) API is required.

Measurement and 5G internal APIs

These APIs should be based on standard interfaces. However, it could be sufficient to rely on APIs defined for 5G security enablers such as Micro-segmentation Enabler (network capabilities) and Security Monitoring Enabler (security related measurements) in some use cases.

Producing trust metric values

Trust metric values are produced in Aggregator component based on trust models and measurements. The trust models include the high-level information to map measurements to trust values. It is essential to develop a well-defined API for this purpose. The enabler provides an abstraction layer to third-party by e.g. hiding the details of network requirement validation.

Dynamic network management

The third-party trust model could define network requirements that require dynamic network configurations, at least in the setup phase. The 5G system should facilitate dynamic network management e.g. through SDN and NFV or otherwise this functionality could be restricted to be used only with Micro-Segment Enabler.

4.2.9.2 Quality attributes

The following list presents quality attributes are relevant when assessing the realizations of the enabler. The list also illustrates how the current framework plans support these attributes:

- Reliability – use of mature software technologies
- Operability – use of widely adopted and accepted software technologies;
- Performance efficiency – scalability through micro-segmenting to handle large amount of real-time events
- Security – advancing security through integrating trust models of the third party service provider and the network operators
- Compatibility – support for various standardized event sources and use of open interfaces for output format
- Maintainability – use of easily utilized programming languages and widely utilized technologies;
- Efficiency – capability to cover large variety of applications through one API

4.2.9.3 Technical constraints

5G network capabilities could restrict deployment of some use cases e.g. because of lack of dynamic network management. The feasibility of the Enabler is uncertain in use cases where the trust assessment of the whole end-to-end transport network cannot be ensured.

4.2.9.4 Business constraints

The business relationships between the entities need to be studied further. The basic assumption is that the third-party service provider purchases the service enabled by the Trust Metric Enabler (and other Security Enablers) from the MNO. The pricing could be based on the characteristics (e.g. network requirements and NFVs) defined in the trust model which is provided by the third-party.

4.2.10 Detailed specifications

Since the 'Trust Metric Enabler' is closely related to 'Micro Segmentation Enabler' (see Chapter 6.4 of this document) and 'Security Monitor for 5G Micro-Segments' (Chapter 5.3), its implementation is also close to these, and it will be based on similar technologies.

This section specifies the APIs and protocols utilized. The interfaces may be considered internal for the Trust Metric Enabler. External interfaces (including user interfaces) for controlling the behaviour of inference layer will be specified in the forthcoming releases.

In testing Trust Metric Enabler in a mobile networking architecture, there needs to be a way to integrate the different functions of mobile networks (e.g. PGW, SGW, MME, PCRF) with SDN and network virtualization technologies. One possible solution could be to use the OpenEPC framework [1] that covers all the functional elements in the 3GPP Evolved Packet Core (EPC) and Systems Architecture Evolution (SAE) technologies up to 3GPP Release 12. Another alternative is the OpenAirInterface [2].

4.2.10.1 Conformance

The implementation of the enabler relies on SDN and virtualization technologies. For SDN, an SDN controller that can be chosen quite freely is needed. In this work we selected the Ryu SDN controller [3]. For network virtualization, OpenVirteX software [5] is used, but another type of network hypervisor is also plausible.

4.2.10.2 API specifications

The Trust Metric Enabler takes the following inputs:

- Validated network requirements (which may dynamically change)
- Number of connected IoT Devices (and to which UEs they are connected)
- Number of connected UEs
- End-to-end encrypted traffic or not
- Subscribed IDS alerts
    - High severity (i.e. indicates attacks and malware)

The enabler produces a binary value (0,1) output based on the input actions:

- Value 0 (trust metric unacceptable)
- Value 1 (trust metric acceptable)

The specific technical details of the API depend on the selection of the network hypervisor and the SDN controller. For example, in this work (as also to implement the Micro-Segmentation Enabler) OpenVirteX is used as the network hypervisor to accomplish the network virtualization. Ryu SDN framework is utilized as a SDN controller. Apache Kafka [5] may produce events coming from the enabler while REST API could send commands to the enabler. Information needed from the Ryu SDN controller can be retrieved via REST API.

4.2.10.3 Examples

After initialization, a third-party service provider is accepted by the Trust Metric Enabler. Micro-segment Orchestrator (Figure 34) accepts IoT devices from an untrusted access network through 802.1X authentication. The Trust Metric Enabler may enable data plane transmission from IoT devices through an untrusted micro-segment to an UE. When number of IoT devices connected to one UE exceeds its limit (e.g. 10 devices), Trust Metric Enabler disables the traffic.

4.2.11 References

[1] "OpenEPC framework," [Online]. Available: http://www.openepc.com.
[2] "OpenAirInterface," [Online]. Available: http://www.openairinterface.org.
[3] "Ryu SDN framework," [Online]. Available: https://osrg.github.io/ryu.
[4] "OpenVirteX Network Virtualization Platform," [Online]. Available: http://ovx.onlab.us/.
[5] "Apache Kafka," [Online]. Available: http://kafka.apache.org/.

4.3 VNF Certification enabler Open specifications

4.3.1 Preface

The goal of this enabler is to certify the trustworthy implementation of the VNF and to expose their characteristics through a Digital Trustworthiness Certificate

4.3.2 Status

The version 1.0 of this component is currently under development.

4.3.3 Copyright

4.3.4 Legal notice

The Legal notice that applies to these specifications is given in Annex A.

4.3.5 Terms and definitions

VNF	Virtualized network functions
DTwC	Digital Trustworthiness Certificate
OPTET	Operational Trustworthiness Enabling Technologies
VMNO	Virtual Mobile Network Operator

4.3.6 Overview

The enabler can be used in a variety of use cases and by a variety of users, both when designing new network configurations enabled by 5G technologies and when making trust decisions during the use and operation of networks

This enabler has a roadmap with two releases. The first release will provide different elements coming from OPTET project and their adaptation for VNF and 5G environments. The second version release is expected to provide a complete prototype for the VNF certification and for the Digital Trustworthiness Certificate.

4.3.7 Basic concepts

The goal of this enabler is to provide, through a certification process, a Digital Trustworthiness Certificate (DTwC) containing trustworthiness information (evidence with metrics values) about the VNF. Using this Certificate, the infrastructure owner could decide whether to deploy this VNF into one's infrastructure by comparing one's trustworthy infrastructure requirements against the trustworthy information contained in the DTwC of the VNF. The certification process is intended to include testing phases, so the certification is not based solely on the claims made by the VNF owner.

This certification enabler has two main objectives:

1. Help the certifier to collect evidence about the VNF and to subsequently produce a DTwC.
2. Provide a centralised service where all the DTwCs produced will be stored.

These two objectives lead to the fact that this enabler will be used differently following the life cycle of the NVF. Indeed, the certification of a VNF is more at "design time" when the VNF is finished at the developmental level and ready to be deployed. Whereas making the different DTwCs available is more at runtime, when the platform owner decides whether to deploy a new VNF into one's infrastructure.

The DTwC is the result of a certification process dedicated to the certification of VNF and based on existing processes like the ETSI NFV-SEC evaluation process[3]. It is worth noting that many of the security certification programs view security broadly, i.e., the assessment includes also organizational functions to ensure that the organization is also managed in a secure manner. This can also include assessing the software development practises. It is for further study whether such elements could be included into the DTwC process as well.

This process involves three different stakeholders:

- The VNF owner in charge of providing the initial information and the VNF. At the end of the certification process, the VNF owner has the right to decide to publish the certificate.
- The evaluator in charge of collecting evidence about the VNF and to provide the evaluation results to the certifier.
- The certifier in charge of validating and consolidating the evaluation results and producing the DTwC containing certified evidence and some VNF description. For that, the certifier could use the VNF certification enabler which provides through certification process defined a User Interface. This User Interface helps the certifier to follow the different steps of the certification process.

At the end, a DTwC is generated for a specific VNF and stored into a centralised server to be accessible by the different infrastructure owners interested in finding trustworthiness information about it, if the VNF owner authorised the publication. This DTwC is an XML file signed by the certifier and linked with the VNF involved in this certification process by the inclusion of the hash of the VNF.

The second part of this enabler is the centralised server containing all the DTwCs generated by the different VNF certifications. This centralised server provides a secured interface to upload the DTwCs and, also, an interface to search for some specific DTwCs using the hash of the VNF (The DTwC is linked with the VNF

[3]See the http://www.etsi.org/deliver/etsi_gs/NFV-SEC/001_099/003/01.01.01_60/gs_NFV-SEC003v010101p.pdf document

using the hash of this. This Repository must be managed by a third party not involved in the certification process and independent of the VNF owner. It could be a state institution or an independent organization.

4.3.8 Main interactions

4.3.8.1 Use cases

The virtualization of network functions and network equipment enable to instantiate several of them on commodity servers, thus sharing physical resources (CPU, RAM, memory and network) with other hosted virtual machines. Nowadays, the infrastructure provider manages its own VNFs on its own infrastructure. In case a VMNO wants to use a proprietary VNF (developed by another VMNO for example), how could a VMNO actor provides trustworthiness assurance to the infrastructure provider? How the infrastructure provider could trust a VNF coming from a third party?

In a simple use case, the different actors involved into the certification process are:

- The VNF owner who provides the VNF and also some technical information about the implementation of it. He must also validate the publication of the certificate.
- The evaluator who is in charge of evaluating the VNF to extract trustworthiness evidence. The result of the evaluation will be used by the certifier to produce the DTwC. The evaluation could be realised by inspection or using automatic analysis tools to extract independently information about the VNF. For a VNF evaluation, there could be different evaluators providing different kind of evidences.
- The certifier who collects information regarding the VNF in order to fill the trustworthiness elements of the DTwC. He is responsible of the validity of the information set into the certificate. For that, he must verify the different information provided by the VNF owner and evaluators. For a VNF certification, only one certifier is involved into the certification. However, we could have different certifiers authorized to certify VNF (dependent, for instance, of their area of expertise).
- Each certifier must have a certificate delivered by certification authority trusted by the DTwCs repository. This certificate is used to sign the DTwC and also to authenticate the certifier during the transfer of the DTwC to the DTwCs repository. (Note: the PKI is not part of this open specification)
- The VNF consumer (here the infrastructure provider) who uses the DTwC to know more trustworthiness information about the VNF he wants to deploy. Using this DTwC, he could compare the information against his internal deployment policies and decide whether to deploy or not the VNF into his infrastructure.

VNF owner and VNF consumer need to trust certifier to provide trustworthy services. This can take place either through contractual business relationships or through industry agreements (i.e. commonly established certification body). The main use case is the deployment of a new VNF into an NFV infrastructure where the basic flow of events is the following:

- The VNF owner wants to propose his VNF to be deployed by different VNF consumers. For that, he must, beforehand, provide the VNF element and some information about it to the certifier and to the different evaluators.

- The evaluator(s) will extract evidence from the VNF by inspection or by tests in order to provide trustworthiness evidences to the certifier

- Using the different elements provided by the VNF owner and the evaluator(s), the certifier will produce a DTwC representing the trustworthiness of the VNF.

- If the VNF owner authorizes the publication, the certifier will upload this DTwC into a centralised service containing all the certificate of all the VNFs. This service is unique and could be replicated for security and performance aspect.

- In the next step, when a VNF consumer wants to deploy a VNF, he could find the DTwC for it in the centralised service and decide whether to deploy (or not) this element into his infrastructure by comparing the trustworthiness elements provided by the DTwC with the trustworthiness requirements of his platform.

This simple use case could be integrated into the different use cases of D2.1, like 5.2 “Adding a 5G Node to a Virtualized Core Network” , 5.4 “Verification of the Virtualized Node and the Virtualization Platform“, 5.5 “Control and Monitoring of Slice by Service Provider” or 9.3 “Authentication of New Network Elements “. For example, in the 5.4 “Verification of the Virtualized Node and the Virtualization Platform“ use case, the DTwC certificate could be used to validate the integrity of the VNF or know the different threats and controls around this VNF before the deployment of a new instance.

4.3.8.2 Components and interaction overview

The following diagram describes the logical architecture of the VNF Certification enabler. It covers the whole certification lifecycle.

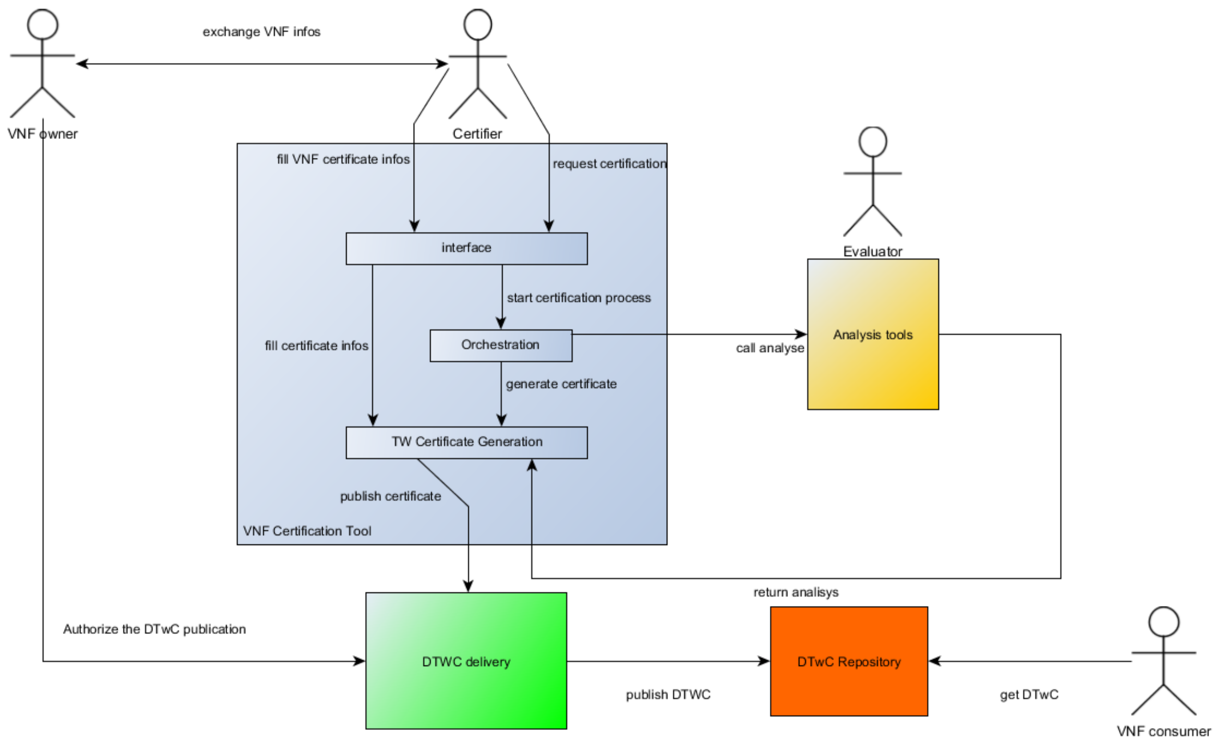


Figure 38: Logical architecture of the VNF Certification enabler

In this section we describe the logical components.

- The VNF Certification Tool: this component manages the trustworthiness evaluation of the VNF. It is composed by three main elements,
  - the user interface which must guide the certifier into the certification process,
  - the orchestration element which manages the different evaluations involved in the certification process
  - and the Certification generation element in charge to collect the trustworthiness information provided by the certifier and by the different evaluations to produce the DTwC.
- The Analysis tools: These elements, managed by evaluators, represent a set of external tools called by the certification to retrieve information about the VNF. Each analysis tool must return the result of its analysis to the certification tool. Then each result will be validated and inserted into the DTwC during the generation. This validation and insertion could be automatic or manually interpreted by the certifier (following his experience and the other evaluation results)
- The DTwC delivery: This element is in charge of uploading the DTwC generated to the DTwC repository in a secured way after validation of the VNF owner.
- The DTwC repository: This element stores and manages the different DTwCs generated by the different certifications. It also provides an interface to retrieve certificates for a specific VNF (One certificate by VNF version).

Regarding the different workflows, we have the generation of the DTwC and the usage of this DTwC. Sequence diagrams are given below to clarify how these components interact. The list of diagrams is not exhaustive but assists in understanding the links between actors and logical components.

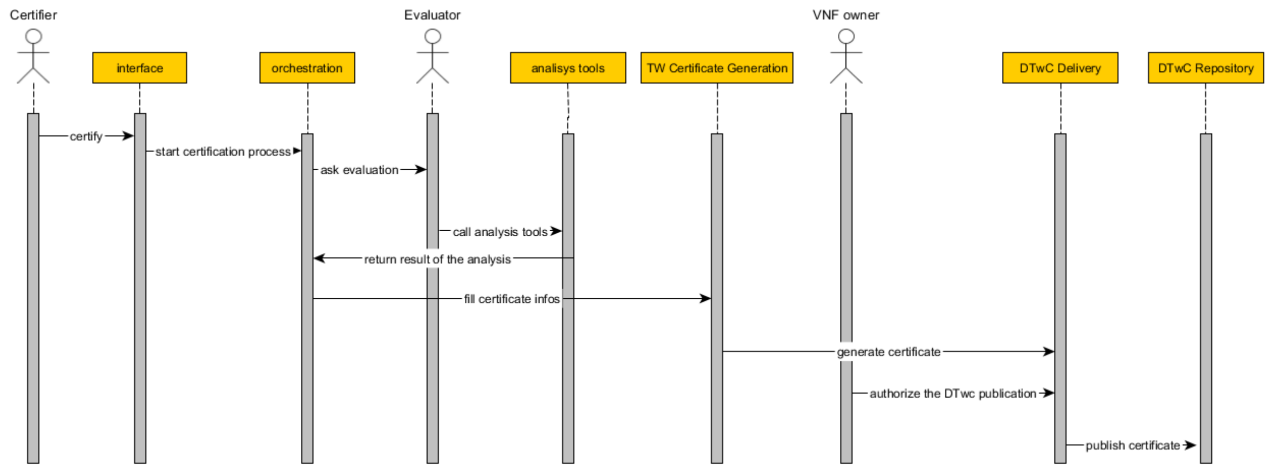


Figure 39: DTwC generation

This sequence diagram depicted on Figure 39 focuses on the DTwC generation:

- The certifier, through the Certification platform interface, asks the evaluators to collect the evidences using analysis tools or fill manually information regarding the evaluation of the VNF

- The evaluator analyses the VNF (by inspection or by testing) and returns the result to the DTwC generator element.

- The values are verified and consolidated in order to be pushed into the DTwC

- The certifier generates the DTwC using the information collected before and inserts security information to link strongly the certificate, the VNF and the certifier (Hash and signature). If some evaluations can't be realized, the associated metric presented into the certificate will be put to undefined; otherwise, a metric value will be set to characterize the evidence

- The certifier publishes the DTwC into the centralized repository, after authorization of the VNF owner, in a secured way (the repository must authenticate the certifier in order to accept the DTwC published).

This second workflow shows the interaction between the VNF consumer and the DTwC repository.

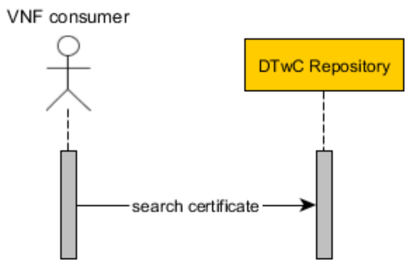


Figure 40: Interaction between the VNF consumer and the DTwC repository

In this workflow, the VNF consumer:

- Calls the DTwC repository to retrieve the DTwC of the VNF he wants to deploy. This search is not secured (at the authentication level but the communication must be secured using TLS) because the DTwC are considered as public and the information inside the certificate are validated and authorized to be published through the authorization of the VNF ownerArchitectural drivers

4.3.8.3 *High-Level functional requirements*

The main feature of this enabler is the VNF trustworthiness evaluation. This feature could be described by two functions: the certification of the VNF implementation and the exposition of their characteristics through a DTwC.

4.3.8.4 *Quality attributes*

The following list presents quality attributes which are relevant when assessing the realization of the enabler. The list also illustrates how the current framework plans to support these attributes:

- Operability- The User Interface provided to generate the certificate must be "user friendly" to guide the certifier into the certification process
- Reliability - mature software technologies must be used
- Security - The publication of DtWC is limited only to the authorized persons. In addition, the security mechanisms put in place to secure the DtWC must guarantee the integrity, the accountability and the non-repudiation of it.
- Compatibility - The Trustworthiness elements used to characterize the VNF must be compatible with standards like ETSI or 3GPP.

4.3.8.5 *Technical constraints*

4.3.8.5.1 The evaluation:

To find evidences to characterize the trustworthiness of a VNF, the different possibilities are:

- The blackbox testing (e.g., fuzzing) and/or source code analysis if available

- The deployment of probes into the VNF
- The technical information coming from the VNF owner

The selection of methods is up to the certifier and the evaluators. The different methods have their interests and combined together, provide information to characterize the trustworthiness of an element. However, the realization of probes and tests for VNF is complicated due to the heterogeneity of the different VNFs (different functionality and implementation). More, the deployment of probes directly into the VNF could be a problem regarding deployment due to some security constraints imposed by the VNF.

The blackbox testing does not necessarily reveal all the possible vulnerabilities. If this is complemented with source code analysis, then the coverage of testing is more complete. However, source code analysis can be time consuming.

4.3.8.5.2 The certification process

Also, the different elements provided by the VNF Owner must be validated to be taken into account in the certification process. It’s the responsibility of the certifier to validate all the evidences collected about the VNF before the insertion into the certificate.

Additional considerations can be given to the possibility of assessing also the development practices of the VNF owner. This could also be performed by complementing the certification process with other applicable certificates the organization possesses, e.g., ISO 27001 or PCI DSS (one ought to make sure that the scope of the certification matches the scope of VNF owner development activities).

Another consideration relates to the new versions of a specific VNF as bug or feature updates are likely to invalidate the certificate. Applying the whole process to each version of VNF might end up being too restrictive. Some alternative approaches (such as used in Mirrorlink DAP certification) include the possibility to provide a certification hierarchy, which certifies the VNF owner, who then has the possibility of issuing its own certificates. However, this makes system more complex and the assessment process ought to also ensure that VNF owner is capable of sound key management practices.

4.3.8.6 Business constraints

The business relationships between the different entities need to be further studied. Especially the potential liability aspects that might arise from misbehaving VNFs need to be solved. VNF consumer might need to make a risk assessment, whether to rely on testing done by another entity or whether to conduct its own testing. It is likely that at least VNF owner needs to have a business contract with the certifier as there likely is a cost involved (and evaluators most likely wish to be compensated).

The certifier could be a commercial entity or an industry body. One needs to study whether several such entities exist or whether there is just one. As this has regulatory implications, so it is more likely that several entities will exist. Also, evaluators could be separate entities from the certifier, thus it has to be decided what sort of requirements are set for these. One possibility is to expect them to be accredited ISO 27001 auditors or other similar accreditations.

4.3.9 Detailed specifications

4.3.9.1 Introduction

The implementation of this enabler imposes the API specification to be compliant with and also to use the same DTwC format specified in the next paragraph.

4.3.9.2 Conformance

All the interfaces described by this specification are mandatory and must be implemented in order to be compliant with.

The usage of DTwC model is also mandatory in order to have the same level of information for all the certifications. This DTwC concept represents the basic element for the definition of a certificate instance. Four concepts are part of its definition: SystemDescription, TWProblemDefinition, TWPropertySpecification and Evidence.

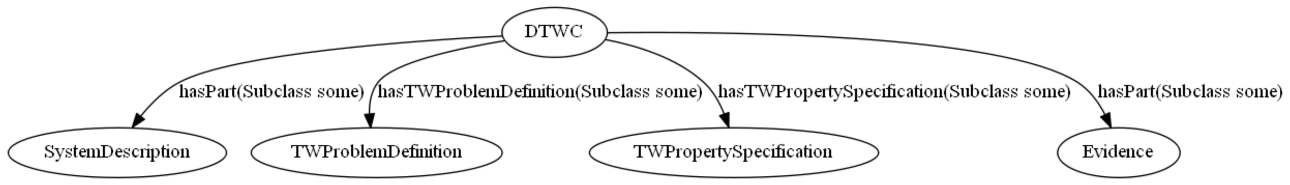


Figure 41: DTwC model concepts

Let us start considering SystemDescription

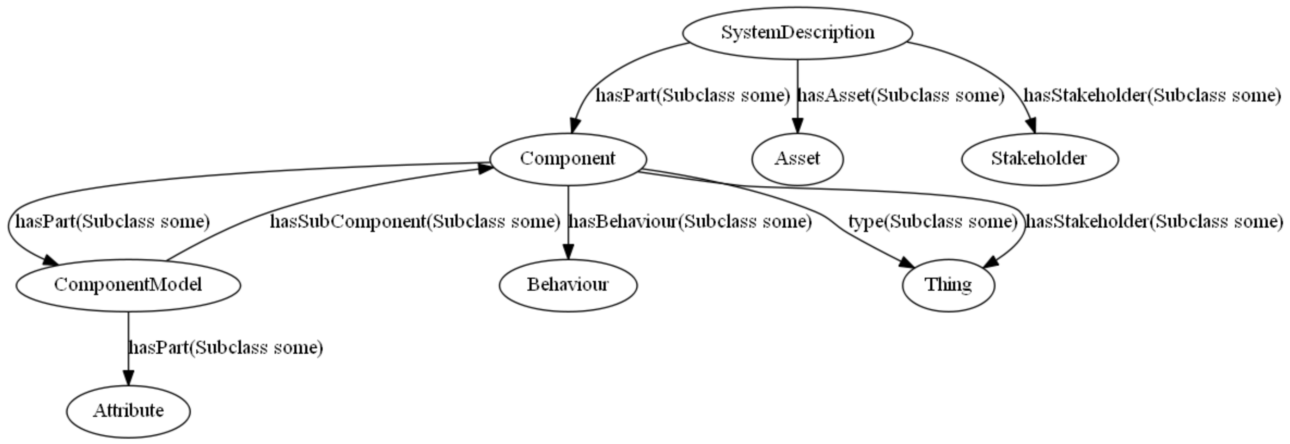


Figure 42: System description

The SystemDescription concept allows for detailing the NVF component and the system being certified. The three main elements of a SystemDescription are Stakeholder, Component and Asset. The Stakeholder concept can be used to indicate the stakeholders (or actors) having a role in the system being described. It is possible to detail the system's architecture through a set of Components, and through the creation of a ComponentModel instance, it is possible to illustrate all subcomponents of a Component. The Asset concept allows for declaring which Components are verified by the Certification Authority.

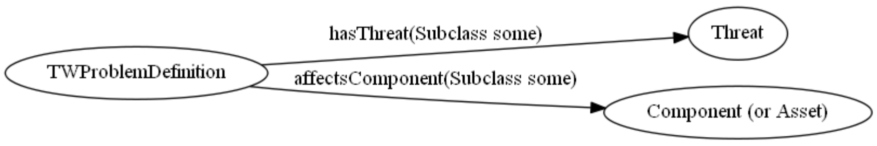


Figure 43: TWProblemDefintion concept

The TWProblemDefinition concept aims at illustrating how a threat affects an Asset

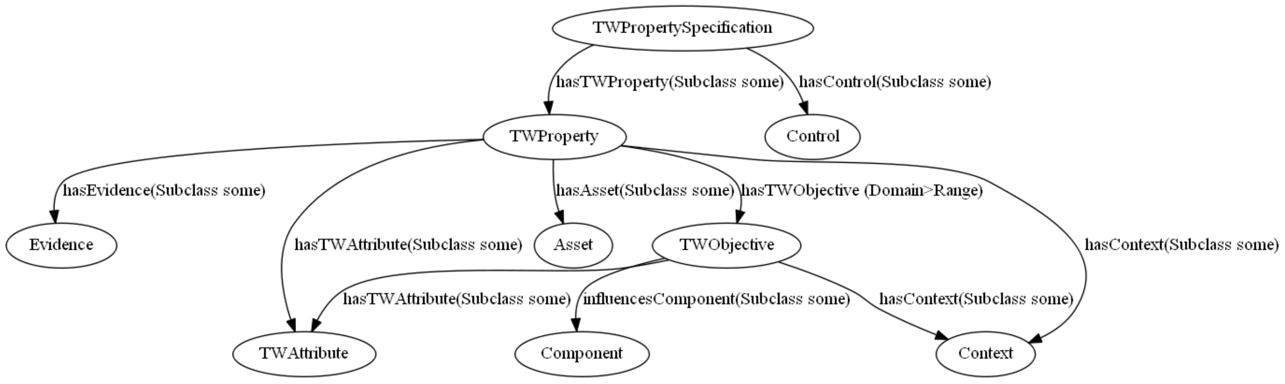

TWPropertySpecification
hasTWProperty(Subclass some)
hasControl(Subclass some)
TWProperty
Control
hasEvidence(Subclass some)
hasAsset(Subclass some)
hasTWObjective (Domain>Range)
hasContext(Subclass some)
Evidence
hasTWAttribute(Subclass some)
Asset
TWObjective
hasTWAttribute(Subclass some)
influencesComponent(Subclass some)
hasContext(Subclass some)
TWAttribute
Component
Context

Figure 44: TWPropertSpecification

The TWPropertySpecification is a concept that allows for the expression of TW characteristics of Assets: its constituting elements are a TWProperty and a Control. TW Property links an Asset to a TW Attribute and a Context that further specifies the TW Attribute.The Control concept allows for the indication of a mechanism that is able to influence or enforce the TWProperty.

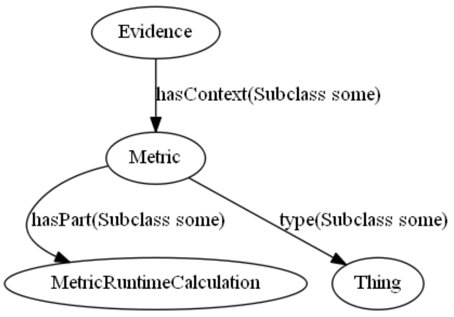


Figure 45: TWPropery concept

The Evidence concept captures any form of proof that is deemed sufficient by the Certification Authority. The nature and form of an Evidence can vary significantly, according for instance to the type of TWProperty it demonstrates.

4.3.9.3 API specifications

This enabler is composed of two parts, the User Interface helping the certifier to produce the DTwC, associated with evaluation tools and the DTwC repository which centrally stores all the DTwCs produced and gives the possibility to retrieve these.

- The Certification UI: This first element is a UI with no specific API. In the reference implementation, this Certification UI will be provided like an eclipse plugin
- The DTwC repository: This second element provides an API to upload the generated DTwC and to download a specific DTwC. In the reference implementation, this element will be provided like a REST service hosted into an application server (like Tomcat)

The different APIs are:

- Push DTwC

This method is used to push the DTwC into the repository. This needs to be authenticated and the integrity of the upload verified in order to ensure that no malicious content gets stored in the repository.

```
Method: POST
Path: /uploadDTwCs
Headers:
   o  Content-Type:multipart/form-data
   o  Accept: text/html,application/xhtml+xml,application/xml
```

- Get a DTwC

To search for a specific DTwC, two methods are possible, a query using the hash of the VNF

The research by hash

```
Method: GET
Path : /downloadDTwCByHash/{hash}")
```

4.3.9.4 *Examples*

Some examples of requests for the previous requests

- Push DTwC

  An example of a push request

```
POST /post HTTP/1.1
Accept: */*
Accept-Encoding: gzip, deflate
Content-Type: multipart/form-data; boundary=38516d25820c4a9aad05f1e42cb442f4
Host: xxx.org

--38516d25820c4a9aad05f1e42cb442f4
Content-Disposition: form-data; name="file"; filename="certificate.dtwc"
Content-Type: application/octet-stream; charset=ISO-8859-1

...contents of certificate.dtwc...
--38516d25820c4a9aad05f1e42cb442f4—
```

And the possible responses are:
HTTP/1.1 200 OK

Indicates that the file entry was successfully created. If an error occurs, this header will contain one of the error codes below.

Error codes

- HTTP/1.1 401 Unauthorized
- HTTP/1.1 403 Forbidden
- HTTP/1.1 404 Not Found
- HTTP/1.1 409 Conflict
- HTTP/1.1 415 Unsupported media type

- Get DtWC

An example of research request using hash

```
GET /downloadDTwCByHash/qiyh4XPJGsOZ2MEAyLkfWqeQ?type=file HTTP/1.1
```

And the possible responses are:

Returned HTTP Headers
HTTP/1.1 200 OK
Indicates that the file entry was successfully downloaded. If an error occurs, this header will contain one of the error codes below.
Error codes

- HTTP/1.1 401 Unauthorized
- HTTP/1.1 403 Forbidden
- HTTP/1.1 404 Not Found

4.3.10 Re-utilised Technologies/Specifications

This enabler specification is based on the technologies already developed in the context of the OPTET European project http://www.optet.eu/. This project provides an equipped certification process which must be adapted to the certification of VNF by adjusting the scope of the certification and the process himself.

This specification follows the “security and trust guidance” defined by the ETSI NFV-SEC. This document provides security and trust elements to characterise the trust and the security aspect at the VNF level. This list of element and methodology are also completed by some information coming from the 3GPP working group around the Security Assurance Methodology (SECAM)

4.3.11 References

[1] http://www.optet.eu/documents/

[2] http://www.etsi.org/deliver/etsi_gs/NFV-SEC/001_099/003/01.01.01_60/gs_NFV-SEC003v010101p.pdf

[3] http://www.3gpp.org/DynaReport/33805.htm

5 Security Monitoring Enablers open specifications

This section contains the open specifications of v1.0 of the five Security Monitoring enablers due to Release-1: the Pulsar (Proactive Security Assessment and Remediation) enabler, the Generic Collector Interface enabler, the security monitor for 5G Micro-Segments, the Satellite Network Monitoring enabler and the System Security State Repository enabler.

Note : The Security Monitoring enablers of 5G-ENSURE Release-1 are built over existing assets coming from former projects on which they are planning to leverage to cover 5G security requirements in scope and are here proposed with some improvements. For this release (i.e. Release1), all enablers proposed are planned to be delivered independently. A specific phase of rationalization, optimization and mutual improvement is planned for Release-2 (based on identification of more efficient sub-components enabler to be reused by other 5G-ENSURE enablers, also assessment performed following their integration – as others - to 5G-ENSURE security testbed).

5.1 PulSAR Open specifications

PulSAR stands for Proactive Security Assessment and Remediation.

5.1.1 Status

Within this document you find a self-contained open specification of the PulSAR Security monitoring enabler as designed at the beginning of the first period of the project ending with Release 1. Nevertheless, only a subset of the 5G specific concepts such as hypervisors, NFV orchestrators and SDN controllers will be implemented in R1.

In Release 2, further investigation on 5G specific concepts and their vulnerabilities will be performed, for example concerning slices or micro-segments (especially with regards to the Security Monitor for 5G Micro-Segments enabler).

Note that the purpose of PulSAR is to provide a clear view on cyber attack's progression though attack graphs. Other monitoring enablers such as the Security Monitor for 5G Micro-Segments enabler which is specialized in detecting and correlating events occurring on micro-segments are useful for PulSAR since they collect relevant information from the systems. This information is needed by PulSAR to process on-going attacks. Direct interoperability of such monitoring enablers with PulSAR could be studied, but within 5G-Ensure project, since the Generic collector should collect and aggregate all type of events from several other monitoring enablers, we will focus first on the interoperability with the Generic collector enabler for PulSAR as the main source to benefit from event information collection from the field.

5.1.2 Copyright

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5.1.3 Legal notice

The Legal notice that applies to these specifications is given in Annex A.

5.1.4 Terms and definitions

CVE: Common Vulnerabilities and Exposures
CVS: Common Vulnerability Scoring
CVSS: Common Vulnerability Scoring System (https://nvd.nist.gov/cvss.cfm)

Datalog: a declarative logic programming language that syntactically is a subset of Prolog.
IDMEF: Intrusion Detection Message Exchange Format (https://www.ietf.org/rfc/rfc4765.txt)
IoT: Internet of Things
MulVAL: Multi-host, Multi-stage Vulnerability Analysis Language. It is a research project at Kansas State University and a logic-based enterprise network security analyser.
NFV: Network Function Virtualization
NIST: National Institute of Standards and Technology (http://www.nist.gov)
NVD: National Vulnerability Database
PulSAR: Proactive Security Analysis and Remediation
SDN: Sofware Defined Network
SIEM: Security Information and Event Management
TVA: Topological Vulnerability Analysis, a framework that combines an exploit knowledge base with a remote network vulnerability scanner to analyse exploit sequences leading to attack goals
XML: eXtended Markup Language

5.1.5 Overview

Cyber Security is the first step towards understanding the actual risk exposure of a communication system and, hence, towards exploiting it with desired security behavior and detection of potential attacks or non-authorized usages. The Proactive Security Analysis and Remediation (PulSAR) enabler deals with detection of Cyber Security risks on sensitive “assets” at large, up to proposing possible remediation. It intends to address the detection and management of cyber-security risks on different kind of environments from classical IT systems to complex 5G environments involving NFV and SDN.

PulSAR enables complex attack detection, provides a clear view on an attack’s progression by giving means to understand on-going attacks when a node is known as compromised and also automatically computes possible remediation depending on the system’s assets, and the system’s vulnerabilities. The possible means of remediation are sorted by a cost function based on the cost of deployment of the different remediation means such as network reconfiguration, patch deployment, etc.

This enabler aims at providing means to protect against cyber-attacks. Its main features can be summarized as follows:

1. Collect the topology and the vulnerabilities, evaluate the potential threats and attack paths, assess risks,
2. Identify most probable and impacting on-going attacks based on third parties’ aggregated Security Information and Event Management (SIEM) and monitoring sensors’ events and alerts about compromised nodes,
3. Propose remediation solutions,
4. Deliver a visualization service centered on risk/attrition level.

Before going into the details of the enabler, Figure 46 shows its eco-system with possible interactions with a 5G eco-system and other enablers of this project. This eco-system includes traditional network and computer infrastructures, virtualized networks and data-centers, satellite networks, and potentially 5G-specific entities such network slices and micro-segments, Internet-Of-Things environments, etc.
For all those environments, PulSAR needs to collect several kinds of data, both to initialize the cyber risk computation and to follow it at run-time.

- Topological data
- Vulnerability data
- User scoring preferences, i.e. user defined scores on attack graph nodes
- Alerts

PulSAR computes then:

- attack paths scored by attrition levels for a better readability by the security operator,
- dynamic risk analysis when it comes to exploit run-time alerts from SIEMs,
- possible remediation and countermeasures.

The results of these computations are made available through a single REST/JSON interface.

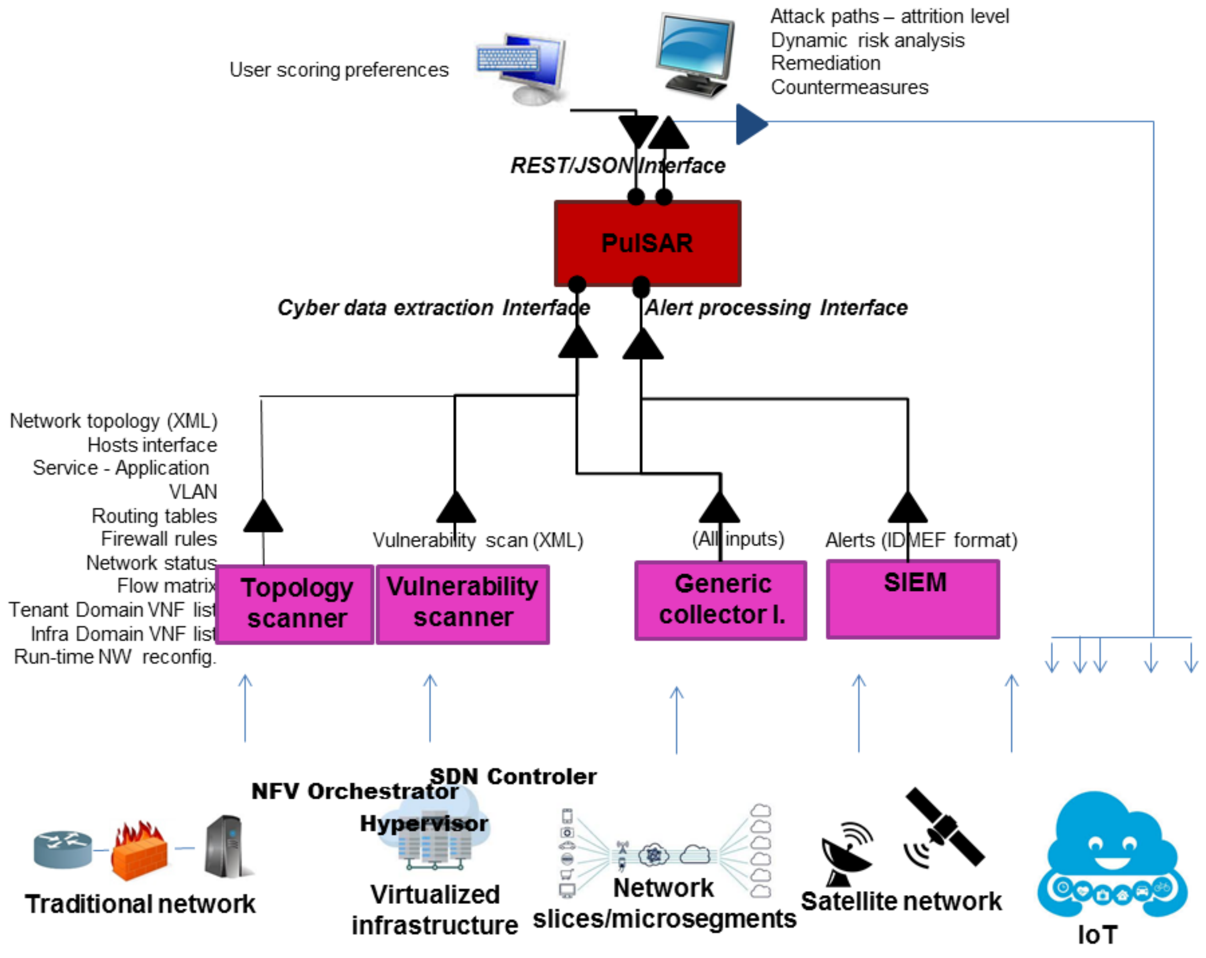

Figure 46: PulSAR in its eco-system

5.1.6 Basic concepts

PulSAR responds mainly to two different goals:

- A proactive engine which computes scored attack paths and associated remediation based on a network topology and a vulnerability scan.
- A reactive engine which shows the progression of on-going attacks based on SIEM alerts, and computes associated counter-measures.

Figure 47 provides an initial architectural sketch of the components inside PulSAR and their main interactions. This section gives a short insight for each component. The figure below is also explained in the following Architecture section.

For its basic operation, PulSAR needs mainly two types of Data as inputs, namely the network topology and a vulnerability scan. These two inputs are fed into the **Cyber Data Extraction module**, which generates a single input file.

This input file is sent to the proactive part of the PulSAR server, and more precisely to one of its components, which is an **Attack Graph Engine**. In order to make the results of the attack graph computation more readable, all the attack paths computed are scored by attrition level. This scoring is performed thanks to the CVS scoring and manually imported user scoring preferences corresponding to his/her knowledge of the most challenging risks according to context at hands. It is done by the **Scored attack paths module**. The **remediation module** computes associated remediation such as network reconfiguration, or virtual patching according to type of remediation supported.

All the results of the PulSAR server are made available through a REST/JSON interface, that is to say the attack paths scored by attrition level, the remediation, but also the active attack paths and the countermeasures. A **visualization module** exploits all these results and makes them accessible to the Security operator. This module is also to security operator scoring preferences.

PulSAR reactive part provides a view on on-going attacks. It leverages external SIEM reports in IDMEF format. These alerts are sent to a **Dynamic Risk Analysis module** which confronts the in-coming alerts to the scored attack paths. This enables to show the already compromised nodes and to predict the next steps of an attack. From this, a **Counter-measures module** computes possible countermeasures to stop the on-going attack.

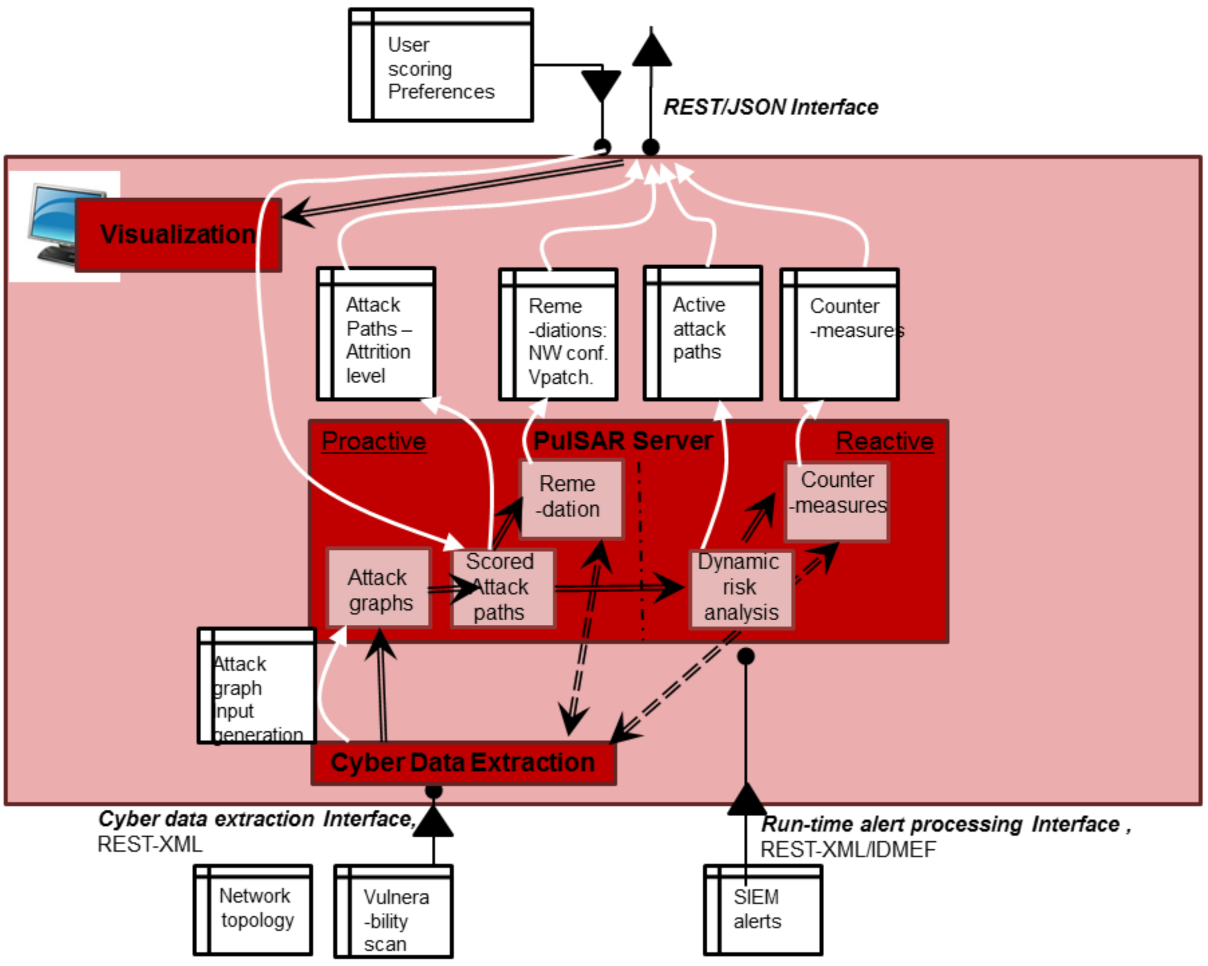

Figure 47: Building blocks of PulSAR

5.1.7 Main interactions

5.1.7.1 Use cases

Visualization and User scoring preferences

The use case below in Figure 48 shows a Security Operator using PulSAR through the visualization interface. S/he is also able to set her/his own preferences for scoring the impact of the vulnerability on the nodes of the graph.

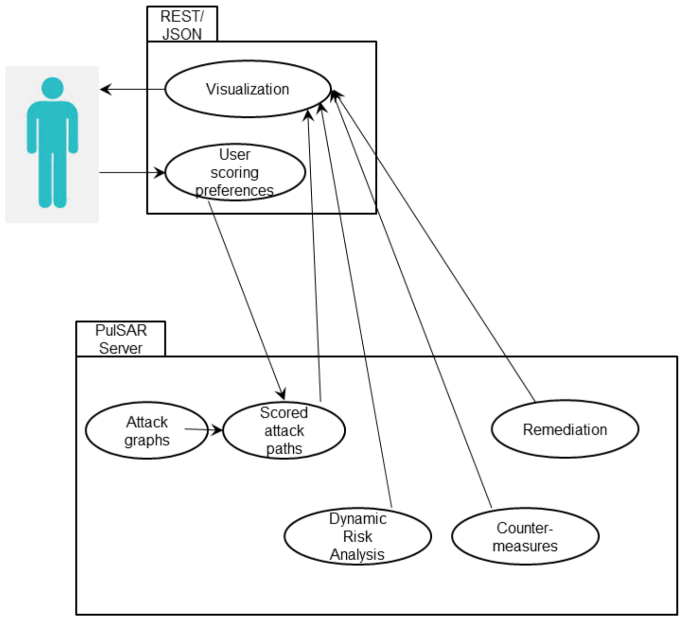

Figure 48: Visualization and user scoring preferences use case

SIEM alerts

The use case below in Figure 49 shows a SIEM equipment sending alerts to the PulSAR server, used internally by the Dynamic Risk Analysis of PulSAR.

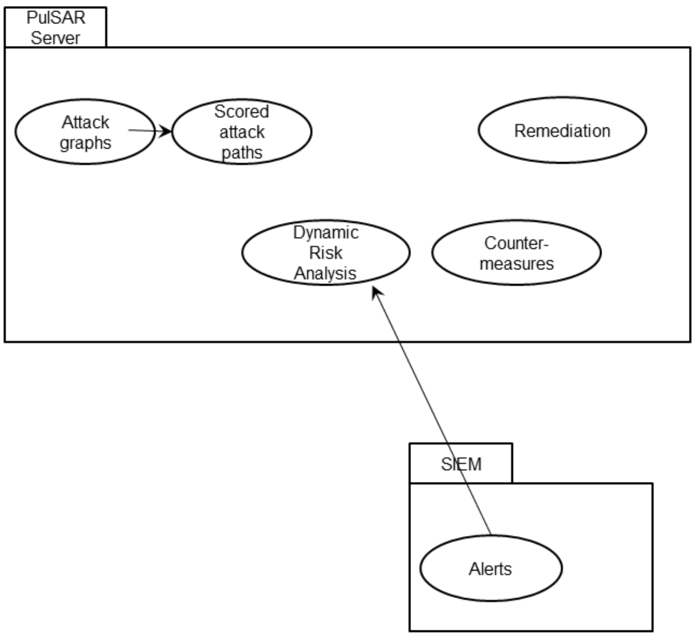

Figure 49: SIEM alerts use case

5.1.7.2 Components and Interactions overview

Figure 47 above gives an overview of the internal architecture of the PulSAR enabler. As presented in the Basic concepts section, PulSAR includes the following components, which are described in detail below:

- Cyber data extraction
- Attack graphs
- Scored attack paths
- Remediation
- Dynamic Analysis
- Counter-measures
- Visualization

Cyber Data Extraction

The Cyber Data Extraction component provides an external interface called ***Cyber Data Extraction Interface*** for Cyber data collection. This interface is specified in the API specification section. It collects network topology information and vulnerability scan reports.

In order to give access to the vulnerability and topological information to the other components internally, the Cyber Data Extraction can generate two types of inputs:

- The Attack graph input generation file which is a Datalog file used by the Attack graph engine,
- A XML file aggregating all vulnerabilities and topological information needed by the Remediation and the Countermeasure components.

Attack graph Engine

The attack graph engine relies on a MulVAL attack Graph Engine.
This component takes as input the Attack graph input generation file generated by the Cyber Data Extractor. The first action of this component is to generate the attack graph using MulVAL.

The attack graph output will be the basis used by the scored attack paths component. This attack graph gives the probability scores of each attack graph node, translating the probability of success of each step in the attack graph.

Scored Attack Paths

The scored attack paths takes as input the attack graph computed by the Attack graph Engine.

This Attack graph gives the basic information for the scored attack path to be computed, that is to say both the potential attack paths and the probability scores of each attack graph node, translating the probability of success to each step in the attack graph. These probability scores are the basis for computing the risk score of an attack path.
PulSAR offers here the possibility for the Security operator to enter its own scores for each node of an attack, based on its own vision of the attack probability or of the asset criticality for the business. This input is performed through the external REST/JSON interface by mean of the visualization component.

Therefore, the scored attack paths component uses two types of inputs:

- The attack graph from the attack graph component,
- The user scoring preferences from the external REST/JASON Interface via the visualization component.

The scored attack paths are the output available through PulSAR external ***REST/JASON Interface*** and used internally by the other components of PulSAR:

- The remediation component uses it as the basis to remediate the most critical attack paths,
- The dynamic risk analysis component uses it as the support to identify on-going attacks,
- The visualization component exploits it as the basis of the visualization.

Mainly, the internal and external interfaces will operate via file input/output with a defined XML data structure for the file content.

Remediation

The remediation application needs two types of inputs:

- The scored attack paths from the Scored Attack Paths component,
- The XML file aggregating all vulnerabilities and topological information generated by the Cyber Data Extraction component.

The interactions between the Scored Attack Paths and the remediation are necessary because attack paths are the starting point of the remediation process. Security operators need to select an attack path for remediation in the list provided by the Scored Attack Paths. On the other hand, the attack path engine is also useful to validate the remediation selected by the security operators. This feedback is necessary to compare the security state of the system before and after deploying a remediation.

The interactions between the remediation tool and the Cyber Data Extraction are necessary because the network topology (hosts, routes, deployed firewall rules …) is necessary to compute the topological related remediation (attack signature deployment and firewall rules). The remediation tool provides also a means to apply automatically some of the remediation chosen by the security operators. To do that, this tool needs to change some parameters (e.g. a firewall rule) in the Cyber Data Extraction.

Besides the internal interactions between the Remediation engine and the Cyber Data Extraction and Scored Attack Paths, the Remediation engine especially provides output through the external ***REST/JSON interface*** which is then exploited by the Visualization component to display to the user the possible remediation for the risks on his/her information system.

Dynamic Risk Analysis

The dynamic Risk analysis is computed using the attack graph, SOC alerts and assets value for inputs. It computes which machines on the network are likely to have been compromised (the risk probability), and uses this result to determine the risk, using the impact of compromising.

Counter-measures

Attacks can be followed on the attack graph, and so the attacker's next step can be foreseen. Following a dynamic risk analysis, the engine can provide to an operator a list of possible counter-measures which are likely to block the next step of the attacker's path in the attack graph. Some chosen simple counter measures could be applied automatically (IP blacklisting for example).

Visualization

The Visualization offers a visualization service that allows users to visualize data. It exploits in fact the External ***REST/JSON interface*** which makes available data such as the Scored Attack Paths, the remediation, the active attack paths or the counter-measures.

The user accesses the visualization service through a standard web browser connected to the web application server using some network connection (such as the Internet). The user will experience a single integrated application. Behind the scenes, the browser will get access to the information generated by the other components.

5.1.8 Architectural drivers

5.1.8.1 High level functional requirements

PulSAR leverages upon WP2 –T2.4 architecture introducing the 5G concepts such as NFV and orchestrators, SDN and network controllers, slices, micro-segmentation. It enables to show the consequences of an attack on orchestrators and controllers. In the eventuality of monitoring of slices and micro-segmentations, PulSAR could implement new rules to follow such new attacks.

5.1.8.2 Quality Attributes

Operability/Ease of use

The design of the PulSAR aims at stressing on characteristics such as usability, packaged solutions and solutions that scale.

Compatibility/Interoperability

Therefore, the following transverse design principles have been applied for the PulSAR:

- Standard data formats for exchange between the different components.
- Interoperability with of-the-shelf SIEMs through the IDMEF standard.
- Use of asynchronous process
- Proper error handling: to prevent any wrong analysis due to incorrect use the tools or incorrect input data (non-accurate or incomplete topology information shall be rejected).
- Flexibility and modularity: use a script programming language (such as Python) to develop the Cyber Data Extractor, to make it easy the plug new connectors into the component, if a user of the enabler wants to use another input format, while keeping the same outputs, adapted to each components. For example, if the vulnerability scanner used in a company is OpenVAS, rather than Nessus, it is easily possible, in few lines of code, to develop a connector to OpenVAS, which can be used in addition to the one of Nessus, while keeping the same outputs for MulVAL Attack Graph Engine.

5.1.8.3 Technical Constraints

Reasoning rules specify semantics of different kinds of exploits, compromise propagation, and multi-hop network access.

Datalog is used as the modelling language for the elements in the analysis (bug specification, configuration description, reasoning rules, operating-system permission and privilege model, etc.). It leverages existing vulnerability databases and scanning tools easily by expressing their output in Datalog and feeding it to the Attack Graph reasoning engine. MulVAL Attack Graph Engine adopts this modelling language [1].

Compared with a graph data structure, Datalog provides a declarative specification for the reasoning logic, making it easier to review and augment the reasoning engine when necessary.

MulVAL Attack Graph Engine uses a dependency graph to represent the pre and post conditions for exploits. Then a graph search algorithm can combine individual exploits and find attack paths involving multiple vulnerabilities. This algorithm is adopted in Topological Vulnerability Analysis (TVA), a framework that combines an exploit knowledge base with a remote network vulnerability scanner to analyse exploit sequences leading to attack goals.

5.1.8.4 Business Constraints

The reasoning engine consists of a collection of Datalog rules that captures the operating system behavior and the interaction of various components in the network. Thus, integrating information from the bug-reporting community and off-the-shelf scanning tools in the reasoning model is straightforward.

The interaction rules characterize general attack methodologies (such as “Trojan Horse client program”), not specific vulnerabilities. Thus the rules do not need to be changed frequently, even if new vulnerabilities are reported frequently.

The reasoning engine scales well with the size of the network. Once all the information is collected, the analysis can be performed in seconds for networks with thousands of machines.

A key requirement is the compliance to industrial standards.

5.1.9 Detailed specifications

5.1.9.1 Introduction

PulSAR components presented above are described in detail below.

5.1.9.1.1 Cyber Data Extraction

The Cyber Data Extraction collects several type of input data described hereafter:

1. **The topology of the Information System**: The topology is extracted from CSV files describing the hosts, the services and the IP networks, the available routes from one host to another, the firewall rules, and also information regarding VNF domains, controllers and potentially other needed 5G objects.
2. **The report of a vulnerability scanner (e.g. NESSUS)**: The Cyber Data Extraction component handles the vulnerability scanner reports generated by Nessus for example. Nessus is a vulnerability scanner designed to automate the testing and discovery of known security issues. Nessus uses a client-server technology. Servers can be placed at various strategic points on a network allowing tests to be conducted from various points of view. A central client or multiple distributed clients can control all the servers. Nessus has the ability to detect the flaws of the hosts on the network remotely but it can also detect flaws and missing patches by scanning locally if it is given the credentials to log in and run commands on the host itself. Nessus has the ability to test SSL-enabled services such as https, smtps, imaps, and more. The report generated by the Nessus scanner helps to have an overview of the status of the network and its vulnerabilities, which is the first step to prevent vulnerabilities. It detects only known vulnerabilities for which a detection plugin has been provided by Nessus. Although most of the vulnerabilities that can be exploited by a medium-level attacker have a corresponding Nessus detection plugin, very high-level attackers may know zero-days (unpublished vulnerabilities) that are not addressed by any of those plugins.

The Cyber Data Extraction generates two types of output:

- The first one is the Datalog file needed by the MulVAL Attack Graph Engine to generate the attack graph. This file contains both vulnerability and topological information.
- The second one is an XML file aggregating all vulnerabilities and topological information needed by the Remediation application, in order to simulate remediation in the network topology.

5.1.9.1.2 Attack graph

The attack graph engine relies on a MulVAL attack Graph Engine.

The first action of this component is to generate the attack graph using MulVAL, thanks to the input file generated by the Cyber Data Extractor.

In this process, for example, the results of the vulnerability scanner are converted into Datalog clauses like the following ones:

> **vulExists**(webServer, ’CAN-2002-0392’, httpd).
>
> Namely, it identifies a vulnerability with CVE id CAN-2002-0392 on machine webServer. The vulnerability involved the server program httpd. However, the effect of the vulnerability — how it can be exploited and what its consequences are — is not contained directly in the results of the vulnerability scanner. The National Vulnerability Database (NDV) developed by the National

Institute of Standards and Technology (NIST), provides the information about a vulnerability's effect through CVSS Impact metrics. The relevant information is converted from CVSS into Datalog clauses such as:

vulProperty('CAN-2002-0392', remoteExploit,privilegeEscalation).
The MulVAL Attack Graph Engine models elements in Datalog. The model elements are recorded as Datalog facts. The MulVAL Attack Graph Engine requires all Datalog facts to be defined prior to performing any analysis. Missing or incorrect facts will result in a misleading analysis of the system being modeled.

The interactions among multiple network elements must be considered in order to determine which security impact software vulnerabilities have on a particular network. The model used in the vulnerability analysis must be able to automatically integrate formal vulnerability specifications from heterogeneous vulnerability sources. The MulVAL Attack Graph Engine is an end-to-end framework and reasoning system that conducts multi-host, multi-stage vulnerability analysis on a network. The MulVAL Attack Graph Engine adopts Datalog (a query and rule language for deductive databases) as the modeling language for the elements in the analysis (bug specification, configuration description, reasoning rules, operating-system permission and privilege model, etc.). It has leveraged existing vulnerability database and scanning tools by expressing their output in Datalog to feed the Attack Path Engine. The rules can be modeled according the security expertise and skills. In other terms, the normal users do not need to modify these rules and just need to update the database with all published vulnerabilities from NIST (http://www.nist.gov/itl/csd/stvm/nvd.cfm). The inputs to the MulVAL Attack Graph Engine's analysis are:

- Advisories: What vulnerabilities have been reported and do they exist on my machines?
- Host configuration: What software and services are running on my hosts, and how are they configured?
- Network configuration: How are my network routers and firewalls configured?
- Principals: Who are the users of my network?
- Interaction: What is the model of how all these components interact?
- Policy: What accesses do I want to allow?

The Cyber Security Data Extraction allows to generate automatically such inputs, from automatically generated data (such as the vulnerability scanner) or easy to understand data (description of hosts, with their importance on a scale Negligible/Minor/Medium/Severe/Catastrophic). This allows non-expert users such as SMEs to use this tool, without high technical knowledge. The current MulVAL Attack Graph Engine data model relies on the exploit range (local or remote) and the privilege escalation consequence data that are stored in NIST NVD (National Vulnerability Database). The Figure 50 below shows an extract of a logical attack graph computed by the MulVAL Attack Graph Engine. This logical graph explains how an attacker on the Internet (attackerLocated(internet)) can succeed to exec arbitrary code on a webserver (execCode(webserver,apache)) using the vulnerability CAN-2002-0392.

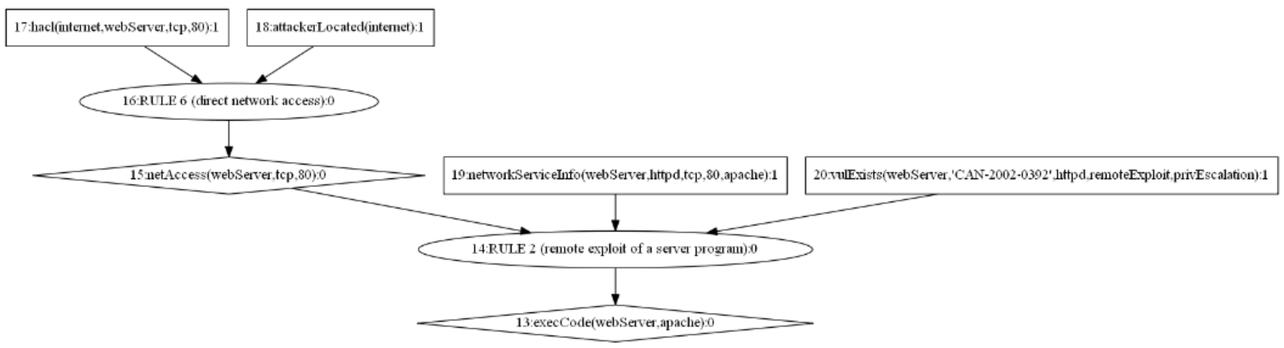
17:hacl(internet,webServer,tcp,80):1
18:attackerLocated(internet):1
16:RULE 6 (direct network access):0
15:netAccess(webServer,tcp,80):0
19:networkServiceInfo(webServer,httpd,tcp,80,apache):1
20:vulExists(webServer,'CAN-2002-0392',httpd,remoteExploit,privEscalation):1
14:RULE 2 (remote exploit of a server program):0
13:execCode(webServer,apache):0

Figure 50: Example of logical attack graph

The MulVAL Attack Graph Engine uses Datalog (a subset of Prolog) to produce logical attack graphs. It takes as input a set of first-order logical configuration predicates and produces the corresponding attack graph. These configuration predicates include network-specific security policies, binding information and vulnerability data gathered from vulnerability databases. These are automatically generated from the NIST NVD, or from the topological configuration, thanks to the Cyber Data Extraction Component. The MulVAL Attack Graph Engine identifies possible policy violations through logical inference.

An attack graph presents a qualitative view of security discrepancies:

- It shows what attacks are possible, but does not tell you how bad the problem is.
- It captures the interactions among all attack possibilities in your system.

CVSS (Common Vulnerability Scoring System (https://nvd.nist.gov/cvss.cfm)) provides a quantitative property of individual vulnerabilities:

- It tells you how bad an individual vulnerability could be.
- But it does not tell you how bad it may be in your system.

The idea is to use CVSS to produce a component metric, i.e. a numeric measure on the conditional probability of success of an attack step. The MulVAL Attack Graph Engine aggregates the probabilities over the attack-graph structure to provide a cumulative metric, i.e. the probability of attacker success in your system. Suppose there is a "dedicated attacker" who will try all possible ways to attack your system. If one path fails, he/she will try another. The cumulative metric is the probability that he/she can succeed in at least one path.

MulVAL Attack Graph Engine rules for 5G

Specific 5G rules must be added to support 5G environment compared to previous traditional network and IT versions.

A special focus is put on the description of the vulnerabilities of hypervisor, NFV orchestrators and SDN controllers and the impact of the compromising of those. For example, if an hypervisor is compromised, all the Virtual Machines (VMs) depending on it might be compromised at next step of an attack. Same type of reasoning is performed for NFV orchestrators and SDN controllers.

5.1.9.1.3 Scored Attack Paths

This Attack graph gives the basic information for the scored attack path to be computed:

- The potential attack paths;
- The probability scores of each attack graph node, translating the probability of success to each step in the attack graph. These probability scores are the basis for computing the risk score of an attack path.

Once the attack paths related to a given target is obtained, altogether with the score for each of the attack paths, the result will be output to the Remediation engine and Visualization component, in order to be employed for the objectives of the latter. Besides the internal interactions with the Attack Graph Engine and the Remediation engine, the Scored attack paths component provides one external interface to get the user preferences for attack path scoring. Scored Attack Paths represents the next step, following the metrics provided by the MulVAL Attack Graph Engine. Based on the Attack Graph provided by the MulVAL Attack Graph Engine, and the individual scores of each step, the objective is to yield the possible attack paths, along with a score associated to each one of the paths.

The considered attack paths that will be included in the list are selected based on the target node selected in the attack graph. The score of each path reflects the risk associated to the path as a whole, based on the individual scores of each step that have been previously calculated by the MulVAL Attack Graph Engine.

Additionally to the risk score metric, the score of each path includes a second scoring component that takes into account the business impact of all IT resource(s) impacted by such attack path. Next section will elaborate on how the business impact is entered.

The main idea of scoring attack paths (see figure 51 below) is to consider paths independently from one another, as opposed to the approach of the MulVAL Attack Graph Engine, composed of individual scores, the latter being computed by taking into account all the connections existing in the attack graph.

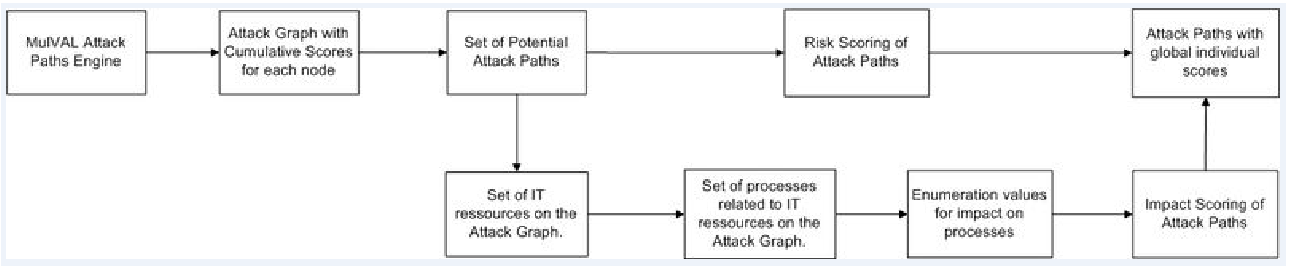
MulVAL Attack Paths Engine
Attack Graph with Cumulative Scores for each node
Set of Potential Attack Paths
Risk Scoring of Attack Paths
Attack Paths with global individual scores
Set of IT ressources on the Attack Graph.
Set of processes related to IT ressources on the Attack Graph.
Enumeration values for impact on processes
Impact Scoring of Attack Paths

Figure 51: Flow diagram of scoring attack paths

5.1.9.1.4 Remediation

The Remediation application provides tools to security operators for proposing cost-sensitive remediation to attack paths. The attack paths are shown to a security operator, ordered by their scores, which allow easily understanding the severity of the consequences of the attack paths. To calculate remediation (see Figure 52 below) to the chosen attack path, the tool first extracts the necessary information from the attack path to be corrected. Then, it computes several lists of remediation that could reduce / cut this attack path. Finally, it estimates the cost of each list of remediation and proposes all the lists of remediation, ordered by cost, to security operators. Operators can choose one remediation list and, thanks to the remediation validation, check whether or not the system is more secure after applying this remediation.

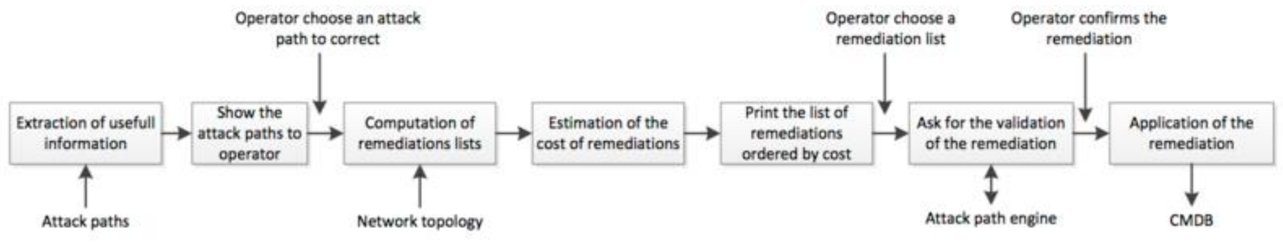
Operator choose an attack path to correct
Operator choose a remediation list
Operator confirms the remediation
Extraction of usefull information
Show the attack paths to operator
Computation of remediations lists
Estimation of the cost of remediations
Print the list of remediations ordered by cost
Ask for the validation of the remediation
Application of the remediation
Attack paths
Network topology
Attack path engine
CMDB

Figure 52: Remediation process

Remediation using a remediation database

To compute remediation, a remediation database is needed. This database makes a connection between vulnerabilities (for example thanks to a Common Vulnerabilities and Exposures identifier - CVE ID) and a possible adapted remediation. Several types of remediation could be used, for example a patch (it corrects a vulnerability) or Virtual Patching (a signature of known attacks which prevents the exploitation of a vulnerability) to quote few examples. To build the remediation database, information about patches can be extracted from publicly available sources of data (for example the National Vulnerability Database), or in Security Advisories (for example, coming from CERT-EU). Information about signatures and the related vulnerability could be extracted from the signatures database that contains the CVE ID. Python scripts are given together with the tool, in order to populate or update automatically the remediation database, from such open sources. The only action needed by the user, in order to do that, is to launch the script, which will download the files from the Internet, and populate the database.

Network remediation

The other types of remediation provided by the Remediation application cannot be stored in the remediation database, because these are network remediation, such as firewall or routing configuration change. The network configuration feature needs the simulation of the network topology obtained after modifying the network configuration, in order to confirm that it removes the vulnerability and reduces the risk to attacks. To sort the list of remediation, a cost function is applied to compute an estimate cost of each list. This cost contains two main components: operational costs and impact costs. The operational costs represent the costs caused by the deployment of the remediation (length of the deployment, maintenance costs, tests costs, …) whereas the impact costs represents the negative impact (side effects) that could happen following a remediation deployment.

Remediation Automation

One main feature of this Remediation application is the proposition to highlight automatically the best remediation to some risks through an adaptive tuning and machine learning. This is done with a learning of the responses that have been applied by operators on similar attack paths. A similar attack path can be, for example, an attack path targeting the same machines, but using a different vulnerability. When a remediation is applied by an operator, the server learns what has been done by the operator. When a new attack path is detected, if it is similar to an attack path already corrected, and has a remediation similar to the one that has been applied before, the remediation that will be the first to be proposed to the operator is the similar remediation.

5.1.9.1.5 Dynamic Risk Analysis

The Dynamic Risk Analysis Engine takes as input the attack graph, in XML format, the alerts in XML format, following the IDMEF standard (RFC 4765), and information about the value of each assets in the network.

As alerts come by, the probability of each asset to have been compromised will be computed. The analysis output is the risk on every machine in the network, based on the calculated probability and the value (given as input) of the asset.

This technique can lower the false-negative rate, at it is able to detect a step which must have occurred in the graph, but has not been detected by the SIEM.

5.1.9.1.6 Counter-measures

The counter-measures aim at blocking an attacker while he’s trying to go deeper into the system. This process takes as input the result of the Dynamic Risk Analysis (probability of every machine to have been compromised), and the attack graph. PULSAR can use the Dynamic Risk Analysis and the attack graph to determine what step have been executed by the attackers, and what will be their probable next moves.

Using similar algorithm than the remediation, counter measure can be proposed to the operator, to block specific actions for certain user. Some chosen counter measure could be applied automatically. The counter measures differ from the remediation as it does not correct vulnerability, but reconfigure the network to prevent the exploitation of an unpatched vulnerability. Also, when a counter measure is applied, the attack graph does not need to be recalculated.

5.1.9.1.7 Visualization

The visualization is the main component of the Enabler to manage the computation of attack paths and remediation, and to display them. Systems that evaluate the security of a network, such as the Attack Graph or Scored Attack Paths Engines, can generate a large amount of data. The Visualization aims to find ways to display such big graphs, in order to present to an operator something that he/she can understand. This can for example be done thanks to the display of an attrition level associated to attack paths; therefore the Risk Visualization is performed genuinely by attrition level.

The visualization interface also describes the different remediation that can correct attack paths, in order to help a security operator to make a choice.

The visualization is also used for Dynamic Risk Analysis, by depicting the elements of the attack graphs that have been detected in SIEM alerts and are currently being attacked.

5.1.9.2 Conformance

For an implement to be conformant it should implement specifications as here stated.

5.1.9.3 API specifications

The APIs are pictures on the first and second figure of this enabler section. The main external Interfaces of the PulSAR enabler are:

- Cyber data extraction Interface
- Run-time alert processing interface
- XML/JSON interface

Cyber Data extraction Interface

The Cyber Data extraction Interface collects all kind of data useful to feed the computation of the Attack Graphs. These data are mainly twofold:

- Network topology
- Vulnerability scan

These external interfaces will operate via file input/output with a defined CSV data structure for the file content.

Network topology includes elements that can be listed as follow:

- Hosts interface
- Service - Application
- VLAN
- Routing tables
- Firewall rules
- Network status
- Flow matrix

And specifically for 5G/NFV/SDN environments

- Tenant Domain VNF list
- Infra or Party Domain VNF list
- Run-time network reconfiguration
- Slices
- Micro-segments…

Rules related to slices and micro-segments are not defined in R1. The opportunity to develop special rules around such concepts will be considered in R2.

Vulnerability scanis typically a report generated by a tool like Nessus for example.

Run-time alert processing interface

Alerts coming from the SIEM are used for the dynamic risk analysis and counter measures. They will be received in XML format, following the IDMEF standard (RFC 4765), through a REST API exposed to the SIEM.

XML/JSON interface

A REST API will be used to query the results: attack paths, remediation, actives paths (dynamic risk analysis) and the counter measures. The answers will be in JSON format.

5.1.9.4 Examples

The example illustrates the SIEM alert use case presented in 5.1.7.1. It shows the format used by the run-time alert processing interface to receive IDMEF alerts and response.

Add IDMEF alerts

[/rest/json/idmef/add]

Add IDMEF alerts **POST /rest/json/idmef/add**

Request (application/xml)

Headers

Content-Type: **application/xml**

Body

```
<?xml version="1.0" encoding="UTF-8"?>
<idmef:IDMEF-Message xmlns:idmef="http://iana.org/idmef" version="1.0">
<idmef:Alertmessageid="abc123456789">
<idmef:Analyzeranalyzerid="bc-sensor01">
<idmef:Nodecategory="dns">
<idmef:name>sensor.example.com</idmef:name>
</idmef:Node>
</idmef:Analyzer>
<idmef:CreateTimentpstamp="0xbc71f4f5.0xef449129">2000-03-09T10:01:2
5.93464Z</idmef:CreateTime>
<idmef:Sourceident="a1a2" spoofed="yes">
<idmef:Nodeident="a1a2-1">
<idmef:Addressident="a1a2-2" category="ipv4-addr">
<idmef:address>192.0.2.200</idmef:address>
</idmef:Address>
</idmef:Node>
</idmef:Source>
<idmef:Targetident="b3b4">
<idmef:Node>
<idmef:Addressident="b3b4-1" category="ipv4-addr">
<idmef:address>192.0.2.50</idmef:address>
</idmef:Address>
</idmef:Node>
</idmef:Target>
<idmef:Targetident="c5c6">
<idmef:Nodeident="c5c6-1" category="nisplus">
<idmef:name>lollipop</idmef:name>
</idmef:Node>
</idmef:Target>
<idmef:Targetident="d7d8">
<idmef:Nodeident="d7d8-1">
<idmef:location>Cabinet B10</idmef:location>
<idmef:name>Cisco.router.b10</idmef:name>
</idmef:Node>
</idmef:Target>
<idmef:Classificationtext="Ping-of-death detected">
<idmef:Referenceorigin="cve">
<idmef:name>CVE-1999-128</idmef:name>
<idmef:url>http://www.cve.mitre.org/cgi-bin/cvename.cgi?name=CVE-1999-128</idmef:url>
</idmef:Reference>
</idmef:Classification>
</idmef:Alert>
</idmef:IDMEF-Message>
```

Response 200 (application/json)

Headers

Content-Type: **application/json**

Body

```
{"success":"IDMEF alerts added successfully"}
```

Go to specification

5.1.10 Re-utilised Technologies/Specifications

PulSAR leverages on assets defined and developed in FI-PPP and FI-WARE/FI-Core FP7 projects, especially the Cybersecurity Monitoring Generic Enabler and its Generic Enabler Reference Implementation called CyberCAPTOR.

5.1.11 References

[1] https://www.ietf.org/rfc/rfc4765.txt
[2]https://github.com/fiware-cybercaptor/cybercaptor-dataextraction/blob/master/doc/topology-file-specifications.md
[3] François Reynaud, François-Xavier Aguessy, Olivier Bettan, Mathieu Bouet and Vania Conan: Attacks against Network Functions Virtualization and Software-Defined Networking: State-of-the-art, in SecVirtNet 2016

5.1.12 Acknowledgements

Acknowledgements are dedicated to the FI-PPP FI-WARE & FI-Core projects' participants who have been working on security monitoring and cyber security monitoring assets development on which the PulSAR enabler will leverage to address 5G security requirements on the field.

5.2 Generic Collector Interface Open specifications

5.2.1 Preface

In this section, we present the "Generic Collector interface". This enabler mainly aims at monitoring the 5G core network elements / components.

5.2.2 Status

At the writing time of this document, the Generic Collector interface is still under research and development. Therefore, the open specifications of Generic Collector Interface are preliminary and are subject of improvements. In the scope of Release-1, we plan to develop some features as a proof of concept.

5.2.3 Copyright

Orange is currently the only contributor to this enabler.

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5.2.4 Legal notice

The Legal notice that applies to these specifications is given in Annex A.

5.2.5 Terms and definitions

MME	Mobility Management Entity
HSS	Home Subscriber Server
P-GW	Packet Data Network GateWay
S-GW	Serving GateWay
NFV	Network Function Virtualization

NFVO	NFV Orchestrator
VNFM	Virtualized network Function Manager
VIM	Virtualized Infrastructure Manager
SDN	Software Defined Network

Table 4: Acronyms list

5.2.6 Overview

The Generic Collector Enabler, presented in Figure 53, aims at collecting logs and events basically generated by the 5G core network components (e.g., MME, HSS, P-GW, S-GW…). To this end, the Generic Collector Enabler consists of two engines: Server engine and Client engine.

- The Server engine is the software managing the monitoring operations. It is responsible of
  - Triggering and ending the real-time monitoring (basic function)
  - Trigger specific commands, for instance, to get data specific to a component and / or a given Network layer and /or a particular protocol (cf §5.2.8.1 Use Cases).
  - Data processing: based on the retrieved data and some other information (e.g., security patterns), the server engine can identify abnormal behaviors and incidents.
  - Providing inputs to other enablers such as PulSAR and System Security State repository
- The Client engine is the software installed in the 5G core network components. This software is responsible of
  - Reporting data about its state, for instance, the type of the component, Component ID, active interfaces, etc.
  - Reporting signalling data (i.e., control plane) that transit by it.
  - Answering any specific request originating from the Server engine.

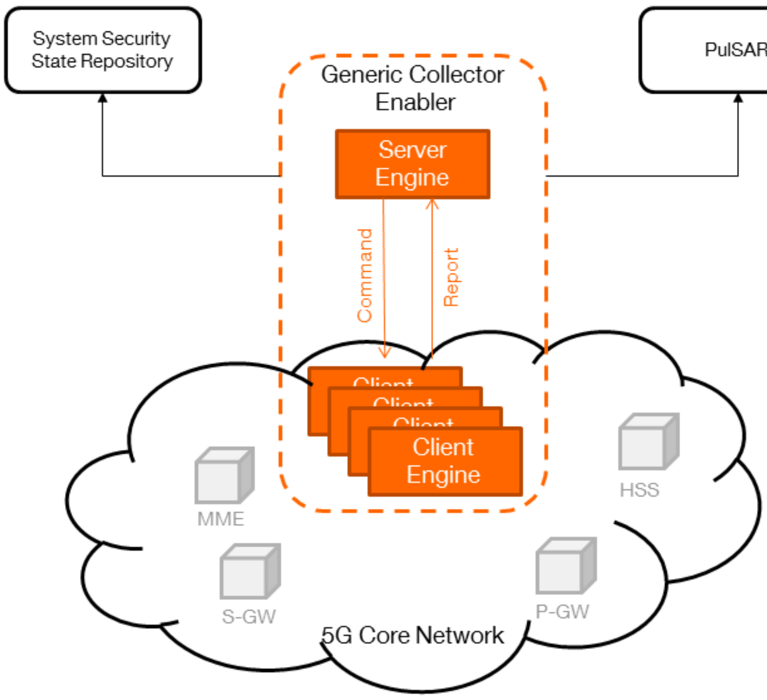

Figure 53: Generic Collector Enabler Overview

In Figure 53, the Generic Collector enabler provides inputs to PulSAR enabler as well as System security State Repository enabler. PulSAR enabler receives the set of identified incidents in the network. Regarding

System security State Repository enabler, it receives all the collected events extracted from logs. These two enablers may also have other inputs in addition to the data provided by the Generic Collector enabler. In a second phase, the interactions between these enablers should be formalized. Generic Collector enabler can also have interaction with other enablers namely other monitoring enablers. This should also be investigated in a further phase.

5.2.7 Basic concepts

In this section, we provide the definition of the Core Network main components / functions.

Mobility Management Entity (MME) [TS 23.401, TS 23.402, TS 36.300**]:** it is a control plane entity that handles the signalling related to mobility and security such as Non-Access Stratum signalling and security, inter Core Network node signalling for mobility between 3GPP access networks, tracking Area list management, packet Data Network GateWay and Serving GateWay selection, roaming, authentication, and lawful Interception of signalling traffic.

Home Subscriber Server (HSS) [TS 23002**]:** it is a database that contains subscription related information namely:

- User Identification, Numbering and addressing information;
- User Security information: Network access control information for authentication and authorization;
- User Location information at inter-system level: the HSS supports the user registration, and stores inter-system location information, etc.;
- User profile information.

It also provides support functions in mobility management, call and session setup, user authentication and access authorization.

Packet Data Network GateWay (P-GW) [TS 23.002, TS 23.401,TS 23.402**]:** it is the point of interconnect between the EPC and the Packet Data Network (i.e., external IP networks). It is a user plane entity. Among the functions of P-GW:

- Per-user based packet filtering (by e.g. deep packet inspection);
- Lawful Interception;
- User equipment IP address allocation;
- Transport level packet marking in the uplink and downlink
- UL and DL service level charging, gating control, rate enforcement;
- UL and DL rate enforcement based on APN-AMBR;
- DL rate enforcement based on the accumulated MBRs of the aggregate of SDFs with the same GBR QCI (e.g. by rate policing/shaping);
- DHCPv4 (server and client) and DHCPv6 (client and server) functions;

Serving GateWay (S-GW) [TS 23.401, TS 23.402**]:** it is the point of interconnect between the Core Network and the radio. It is a user plane entity. It provides a set of functions such as:

- the local Mobility Anchor point for inter-eNodeB handover;
- Mobility anchoring for inter-3GPP mobility;
- Lawful Interception;
- Packet routeing and forwarding;
- Transport level packet marking in the uplink and the downlink;

- Accounting on user and QCI granularity for inter-operator charging;
- Event reporting (change of RAT, etc.) to the Policy and Charging Rules Function (PCRF);

Network Function Virtualization (NFV) [ETSI, NFV]**:** it is a networking initiative led by Telcos, to embed current network functions (e.g., ciphering, firewall, load balancing, TCP accelerators, concentrators, DNS, QoE Management, video optimizers, etc.) in commodity hardware (high-volume standard servers, storage and switches). Network functions become then VNFs (Virtualized Network Functions). The NFV reference architecture defined by ETSI NFV group is composed of:

- **NFV Orchestrator** manages a networking service;
- **VNF Manager** ensures the life-cycle of the VNFs
- **VIM** maps the VNFs and virtual links on to the physical infrastructure (i.e., computing, memory and network)

Software Defined network (SDN) [ONF]**:** it is a novel network architecture based on abstraction, open interfaces, and control plane-data plane separation. The SDN concept is centered on the abstraction and network programmability. Open Networking Foundation (ONF) defines SDN as “The physical separation of the network control plane from the forwarding plane, where the control plane controls several devices”. A controller SDN dictates the forwarding rules to the network elements (SDN resources) by means of flows through the southbound protocol (de facto standard OpenFlow).

Authentication, Authorization and Accounting (AAA): this is a type of applications and protocols enabling the authentication of users, the authorization of some services to these users, and collecting data about the usage of resources for billing. Diameter is one of the current AAA protocols.

5.2.8 Main interactions

5.2.8.1 Use cases

A mobile network operator can send a specific request to an instance of P-GW (P-GW-VNF). The request consists on retrieving the following information:

- Its unique identifier (ID)
- The ID of the VNF Manager that manages this instance
- The ID of the VIM that manages this instance
- Its state (functional “0” or defective “1”)
- The used operating system
- The size of the instance
- The physical address (Host ID)
- The number of received packets

This request can be direct from the Operator Server engine to the P-GW instance. In addition, the request can be indirect, via other Server Engines as shown in Figure 54. The Operator Server engine sends the request to the relevant Server engine. This latter forwards the request to Layer Server engine in the Virtualized functions layer that transmits the request to the designated P-GW instance. Note that the request path and the Server / Client engine hierarchical architecture would vary based on the architectural choices that will be made in the project.

5.2.8.2 Components and interaction overview

We distinguish two main building blocks of the Generic Collector Enabler. First, the Client Engines are the collect points. Client Engines receive Commands and return back reports containing its state and the collected data. Second, Server Engines are the analysis and stance points which can be physical as well as functional / logical. Server Engines send Commands to Client engines and other Server engines, and receive reports about the network state. Given that in 5G, new layers will arise such as Virtualization and virtualized functions layers, the security monitoring of the 5G core network will not be limited to monitoring the infrastructure. Therefore, we propose to have Client and Server engines dedicated to every layer (i.e., Access layer, Infrastructure layer, Virtualization layer, Virtualization function layer and Applications services layer). Then, we organize Server engines into a hierarchically distributed architecture, as shown in Figure 54. There are three categories / levels of Server engines: Layer server engines, Slice server engine and Operator server engine.

A Layer server engine is a server engine dedicated to a given layer (e.g., Infrastructure Server engine). For instance, Client engine implemented in the Infrastructure nodes communicates only with the Layer Server engine of this layer. Thus, it only accepts commands coming from this given layer Server engine and make reports to it. Similarly, a slice server engine (that can be physical as well as functional / logical) is a server engine dedicated to a given slice. Hence, Layer server engines located in a slice S will communicate only with the slice server engine of S. Finally, Operator server engine is the root. Only Slice server engines and some layer server engines can communicate with it.

Communications between two categories of server engines respect the same protocol (Command / Report) and the same message format. Indeed, we propose a 3GPP compliant format, i.e. an xml file that describes the requested data or reports data. The format that we propose is an enhancement of the 3GPP proposal [TS 32.421, TS 32.422, TS 32.423]. We give further details about the format in section 5.2.10.1.

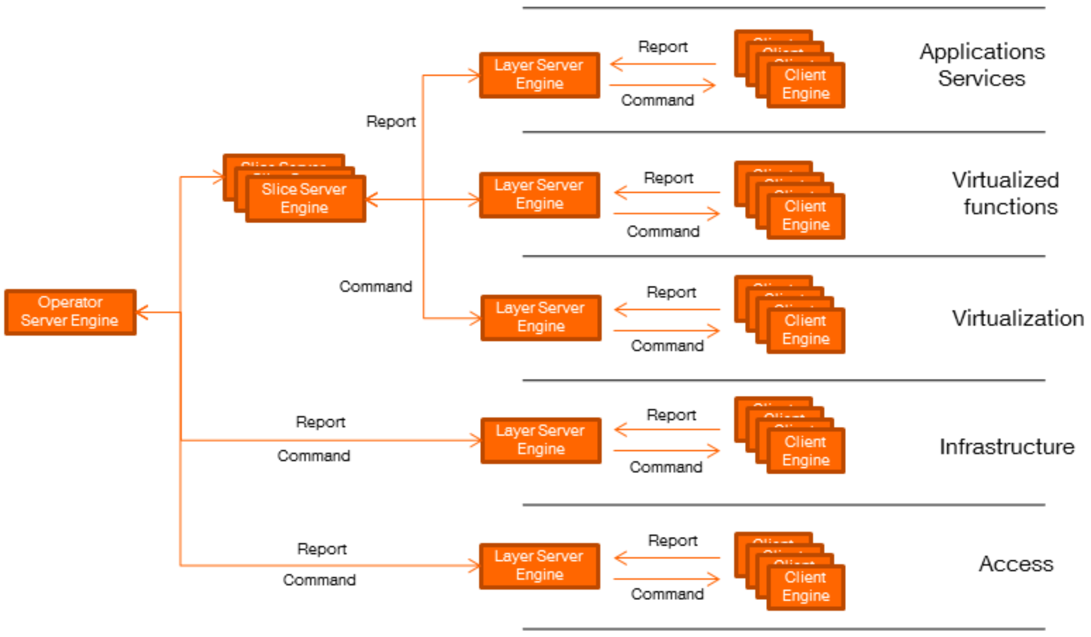

Figure 54: Generic Collector Enabler in layers

5.2.9 Architectural drivers

5.2.9.1 High-Level functional requirements

The Generic Collector enabler should ensure two main functional requirements. First, the monitoring of the network should not result in an overload. Interactions between the network equipment and the Generic Collector enabler may be imply additional load in the network. This may alter the statistics, hence; impact the following processes (e.g., incident identification and remediation). Second, the Generic Collector enabler aims to collect events and incidents from the network and perform real-time operations (in R2) on the collected data. This implies a high performance. The Generic Collector enabler should then provide an efficient solution.

5.2.9.2 Quality attributes

For R 1, there are only the following quality attributes:

- **Performance**: capacity to handle large amount of real-time events
- **Security**: the enabler should authenticate the event sources and the user of the enabler.

5.2.9.3 Technical constraints

As previously explained, the Generic Collector enabler contains two main components, i.e., Client engine (Collect points) and Server engine (analysis and stand points). The major constraint is on the collect points. The latter will be developed on network components. A network component may provide monitoring interfaces. The ideal situation is when the monitoring interfaces provide the required data. Otherwise, if the monitoring interfaces do not cover all the requested data or there are no monitoring interfaces, we must develop a solution that can extract the required data without any interfaces. In other words, the dilemma consists in "what can we really collect VS what we want to retrieve".

5.2.9.4 Business constraints

No business constraints.

5.2.10 Detailed specifications

5.2.10.1 API specifications

In this section, we detail the format of the XML files "Command" and "Report"" and describe the interfaces of the Generic Collector enabler. In this first draft, we mainly focus on four mobile core network entities, i.e., MME, HSS, P-GW and S-GW. Therefore, our specification is strongly inspired by the 3GPP proposal in [TS 33.421, TS 33.422, TS 33.423]. Indeed, we consider MME, HSS, P-GW and S-GW as virtualized network functions (VNFs). Hence, we improve the 3GPP proposal with VNF monitoring information. In Table 5, we provide details about the format of a Report file (i.e., fields). Table 5 is organized as follows: Interface / Entity Name - IE name – Notes. Table 6 and Table 7 give further details about two fields (i.e., "SwImageDescriptor" and "VirtualStorageDescriptor").

Interface name	**IE name**	**Notes**
NFV Orchestrator		
	ID	This is a unique identifier of a NFV Orchestrator.
	NFV Managers number	We cannot directly retrieve this value. We need to perform some computation to have it.

	State	Ideally, this value will be “0” if the NFV Orchestrator is functional and “1” if the NFV Orchestrator is defective. But as there is no implementation (to the best of our knowledge), we do not know if we can get such an information.
	VNF Managers IDs	These are a set of the identifiers of VNF Managers managed by a given NFV Orchestrator
	VNF Managers states	Ideally, for every NFV Manager, this value will be “0” if the NFV Manager is functional and “1” if the node is defective. But as there is no implementation (to the best of our knowledge), we do not know if we can get such an information.
	VNF ID – VL ID	Ideally, a NFV Orchetrator should have the list of VNFs that it is managing and its associated virtual links (VL).
VIM		
	ID	This is the identifier of VIM
	NFV Orchestrator ID	This is the ID of the NFV Orchestrator that manages the VIM.
	VNF address	This is the physical address of the VNFs
	VNF-StorageID	For every VNF, this is the Identifier of the virtualised storage resource.
	VNF-storageName	For every VNF, this is the name of the virtualised storage resource.
	VNF-typeOfStorage	For every VNF, this is the type of virtualised storage resource (e.g. volume, object).
	VNF-sizeOfStorage	For every VNF, this is the size of virtualised storage resource (e.g. size of volume, in GB).
	VNF-ownerId	For every VNF, this is the identifier of the virtualised resource that owns and uses such a virtualised storage resource. The value can be NULL if the virtualised storage is not attached yet to any other resource (e.g., a virtual machine).
	VNF-zoneId	For every VNF, If present, it identifies the Resource Zone where the virtual storage resources have been allocated.
	VNF-hostId	For every VNF, this is the identifier of the host where the virtualised storage resource is allocated. A cardinality of 0 refers to distributed storage solutions.
	State	For every VNF, this is the state of the resource allocated to the VNF.
	VNF-metadata	List of metadata key-value pairs used by the consumer to associate meaningful metadata to the related virtualised resource.
	VNF-startTime	Timestamp to start the consumption of the VNF resources. If the time value is 0, resources are reserved for immediate use.
	VNF-endTime	Timestamp indicating the end time of the reservation (when it is expected that the resources will no longer be needed) and used by the VIM to schedule the reservation. If not present, resources are reserved to the VNF for unlimited usage time.
VNF Manager		
	ID	This is a unique identifier of the VNF Manager.

	State	Ideally, this value will be “0” if the VNF Manager is functional and “1” if the VNF Manager is defective. But as there is no implementation (to the best of our knowledge), we do not know if we can get such an information.
	NFV Orchestrator ID	This is the ID of the NFV Orchestrator that manages the VNF Manager
	VNFs number	Perhaps, we cannot directly retrieve this value. We need to perform some computation to have it.
	VNFs IDs	The identifiers of VNFs that are managed by a given VNF Manager.
	VNFs states	Ideally, for every VNF, this value will be “0” if the VNF is functional and “1” if the VNF is defective.
MME-VNF		
	ID	This is the identifier of the MME-VNF
	VNF Manager ID	This is the ID of the VNF Manager that manages the MEE-VNF
	VIM ID	This is the ID of the VIM that manages the MEE-VNF
	MME-VNF state	Ideally, this value will be “0” if the VNF is functional and “1” if the VNF is defective.
	SwImageDescriptor	This describes the loaded software. We give further details about this IE in **Table 6**.
	VirtualStorageDescriptor	This describes the storage parameter of a virtual storage associated to a VNF. We give further details about this IE in **Table 7**.
	The remaining fields are the same as in 3GPP [TS 32 423]	
HSS-VNF		
	ID	This is the identifier of the HSS -VNF
	VNF Manager ID	This is the ID of the VNF Manager that manages the HSS -VNF
	VIM ID	This is the ID of the VIM that manages the HSS -VNF
	HSS-VNF state	Ideally, this value will be “0” if the VNF is functional and “1” if the VNF is defective.
	SwImageDescriptor	This describes the loaded software. We give further details about this IE in **Table 6**.
	VirtualStorageDescriptor	This describes the storage parameter of a virtual storage associated to a VNF. We give further details about this IE in **Table 7**.
	The remaining fields are the same as in 3GPP [TS 32 423]	
P-GW-VNF		
	ID	This is the identifier of the P-GW-VNF
	VNF Manager ID	This is the ID of the VNF Manager that manages the P-GW-VNF
	VIM ID	This is the ID of the VIM that manages the P-GW-VNF
	P-GW-VNF state	Ideally, this value will be “0” if the VNF is functional and “1” if the VNF is defective.
	SwImageDescriptor	This describes the loaded software. We give further details about this IE in **Table 6**.

	VirtualStorageDescriptor	This describes the storage parameter of a virtual storage associated to a VNF. We give further details about this IE in **Table 7**.
	The remaining fields are the same as in 3GPP [TS 32 423]	
S-GW-VNF		
	ID	This is the identifier of the S-GW-VNF
	VNF Manager ID	This is the ID of the VNF Manager that manages the S-GW-VNF
	VIM ID	This is the ID of the VIM that manages the S-GW-VNF
	S-GW-VNF state	Ideally, this value will be “0” if the VNF is functional and “1” if the VNF is defective.
	SwImageDescriptor	This describes the loaded software. We give further details about this IE in **Table 6**.
	VirtualStorageDescriptor	This describes the storage parameter of a virtual storage associated to a VNF. We give further details about this IE in **Table 7**
	The remaining fields are the same as in 3GPP [TS 32 423]	
SDN Controller		
southband interface	**nodes number**	We cannot directly retrieve this value. We need to perform some computation to have it.
	nodes IDs	The node IDs are called Data Path ID (DPID). It consists in 64 bits such that the lower 48 bits are intended for the switch MAC address, while the top 16 bits are up to the implementer.
	links	A link connects two nodes. Therefore, it is identified as a couple of DPID. (DPID - DPID)
	links number	We cannot directly retrieve this value. We need to perform some computation to have it.
	nodes states	Ideally, this value will be “0” if the node is functional and “1” if the node is defective. But current implementations do not allow it.
	hosts number	We cannot directly retrieve this value. We need to perform some computation to have it.
	Hosts IDs	A host ID can be an IP address or / and a MAC address.
	N_packetsPerRule	This is the number of packets assigned to a rule
	N_packetsPerPort	This is the number of packets that passed a port
	N_packetsWRule	This is the number of packets without rules

Table 5: Report file details

IE name	IE Parameters	Notes
SwImageDescriptor		
	ID	This is the identifier of the SwImageDescriptor
	Type	This indicates the type of virtualised storage resource (e.g. volume, object).

	Size	This indicates the size of virtualised storage resource (e.g. size of volume, in GB).
	swImageDescriptorPointer	This is a pointer to Software image of a VNF to be loaded on the VirtualStorage Resource based on this VirtualStorageDescriptor.
	swImage	This is a reference to the actual software image. The reference can be relative to the root of the VNF package or can be a URL.
	Version	This is the version of the software image.
	operatingSystem	This identifies the operating system used in the software image. This may also identify if a 32bit or 64 bit software image is used.
	supportedVirtualisationEnvironment	This identifies the virtualisation environments (e.g. hypervisor) compatible with this software image.

Table 6: The details of "SwImageDescriptor"

IE name	IE Parameters	Notes
VirtualStorageDescriptor		
	ID	This is the identifier of the VirtualStorageDescriptor
	Checksum	
	containerFormat	The container format describes the container file format in which the software image is provided.
	diskFormat	The disk format of a software image is the format of the underlying disk image
	minDisk	The minimal Disk for this software image.
	minRam	The minimal RAM for this software image.
	Size	This is the size of the software image

Table 7: The details of "VirtualStorageDescriptor"

In this first draft, we focused on a proactive approach. Indeed, based on the data reported by the different network nodes in the "Report" file, the operator server engine will study these logs, identify events and incidents, and consider further actions. In the forward version of the enabler (i.e., release 2), we will consider studying and implementing an active approach for incident reporting. Therefore, we propose a first draft of an incident format, as detailed in Table 8.

IE name	Attributes	Notes
HostID	MAC Address and / or IP address	The identifier of the host that detected / reported an incident.
VNFdescriptor	- ID - VNF Manager ID - VIM ID - VNF state - SwImageDescriptor - VirtualStorageDescriptor	The VNF descriptor contains all the information associated to the VNF that generated / identified the incident.

IncidentDescriptor	- ID - Session ID - Protocol ID	The Incident descriptor contains all the information associated to incident that occurred.

Table 8: Incident format details

Generic Collector API

The Generic Collector enabler encompasses two main types of components, i.e., Client Engine and Server Engine. Both have two interfaces types: southbound and northbound interfaces (we borrow the SDN terminology). The southbound interfaces of a Client Engine are two and enable it to exchange with the network component, i.e., request (first interface) and retrieve data (second interface). The northbound interfaces of a Client engine are also two and enable it to communicate with a Server Engine, i.e., receive "commands" (first interface) and send "reports" (second interface). The northbound and southbound interfaces of a Server Engine are similar. Indeed, there two interfaces: the first is dedicated to receive "Commands" and the second interface is to send "reports". Only the northbound interfaces of an Operator Server Engine are used to communicate with other enablers.

5.2.10.2 Examples

5.2.11 Re-utilised Technologies/Specifications

We would like to enhance the following 3GPP specifications [TS 32.421, TS 32.422, TS 32.423]. These specifications provide details about subscriber and equipment trace namely trace data definition and management, trace concept and requirements, and trace control and configuration management. Indeed, these specifications focus on the call level (User plane) in UMTS to enable monitoring and optimization operations.

Compared to UMTS, 5G network will encompass new layers. In addition to the physical and application layers, a virtualization and slicing layers will probably arise. Along with the new layers, new network components / entities will show up such us the NFV Orchestrator, VIM, VNF Manager or SDN controller. Because of this new context, we need to enhance the current security monitoring approaches in order to face the new security challenges of 5G.

In these circumstances, the Generic Collector enabler will perform security monitoring. However, we pay further attention on the control plane (contrarily to [TS 32.421, TS 32.422, TS 32.423]). In the scope of R1, we provide a common format of collected events and logs.

5.2.12 References

[ETSI] ETSI NFV Group Specification: "Network Functions Virtualisation (NFV); Management And Orchestration", Dec. 2014

[NFV] R. Guerzoni, "Network Functions Virtualisation: An Introduction, Benefits, Enablers, Challenges and Call for Action. Introductory white paper," in SDN and OpenFlow World Congress, June 2012.

[ONF] Open Networking Foundation, 'SDN Architecture Overview'. December 2013. Available at: https://www.opennetworking.org/images/stories/downloads/sdn-resources/technical-reports/SDN-architecture-overview-1.0.pdf

[TS 32.421] 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Telecommunication management; Subscriber and equipment trace; Trace concepts and requirements (Release 13)

[TS 32.422] 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Telecommunication management; Subscriber and equipment trace; Trace control and configuration management (Release 13)
[TS 32.423] 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Telecommunication management; Subscriber and equipment trace; Trace data definition and management (Release 13)

5.3 Security Monitor for 5G Micro-Segments -Open specifications

5.3.1 Preface

This section presents 'Security Monitor for 5G Micro-Segments' enabler. The enabler is related to two other 5G-ENSURE security enablers, namely 'Micro Segmentation' and 'Trust Metric'.

5.3.2 Status

This document provides an open specification of the framework feature that will be implemented for the first release of the enabler. The status of these open specifications is preliminary especially for what concerns API definition since the enabler with R1 feature is under development.

5.3.3 Copyright

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5.3.4 Legal notice

The Legal notice that applies to these specifications is given in Annex A.

5.3.5 Terms and definitions

AAA	Authentication, Authorization and Accounting
CEP	Complex Event Processing
JSON	JavaScript Object Notation
IDS	Intrusion Detection System
IPS	Intrusion Protection System
SDN	Software Defined Network
SIEM	Security Information and Event Management

5.3.6 Overview

5.3.6.1 5G Micro-Segments

Micro-segments[4]or network slices are isolated parts of 5G network that have been dedicated e.g. for particular applications or organizations. For instance, a micro-segment may be dedicated for IoT communication of a company or for vehicular communication. Micro-segments can be created using software defined networking (SDN) and virtualization concepts. Micro-segments, if correctly implemented, minimize the attack surface – an attack in 5G networks or in one micro-segment is restricted from spreading and affecting other micro-segments. They also ease configuration and customization of security as each micro-segment may have its own security functions.

[4] The concept of micro-segments - often used in data centers - is a similar to the concept of a (small) network slice (or sub-slice). Here we use the term micro-segmentation to emphasize the focus on security. See Micro-segmentation Enabler description in Section 6.4 for more detailed discussion on micro-segments.

5.3.6.2 Security Monitor for 5G Micro-Segments

The 'security monitoring enabler' collects information on security related events in micro-segments and infers knowledge by processing and combining these events. The goal of is to enable gaining of real-time awareness of the security situation in micro-segments and detection of some ongoing security incidents.

Micro-segmentation based monitoring provides:

- ***Customization*** - Security monitoring for different micro-segments can be customized and provide different security levels. For instance, some micro-segments can be deeply monitored to detect stealth incidents (e.g. advanced persistent threats) and some micro-segments can be monitored only in lightweight-manner (e.g. to detect denial of service attacks). The light monitoring could, for instance, inspection of communication statistics while the heavier monitoring could include inspection of communication in the different levels (cross-layer monitoring), inspection of encrypted traffic (decrypting payload for monitoring). The monitored aspects may also vary from segment to segment (e.g. searching different known threat patterns against availability and versus detection of anomalies caused by sophisticated attacks).
- ***Dynamic adaptation*** - The monitoring solution may be used to make micro-segment's security solutions more autonomous. The intensity or focus of monitoring may change dynamically based e.g. on changes on micro-segment's topology or (monitored) risk levels. For instance, detected suspicious traffic may trigger more intensified monitoring. Also, other security functions may be adapted according to knowledge inferred by monitoring (tightening AAA policies, quarantining nodes etc.).
- ***Scalability*** – as heavy monitoring solutions do not have to be resourced for whole 5G network but resources may be targeted only for micro-segmented part of the network.
- ***Accuracy*** – as micro-segments have fewer nodes, the system can monitor more parameters and features. Further, in some cases the micro-segments may contain more homogeneous traffic - coherent traffic patterns - enabling anomalies to be more easily detected.

5.3.6.3 Distributed Complex Event Processing Framework – Release 1 Feature

The first phase of development – Release 1 – will provide a 'distributed complex event processing framework'. The framework provides a *tool chain* that can be used when constructing different monitoring setups. It provides a mechanism to collect and share events from various sources and to distribute them to security inherence components.

The framework increases **scalability** and **flexibility** of 5G security monitoring by:

- enabling new heterogeneous event sources to be easily added and reusable components to be used for event stream to be processing (e.g. merging, aggregating, inferring)
- enabling different 'inherence components' - such as pattern detectors, machine learners, correlation analyzers… - to be integrated to the system when a need arises in different micro-segments (the solution provides efficiency as events are provided to those components that are interested on them and only for those)

- deploying *state-of-the-art analytics 'big data' technologies*(in particular Apache Kafka[5] and Spark[6]) that are able to handle large amounts of event streams in near real-time

A downside of the approach is increased complexity. Existing sources of monitoring information ('probes'), Security Information and Event Management (SIEM), Intrusion Detection or Protection Systems (IDS/IPS) etc. must be adapted to connect through the framework. However, the hypothesis is that the scalability and flexibility benefits exceed the adaptation costs.

5.3.7 Basic concepts

Security event is an occurrence in a system that is relevant to the security of the system. For instance, changes in network topologies and new communication flows between devices are events.

Security Monitoring is a process of colleting, analysing, and inferring of security events information in order to gain awareness of system's security state and to detect and respond to security incidents.

Complex Event Processing (CEP) is a process of analysing streams of information about events from multiple sources in order to extract meaningful knowledge. Typical CEP functions are, for instance, event filtering, aggregation and transformation, as well as pattern and correlation detection. When combined with history information there may also be functions for anomaly detection. CEP functions are typically chained to derive new knowledge from the event streams as illustrated in the simple example in Figure 55.

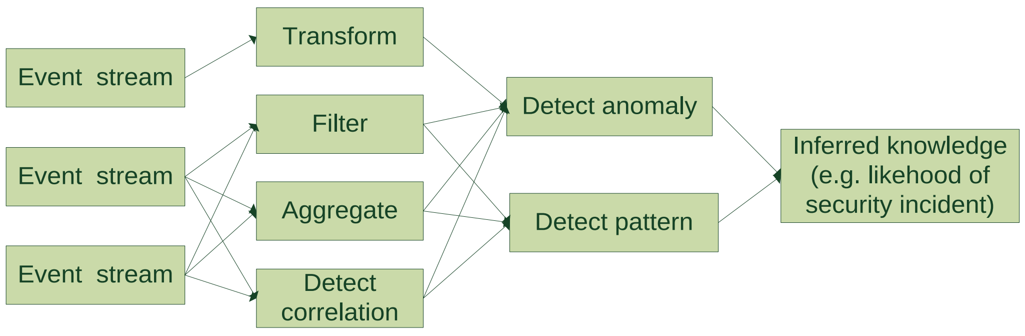

Figure 55: Example illustrating typical CEP functions which are chained to infer knowledge from events.

To ease development of CEP applications, different software engines have emerged, enabling developers to easily specify CEP rules. Processing of large event streams (big data) can be based on frameworks which enable parallelization of the computation. Notable existing stream processing tools are e.g. Apache Storm [Storm] and Apache Spark Streaming [Spark].

[5]Apache ***Kafka*** is publish-and-subscribe system that wasdeveloped originally by LinkedIn. It is designed to be fast, scalable, and durable.Kafka brokers can be clustered to provide more resources elastically and transparently. A broker keeps messages on disk and replicates them within a cluster to prevent data losses. Each broker should be able to store terabytes of messages and handle megabytes of reads and writes per second from thousands of clients.

[6]Apache ***Spark*** is a general engine for cluster-based data processing originating from UC Berkeley. It provides specialized data processing libraries (including SQL and DataFrames, MLlib for machine learning, GraphX, and Spark Streaming) which may be combined to create own parallelized applications. Spark is designed to be fast and by supporting mainstream languages (Java, Scala, Python and R languages) it is easily accessible for developers. It can be run as a stand-alone mode or e.g. within Hadoop - which is framework for distributed storage (using HDFS) and processing (using MapReduce) of large sets of (history) data.

Publish-and-subscribe is a communication paradigm (illustrated in Figure 56) where information on a particular topic (event) is published through a broker that forwards this information to those parties that have subscribed the topic related updates.

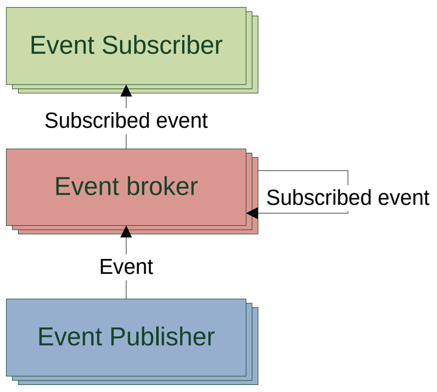

Figure 56: Publish-and-subscribe communication paradigm for event distribution.

The publish-and-subscribe paradigm provides greater scalability and flexibility as network topology can be dynamic (new publishers and subscribers can be added and removed). Examples of open source brokers include e.g. Apache Kafka [Kafka].

Anomaly detection is a process of identifying events that do not conform to an expected event patterns and which might indicate an ongoing security incident. Different machine learning algorithms may be applied for anomaly detection. Typically, an anomaly detection system first learns what is normal behaviour, e.g. by clustering events, and later identifies anomalies as deviations to this behaviour, e.g. events not fitting to learned clusters. Anomaly detection enables capturing of previously unknown attacks. However, application / risk specific symptoms must be known in advance to enable feasible selection of monitored features.

5.3.8 Main interactions

5.3.8.1 Use cases

The framework enables deployment of different security monitoring applications for different use cases. First releases will focus on monitoring of network communication in micro-segments. Here we will highlight one simple scenario.

Actors/roles in the use case are the following:

- Micro-segment provider – entity who controls switches and SDN controller and who is able collect event information e.g. network statistics. This actor is typically the (virtual) operator. The micro-segment provider opens its APIs for inference provider to acquire security relevant information from the network (publishes events).
- Micro-segment subscriber – organization, company requiring isolated 5G network services (and monitoring) for a particular application.
- Security inference provider – an entity inferring security knowledge from the event information and providing new knowledge or controlling micro-segment. The role is its own but the actor may be the micro-segment provider, a third-party, or the micro-segment subscriber. The analytics services may be tailored for each customer or customer segment.

A micro-segment has been subscribed by a company deploying critical IoT devices. The company needs high assurances on the authenticity, availability, and confidentiality of the communication between the devices and the cloud service. There is a risk that the devices or switches in the micro-segment become compromised. The risk cannot be completely prevented with proactive perimeter defences - such as authentication and authorization. However, some ongoing incidents may be reactively detected by security monitoring. The detectable incidents are such which have symptoms that are difficult to hide – for example, delays (a symptom of man-in-the-middle attack), excessive traffic (a symptom of denial-of-service attack), and messages with 'odd' target or source addresses (a symptom of reconnaissance or control channels to infected devices).

The micro-segment subscriber decides to use a security monitoring service that the inference provider is 'selling' as an extra assurance for homogeneous IoT traffic. The switches in the micro-segment collect (and publish) data on who is in communication with whom and when. The anomaly detecting components of the monitoring solution (subscribe and) use this information to produce estimates on the probability of on-going risks. The micro-segment provider, that is considered as the infrastructure operator for Release R1, may also deploy functions for quarantining components. The monitoring system is automatically able to request the micro-segment to quarantine nodes when the probability of node's compromise is considered large enough.

5.3.8.2 Components and interaction overview

The architecture separates (network and infrastructure specific) security event sources from (application and resource specific) security inference components by adding an event distribution and event processing layers between them.

An initial architecture for security event distribution is shown in Figure 57. The figure illustrates planned event publishers (blue in the figure), event consumers (i.e. inference components – green in the figure), and, as central distributing component, event brokers (red in the figure). The figure also encompasses some event sources planned for future releases.

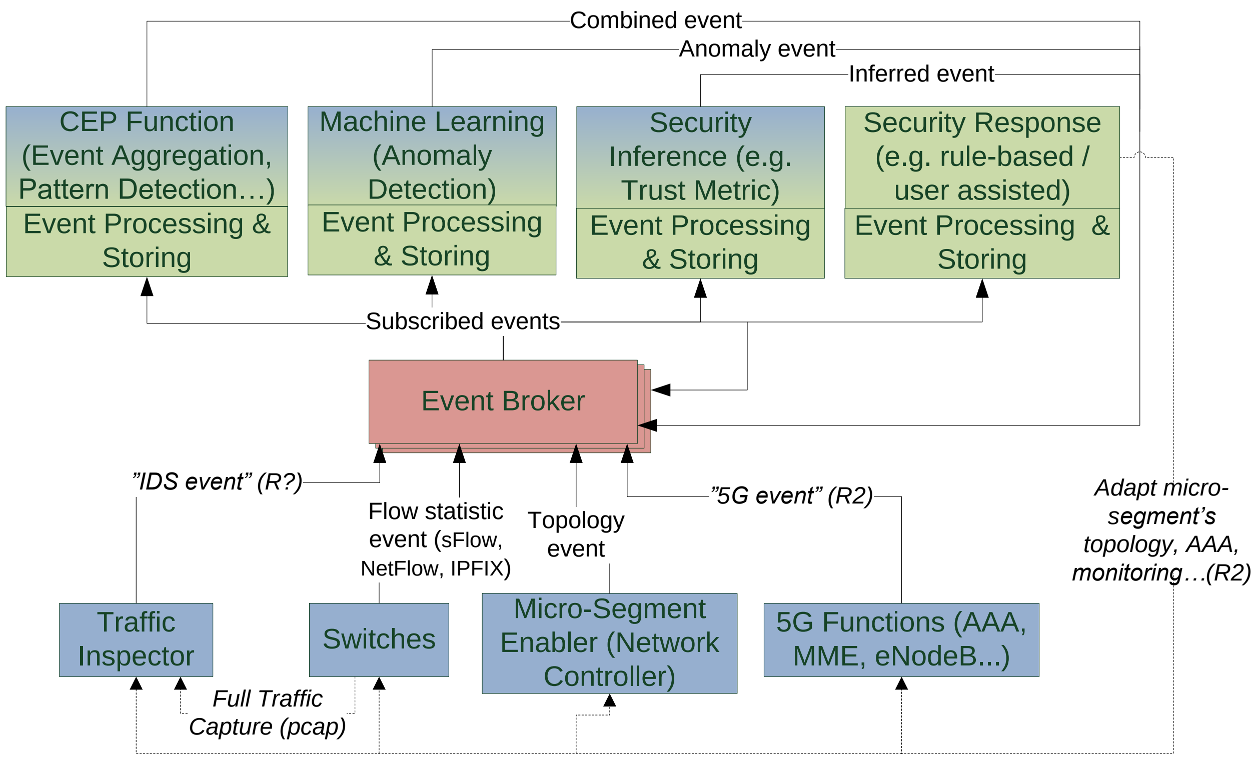
Combined event
Anomaly event
Inferred event
CEP Function (Event Aggregation, Pattern Detection…)
Event Processing & Storing
Machine Learning (Anomaly Detection)
Event Processing & Storing
Security Inference (e.g. Trust Metric)
Event Processing & Storing
Security Response (e.g. rule-based / user assisted)
Event Processing & Storing
Subscribed events
Event Broker
"IDS event" (R?)
Flow statistic event (sFlow, NetFlow, IPFIX)
Topology event
"5G event" (R2)
Adapt micro-segment's topology, AAA, monitoring…(R2)
Traffic Inspector
Switches
Micro-Segment Enabler (Network Controller)
5G Functions (AAA, MME, eNodeB...)
Full Traffic Capture (pcap)

Figure 57: Architecture for security event distribution

In the release 1, the security monitor collects information from communication in a micro-segment. In particular, we aim to support capturing of:

1) traffic statistics available from switches as well as
2) micro-segment information, including e.g. topology, from the micro-segment enabler (essentially SDN controller/application).

In the future releases, more event information from 5G specific sources and deeper packet analysis are planned.

Event information is distributed to event subscribers using the event broker. The broker can carry information on different events and from various sources. New event publishers can be added to the framework according to the availability of event information as well as the need of event subscribers. Existing data sources - log files, traffic analysers – need to be adapted to publish events using the brokering protocol.

Event subscribers provide micro-segment specific security inference, including anomaly detection and pattern detection. The subscribers may utilize common engine for processing the event streams. The subscribers may act also in publishers' role: output events (inferred, anomaly, or combined events) from one publisher can be brokered to other subscribers. Subscribers at the end of the chain are then expected to infer knowledge on micro-segment's security situation e.g. provide Trust Metric Enabler (Section 4.2) or initiate some security responses. Existing security inferencing components may be integrated to the system by providing an adapter that transforms brokered events into the format understood by the component.

The framework is targeted for real-time or near-real-time processing of monitored data streams. However, in security inference, also history data is needed - e.g. short term history for correlation analysis and longer history for machine learning. Smaller amounts of history data can be stored by the broker and for longer term history data the inference components must be integrated with a database for storing relevant events.

Brokers may be clustered and chained. Event information from a broker in one micro-segment may be subscribed and delivered to other brokers in order to further distribute decision making (to enable further scalability) and e.g. to enable micro-segments to share information and detect cross-segment attacks.

The system aims to make micro-segments and monitoring solutions more self-adaptive. Components that implement security response actions may, after being triggered by inferred event, request functions in the micro-segment (e.g. the micro-segment enabler, network controller, or switches) to change their behaviour. For instance, a micro-segment may remove some nodes from its topology or remove access permissions from a particular end-user. The brokering architecture itself enables event subscribers to adapt by subscribing more or less event streams. Additionally, there could be control mechanisms enabling event subscribers to request event publishers to intensify monitoring i.e. to publish more event information.

5.3.9 Architectural drivers

5.3.9.1 High-level functional requirements

Coverage by connecting event sources – Different event streams must be adapted so that event information from these streams can be published through the common brokering mechanism. The more event sources (publishing events) there are, the richer security monitoring applications can be build. In particularly, the larger amount of event sources enables more accurate correlation analyses.

Flexibility to add (easily and dynamically) application specific security inferencing components e.g. for pattern and anomaly detection. Building a solution that can be easily customized for different micro-segments that are dynamic and may have different sizes and types of communication.

5.3.9.2 Quality attributes

The following list presents quality attributes are relevant when assessing the realizations of the enabler. The list also illustrates how the current framework plans support these attributes:

- Functional suitability – accuracy of detecting security incidents is increased by focusing heterogeneous micro-segment which enables analysis to use more (correlated) parameters
- Reliability – use of mature big data software technologies
- Operability – use of widely adopted and accepted big data software technologies; customization as each micro-segment may be provided own monitoring functions
- Performance efficiency – scalability to handle large amount of real-time events supported by micro-segmentation concept and selected technologies
    - Horizontal scalability – the system utilizes event brokering (publish-and-subscribe architecture) to enable new processing nodes and information sources to be added.
    - Vertical scalability – the system should be scalable to micro-segments of different sizes and to *near-real-time* processing of event streams for different inference applications. Vertical scalability (adding more resources for single node) is enabled by software technology

selection (i.e. by using big data components supporting parallel and clustered computation as well as cloud-based deployments).

- Security – Authentication, reliability and confidentiality of event streams – Event information coming from some sources may be unreliable, untrustworthy, or malicious. Consequently, the broker should authenticate the event sources. Trustworthiness and quality of the event data may also be considered when inferring knowledge and determining probabilities of security incident.. In cases where information is shared between different actors also confidentiality and access control policies may be required to determine who can access event streams.
- Compatibility – support for various standardized event sources and use of open interfaces for output format
- Maintainability – use of easily utilized programming languages and widely utilized big data technologies; modularity enabled by brokered architecture
- Effectiveness – accuracy of detecting security incidents in homogenous micro-segments
- Efficiency – capability to cover large amount of security incidents is possible in

5.3.9.3 Technical constraints

To achieve interoperability with legacy event sources (logs etc.), monitored data must be transformed into event information that is understood by the inference components. We do adaptation and parsing in two phases. First the event sources (e.g. switches, traffic inspectors, or log collectors attached to the switches) encapsulate monitored data into events which can be published through the broker. Second, the inference layer transforms the content of events to extract needed information and derive knowledge.

5.3.9.4 Business constraints

The open framework is based on proven and widely adopted open protocols and open source software, which are scalable for large data amounts. Openness and scalability increases acceptability of the solution and eases integration as there are more directly compatible implementations and examples available.

5.3.10 Detailed specifications

5.3.10.1 Introduction

This section specifies the APIs and protocols utilized by the CEP framework (and its projection to security monitoring of micro-segments). The interfaces may be considered internal for the micro-segment monitor. External interfaces (including user interfaces) for controlling the behaviour of inference layer will be specified in the forthcoming releases.

5.3.10.2 Conformance

For an implementation to be conformant it should implement specifications as here stated.

5.3.10.3 API specifications

5.3.10.3.1 Event distribution layer

The event distribution (brokering) follows Apache Kafka API specifications, which are described at [Kafka_API]. The event distribution approach can be replaced with alternative mechanisms but in this case interoperability at the distribution layer with the reference implementation is lost.

Events are presented as {“topic”: “content”} tuples. The “topic” can be directly mapped to Kafka topic. The structure of the content depends on the event source (e.g. flow statistics or network controller event publishers).

The naming of “topics” follows the following format: [“micro-segment_identifier”, “node_identifier”, “event_identifier”], where “node_identifier” should be unique for the micro-segment[7] (or for monitoring system consisting of several segments) and “event_identifier” locally unique for the event publisher (typically a device or virtualized function).

5.3.10.3.2 Flow statisticevents

Flow statistic events from switches are structured using the following standards:

1. *sFlow (sample flow)* [sFlow5]
2. *NetFlow* is Cisco’s defacto standard [NetFlow9]
3. *IP Flow Information Export* [IPFIX]

Published events are parsed by event subscribers.

5.3.10.3.3 Network controller events

Network related information, including micro-segment’s topology and also some data flow statistics from switches, can be collected from Micro-Segment Enabler – and in particular from micro-segment enabler’s SDN controllers and network virtualization components..

Each time a micro-segment changes the relevant event information is published. Information requests may trigger additional events to be published.

In Release 1, the supported formats will follow output formats specified for Micro-Segmentation Enabler (Section 6.4). The micro-segment enabler should be able to publish micro-segment events. These events are triggered by “create”, “modify topology”, and “modify settings” commands, which are made by micro-segment subscriber. Further, the framework can be requested to publish additional flow statistics information using “get information” request.

The micro-segment enabler will support OpenVirteX [openvirtex_API] and Ryu SDN framework [Ryu_API], which output datain JavaScript Object Notation format [JSON]:

1. OpenVirteX monitoring API defines the following methods for querying information: getPhysicalTopology, listVirtualNetworks, getVirtualTopology, getVirtualSwitchMapping, getVirtualLinkMapping, getVirtualHosts, getPhysicalSwitchPorts, getPhysicalHosts, getSubnet, getVirtualFlowtable, getPhysicalFlowtable, getVirtualAddressMapping, and getVirtualSwitchPorts.

2. The Ryu-interface ryu.app.ofctl enables sending OpenFlow messages to the micro-segment. The central Ryu applications for collecting information from micro-segments are ryu.app.ofctl and ryu.app.ofctl_rest [https://ryu.readthedocs.io/en/latest/app/ofctl_rest.html] - for getting switch information and flow statistics - and ryu.app.rest_topology [https://github.com/osrg/ryu/blob/master/ryu/app/rest_topology.py] – for acquiring current topology.

The replies (JSON) to these queries are transformed to events and published through the broker (JSON over Kafka). The broker topic of published event is named using event source identifier and the method / message: [“micro-segment identifier”. “node identifier”. “message/method”].

[7] Registration / allocation of publisher_identifiers is managed in the framework deployment specific manner.

5.3.10.3.4 Processed events

Inferred, anomaly and combinedevents – the 'output' from inference / CEP components – are published using the event broker. The events are distributed as topic-content pairs (see event distribution layer format). The exact format for content of processed event depends on the component publishing the event.

Release 1 does not yet specify APIs for application-specific inferencing components. Some APIs will be specified in Release 2 (when the inferencing components are implemented).[8]

5.3.10.3.5 Event processing rules and user interfaces

Different components can subscribe and process events. Technology planned for the reference implementation is Apache Spark in which case Spark specific APIs [Spark] are used to define rules and models for event stream processing.

Similarly, inference components may provide user interfaces, enabling e.g. the user to configure at run time which components and parameters are used. Specification of these interfaces is outside of the scope of Release 1.

5.3.11 Examples

Each time the topology has been changed a list of all switches in the topology and configuration of added / removed switch will be published through a Kafka broker. The published event information is available e.g. from Ryu-ofct application from where it can be collected and published though Kafka. In this case, the kafka topic of the switch configuration is [<micro-segment_identifier>.ryu.app.ofctl_rest.stats.desc.dpid] and the content is JSON (that is structured as described inryu.app.ofctl_rest – "/stats/desc/<dpid>"). For example:

```
{
"1":{
"mfr_desc":"Manufacturer, Inc.",
"hw_desc":"Open vSwitch",
"sw_desc":"1.2.3",
"serial_num":"123456789",
"dp_desc":"Human readable description of datapath"
}
}
```

Flow statistic events, collected from switches, can follow e.g. NetFlow protocol and be published using a topic [<micro-segment_identifier>. netflow.<dpid>.<params>]. Collected data can contain e.g. statistics on flows between particular destinations, like:

```
Src IP addr.| Dst IP addr. | Next Hop addr. | Packet | Bytes
195.144.1.22 | 10.2.15.254 | 192.168.1.1 | 234 | 234252
```

The event information are processed in Spark-based components, which subscribe events through Kafka broker (see [Spark_streaming_guide] and [Spark&Kafka_guide]). The *simplified* examples below illustrate some essential functions that may be useful for monitoring:

1) attaching Kafka events to spark's stream abstraction (called DStream) using Spark's KafkaUtils:

```
kafkatopic = "micro-segment1.switch1.eventname"
```

[8]Prominent interfaces to be studied and utilized when applicable include formats defined in 'Generic Collector Interface' (T3.4. enabler).

```
eventstream = KafkaUtils.createStream(…kafkatopic…)
```

2) parsing / transforming events using map() and reduce():

```
transformedstream = eventstream.map(parsefunc…).reduce(transformfunc…)
```

3) learning a model of normal behaviour (using Spark MLlib's K-means clustering algorithm and some previously collected reference data) and then finding distance of new data point to the closest cluster (a long distance indicating an anomaly):

```
model = StreamingKMeans(…).setRandomCenters(…)
clusters=KMeans.train(trainingData…)
distance = clusters.computeCost(transformedstream)
```

4) publishing anomaly event using Kafka producer API [Kafka_API]:

```
Producer<String, String> producer = new KafkaProducer<>(properties);
producer.send(new
ProducerRecord<String,String>("anomaly_detector.anomaly1","anomaly",
"eventdetails");
producer.close();
```

5.3.12 Re-utilised Technologies/Specifications

The reference implementation of the framework will be based on Apache Kafka [Kafka] for event distribution. We also plan to use Apache Spark [Spark] for event processing. For short-term history data, Kafka's capability to store short term history data may be utilized. Hadoop which integrates with Spark may be used as a database system to store longer term history data.

In many cases the software components may be replaced with alternative open source tools - in which case the APIs are naturally different. For instance, different information sources may be utilized and the event information may be transmitted through the broker in any format. If other event sources are used, the event subscribers (who need such information) are assumed to be able to parse the content. Also, event streams may alternatively be processed with other stream processing / CEP frameworks such as [Storm] with [Esper]. The broker may be replaced e.g. with [DDE] or FIWARE context broker [Orion]. However, by using incompatible brokers the advantages of having a common framework for distributing different events are lost.

Existing security monitoring software components - SIEM, IDS, log analysers, traffic analysers (like Snort), anomaly detectors etc. - may be integrated to the open framework. The potential of some prominent components will be studied in the forthcoming releases. For instance, potential of 'Generic Collector Interface' enabler (for delivering input on 5G functions), PulSAR (for providing security assessment inference) as well as other monitoring enablers can be evaluated.

Note: all of these extensions will be investigated for the Release R2. In Release R1, as explained in introduction, we only focus on setting in production existing enabler, over the testbed to be delivered by WP4.

5.3.13 References

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[DDE] M. Luoto, T. Rautio, T. Ojanpera, and J. Makela, “Distributed decision engine — An information management architecture for autonomic wireless networking,” in 2015 IFIP/IEEE International Symposium on Integrated Network Management (IM), 2015, pp. 713–719

5.4 Satellite Network Monitoring Open specifications

5.4.1 Preface

This section describes the open specification of the “Satellite Network Monitoring” enabler which focuses on providing pseudo real-time monitoring of logs and alarms on integrated satellite and terrestrial networks and threat detection in these systems.

The aim of this security monitoring enabler is to protect against internal and external threats coming from the heterogeneous 5G networks, to meet security requirements from the 5G-ENSURE trust model.

5.4.2 Status

“Satellite Network Monitoring” enabler features are in various states of research at this moment and there is no planned software delivery for all the features. Nevertheless, some client-side features are currently being developed in a R1 prototype as a preliminary open specification and as a proof of concept.

5.4.3 Copyright

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5.4.4 Legal notice

The Legal notice that applies to these specifications is given in Annex A.

5.4.5 Terms and definitions

This section comprises a summary of terms and definitions used during the later sections.

eNB (E-UTRAN Node B, Evolved Node B or eNodeB)	Hardware connected to the mobile network that communicates directly wirelessly with UEs
HAPS (High Altitude Pseudo-satellites)	Long-endurance aerostatic or aerodyne platforms in the lower stratosphere, above commercial aviation airspace

Indicators	Information periodically collected from the network components (hardware status, alarms…) and counters from the specific business logic (transfer rate, number of requests…). These indicators can be classified in three categories:
	• Health status:
	  o Intrusion detection
	  o Alarms scanned by network devices
	  o Excessive load
	• Configuration state:
	  o Network status (e.g. logged status, SW version…)
	  o Network configuration
	  o Credential status
	• Counters (performance indicators):
	  o Volume counters
	  o Efficiency counters

SatNO (Satellite Network Operator)	Owns and is responsible for maintaining, managing, deploying and operating the Satellite Network, i.e. leasing satellite transponders and providing the associated ground segment equipment
Smart antenna	eNB antenna with self-pointing capabilities

5.4.6 Overview

The introduction of Broadband services through the satellite is increasing significantly over the past years and is supposed to continue in that direction over the years to come. The “Satellite Network Monitoring” enabler is related to broadband telecommunication systems or telecommunication ground user segments, but may also relate to other systems.

Such as a security monitoring enabler is important because there are several 5G use cases that can only be served by satellites or for which satellites provide a more efficient solution.

Current Satellite and Terrestrial communication networks can be complemented by new HAPS or drone based services in the short future.

5.4.6.1 Target Use for R1

The enabler provides a security monitoring solution suitable for an environment of integrated satellite and terrestrial networks. It consists in:

- A client-side feature, able to collect indicators from the network component and send them to the server-side feature.
- A server-side feature, able to configure the client-side features and provide pseudo real-time monitoring of consumed indicators.

The "Satellite Network Monitoring" enabler consists of a client-side feature deployed on each network component. This client-side feature able to collect indicators from the network component and

Network components that are subject to security analysis will be identified.

5.4.6.2 Target Use for R2

The following functionalities will be described and analysed in detail in R2:

- Determine security metrics, counter measures and the mitigation level they provide.
- Server-side security analysis to detect attacks and malicious behavior: use of data analytics to response to the identified threats (e.g. notify the operator, network topology reconfiguration, …). The security level shall be configurable. Some of the threats currently identified are:
  - Attack on network components: RF interference, power or communications lines…
  - Attack on the SNM: intruding the system by hijacking, blackmailing, placing or impersonating the operator, to obtain credentials or/and gain control of the system, …
  - Denial of service: flood the network with dummy indicators to make the network unusable, preventing any useful communications with the network management system.
- Network components topology management. 4G backhaul networks are fixed topologies, therefore the network barely manages accidental/deliberate congestion or link failures. In addition to the security monitoring focus, this enabler will research a dynamic solution, based on satellite links and smart antennas, enabling topology reconfiguration according to traffic demands (ultra-reliable Use Case 8.1 from D2.1).

This security monitoring enabler should improve the security of operators/users, while maintaining or increasing the level of productivity. One of the challenges is the definition of the KPIs that demonstrate such improvements.

5.4.7 Basic concepts

The infrastructure for building the Satellite Access & Transport Networks comprises the following components (see Figure 58):

- Satellite Hub: satellite earth station connected to the 5G network.
- eNBs and Satellite-capable eNBs: (traditional eNB improved with a satellite link).
- Different UEs:
  - Satellite Terminals (Ka band): satellite terminal with a Ka band antenna.
  - Satellite Modems: end-user satellite terminal connected to a satellite antenna using a communications satellite as a relay.
- 5G devices.

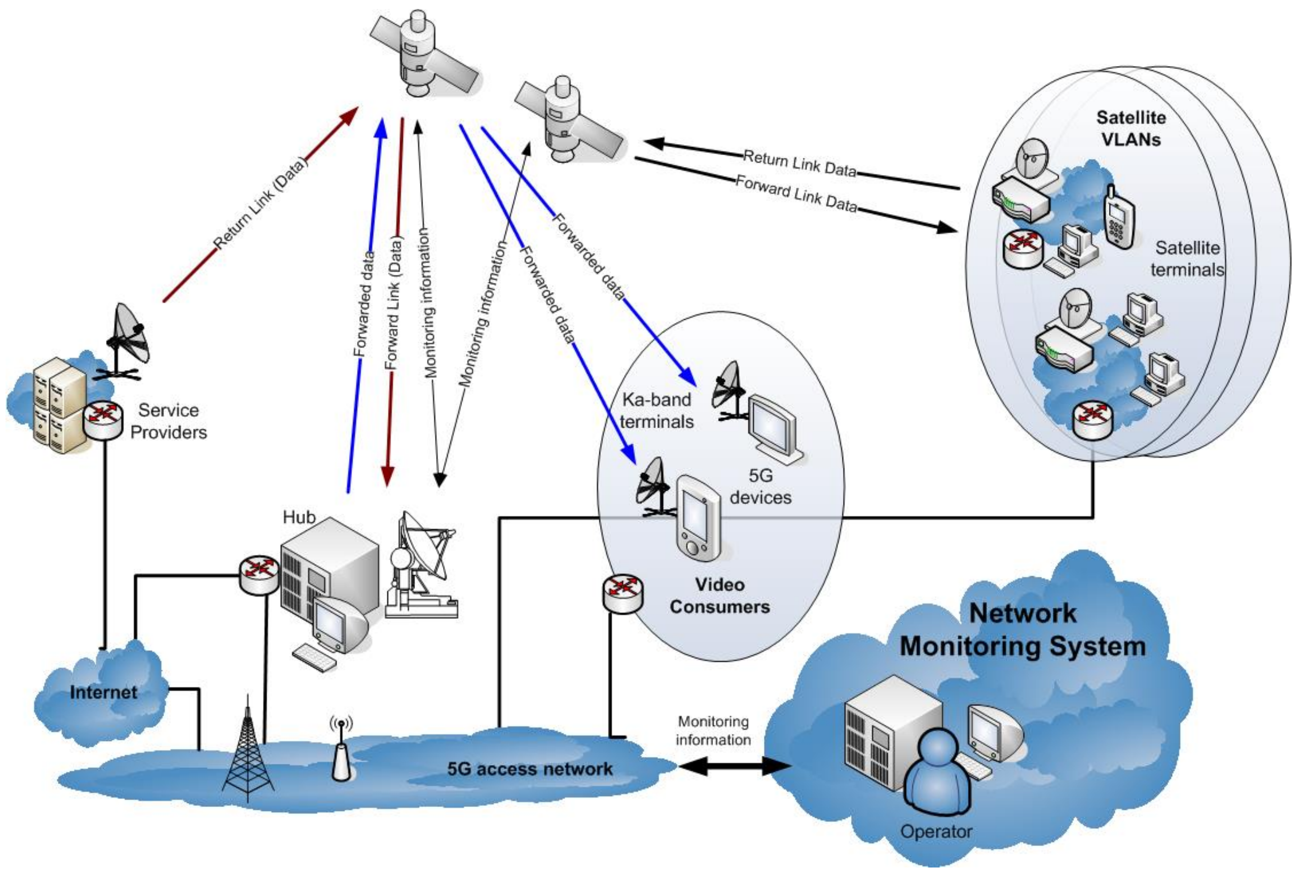

Figure 58: Satellite Access & Transport Network

These components are distributed in a wide-area. Satellite support ensures high network availability and service reliability with a 100% geographic coverage.

5.4.8 Main interactions

5.4.8.1 Use cases

This enabler covers the use case 5.6 “Integrated Satellite and Terrestrial Systems Monitor” and use case 8.1 “Satellite-Capable eNB” defined in D2.1.

Actors in the use cases are the following:

- Network components: satellite terminals, Hub, eNBs…
- Satellite Network operator.

5.4.8.1.1 Collect indicators (client-side feature)

The client-side feature periodically collects security and status indicators from the network components and from the specific business logic and produces a message.

5.4.8.1.2 Network Topology Management (server-side feature)

The server-side feature monitors the indicators collected. In the event of a link failure or congestion, the topology algorithm produces the optimal topology and reconfigure the network components. This use case is provided as an example of data analytics and server-side response to security events in the network.

This use case focuses on evolving the Transport Network Architecture (TNA) by combining both satellite and terrestrial transport architectures. The main goal is the ability to offer resilience to cases of link failure and to provide offloading capability via satellite to the backhaul network in case of congestion.

5.4.8.2 Components and interaction overview

The "Satellite Network Monitoring" enabler consists of two main features:

- Security Network Agent (SNA): periodically collects indicators from the network components and from the specific business logic. The "Generic Collector Interface" enabler will be analysed in order to be used as part of this building block.
- Security Network Manager (SNM): consumes such indicators to monitor the system status (e.g. fault management, performance monitoring) and is in charge of carrying out security analysis to detect attacks and malicious behaviour.

B/OSS (Business and Operational Support Systems) is an external system that receives such indicators and is in charge of service provisioning, network configuration and billing.

5.4.8.2.1 Collect indicators (client-side feature)

NOTE: The network component shall be registered in the server and their credentials shall be periodically updated. The "Fine-grained authorization" enabler will be analysed in order to be used as part of this building block.

1. The SatNO configure the indicators to be collected in the network component.
2. The SNA collects the configured indicators.
3. The SNA produces a message with this information.

5.4.8.2.2 Network Topology Failure / Congestion

1. The SNM detects a link failure / congestion.
2. The Network Topology model is updated.
3. The Topology algorithm produces the optimal topology to guarantee QoS, especially in ultra-reliable services:
    a. Some dynamic beans may be switch on.
    b. Some satellite links may be switch on with the EPC.
4. The new topology is forwarded to the network components.

5.4.8.2.3 Security analysis (R2 server-side feature)

1. SNM performs security analysis on the indicators received:
    a. to detect attacks
    b. to detect malicious behaviour
2. SNM automatically responds based on the configured counter measures or require a response from the SatNO.

5.4.9 Architectural drivers

The enabler shall provide a method for flexible definition of the access control policies.

5.4.9.1 High-Level functional requirements

The high-level functional requirements are:

- The SNA shall be identified

- The SNA shall be registered in the SNM
- The SNA credentials shall be periodically updated
- The SNM shall configure the indicators to be collected by the SNA
- The SNA shall collect the configured indicators
- The SNA shall send the collected indicators to the configured SNM
- The SNM shall consume the indicators
- The indicators shall be used in the SNM to monitor the component status
- Network components subject to security analysis shall be identified

5.4.9.2 Quality attributes

Compliance with standards: JAX-RS and JMS /MQTT / Kafka Wire.

Horizontal scalability: the enabler utilizes a message broker (observer pattern) to enable new collecting agents and consumer managers to be added.

Performance in terms of high-throughput messages.

5.4.9.3 Technical constraints

Main features are scheduled for R2 and are currently in a research phase, thus there are no main technical constraints at this stage.

The amount of data that needs to be analysed at pseudo real-time may be large and heterogeneous. Two complementary approaches will be analysed:

- Partitioning the network into virtual private networks might be an efficient solution, so that each segment is managed separately and appropriate solutions are tailored to each partition.
- Use a scalable and high-throughput distributed messaging system (e.g. Apache Kafka).

Nevertheless, some client-side features (see section 5.4.10.3) are currently being developed in a R1 prototype as a preliminary open specification:

- The client device needs to be capable of running an application server compliant with JAX-RS.
- The message broker shall be compliant with JMS / MQTT / Kafka Wire

5.4.9.4 Business constraints

No known business constraint exists.

5.4.10 Detailed specifications

5.4.10.1 Introduction

This specification defines the “Satellite Security ” API, which provides pseudo real-time security monitoring on integrated satellite and terrestrial networks.

The client-side API follows the RESTful and messaging system design principles.

5.4.10.2 Conformance

An implementation that conforms to this open specification shall implement fully the architecture described.

All the interfaces described are mandatory and must be implemented in order to be compliant with.

5.4.10.3 API specifications

"Satellite Network Monitoring" enabler is under research. Nevertheless, some client-side features are currently being developed in a R1 prototype. Below is a preliminary API specification of the enabler.

5.4.10.3.1 Indicators configuration

Configure the indicators to be collected in the network element

Request:

- Method: POST
- URI: /sna/resource/indicators
- Content-type: application/json
- Body: Indicators to be collected [indicatorType]

Response:

- HTTP status code:
  - 201 when success
  - 400 when error
- Body: None

5.4.10.3.2 Network configuration

Configure the network element

Request:

- Method: POST
- URI: /sna/resource/topology
- Content-type: application/json
- Body: Topology to be used [{interfaceName,interfaceStatus:[on/off]}]

Response:

- HTTP status code:
  - 201 when success
  - 400 when error
- Body: None

5.4.10.3.3 Produce a message

Send an indicator to the message broker

- Method: JMS/ MQTT / Kafka Wire
- topic: "resource-indicators"
- Content-type: application/json
- Body: Collected indicator {indicatorType,[indicatorKey,indicatorValue]}

5.4.10.4 Examples

5.4.11 Re-utilised Technologies/Specifications

The "Satellite Network Monitoring" enabler client-side is based on RESTful and messaging system design principles. The technologies and specifications used in this enabler are:

- HTTP/1.1
- Java API for RESTful Web Services - JAX-RS 2.0
- JSON and/or XML data serialization formats
- Apache Active MQ/Kafka as message broker (JMS 1.1 / MQTT 3.1 / Kafka Wire)
- JIRA issue tracking product
- SVN software versioning and revision control system
- Git software version control system
- Melody Advance system engineering modelling tool
- Thales Control continuous integration tool based on Jenkins and Sonar

The "Satellite Network Monitoring" enabler server-side technologies/specifications will be described in detail in R2.

5.4.12 References

[D2.1] 5G-Ensure Consortium, Deliverable 2.1 Use Cases. Available online at http://www.5gensure.eu/sites/default/files/Deliverables/5G-ENSURE_D2.1-UseCases.pdf.

[D3.1] 5G-Ensure Consortium, Deliverable 3.1 5G-PPP security enablers technical roadmap. Available online at http://www.5gensure.eu/sites/default/files/Deliverables/5G-ENSURE_D2.1-UseCases.pdf.

[TR 101 984]Standard: ETSI - TR 101 984 "SatelliteEarth Stations and Systems (SES); Broadband Satellite Multimedia (BSM); Services and Architectures"

[TR 22.891] 3GPP TR 22.891, "3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Feasibility Study on New Services and Markets Technology Enablers; Stage 1 (Release 14)", v1.0.0, September 2015.

Section 5.3
Section 5.20
Section 5.22
Section 5.72

[5G Vision] 5G vision: the next generation of communication networks and services, The 5G Infrastructure Public Private Partnership, February 2015, www.5g-ppp.eu.

[NGMN WP] "NGMN 5G WHITE PAPER", a Deliverable by NGMN Alliance, 17th of February 2015.

[SatCOM] "The role of satellites in 5G", a white paper from the NetWorld2020's – SatCom WG, published 31st July 2014.

5.5 System Security State Repository

5.5.1 Preface

This enabler consumes monitoring events from the Generic Collector enabler to provide security information about a runtime system. It uses the same technologies and models as the Trust Builder enabler described above.

5.5.2 Status

The model and the software to use the model are both currently being developed.

5.5.3 Copyright

5.5.4 Legal notice

The Legal notice that applies to these specifications is given in Annex A.

5.5.5 Terms and definitions

Core Model – the core ontology, defining common vocabulary and relationships used in all higher level models.

Generic Model – an ontology defining the typology of Assets, Threats and Controls (security measures) for a given domain (e.g. 5G networks). In release R1, this will cover only Assets and some types of Controls.

Design-Time System Model – an abstract model of a particular system, described in terms of the relationships between system specific Asset classes. The design time model can then be enriched by specifying which security Controls should be used to protect each type of system asset, and auto-generating a set of system-specific Threat classes describing potential threats to the system.

Runtime System Model – a model using instances of the Assets, Threats and Controls to describe what is known about the current state of an existing system.

5.5.6 Overview

The purpose of the System Security State Repository is to capture the state of an instantiated 5G network (or portion thereof) in terms of Assets, their relationships and Controls and compare it with a Design-Time System Model created in the Trust Builder enabler. The comparison reveals whether the instantiated network conforms to the Design-Time System Model and whether there are any missing controls and potential threats.

For release one, the technical roadmap specifies that the “deployment model ontology” will be created. This is equivalent to the development of the Generic Model and any updates to the Core Model already described in Trust Builder sections 4.1.7.2 and 4.1.7.1 respectively.

5.5.7 Basic concepts

The Secure System State Repository will create and update a dynamic Runtime System Model based on monitoring data. For release one, just the capability of creating the Runtime System Model is required.

5.5.7.1 The Runtime System Model

A Runtime System Model contains instances of the subclasses defined in a specific Design-Time System Model (as described in section 4.1.7.3). It is created using two sources of information:

1. some Assets, their relations and Controls are added by hand to boot-strap the model;
2. information from monitoring systems is interpreted to determine what other Assets, relationships and Controls are present and incrementally update the model with observed events.

The Runtime System Model can then be examined to understand the Threats to the runtime system.

5.5.8 Main interactions

The model will be updated and queried by software to be defined in R2.

5.5.9 Architectural drivers

5.5.9.1 High-Level functional requirements

The ontology will describe the assets, threats and controls of the 5G domain.

5.5.9.2 Quality attributes

Key entities will be annotated with RDF comment descriptions.

5.5.9.3 Technical constraints

The ontology will be valid RDF.

5.5.9.4 Business constraints

No business constraints.

5.5.10 Detailed specifications

5.5.10.1 Introduction

The R1 release of this enabler is unique in that it does not represent a piece of software: it is an ontology that will be used by the software to be created for the R2 release of this enabler. The ontology will use instances of classes defined in the Generic and Core models (also ontologies) as described in the Trust Builder enabler specification. As such it is specified by those ontologies which are themselves in the process of being defined for R1 and thus there is no detailed specification for this enabler in R1.

5.5.10.2 Conformance

For an implementation to be conformant it should implement specifications as stated herein.

5.5.10.3 API specifications

Release one of this enabler does not have an API as it is an ontology rather than software. Release two of this enabler will include software providing an API to update and query the model and this API will be specified at that point.

5.5.11 Re-utilised Technologies/Specifications

This enabler builds on the Secure System Designer software from the OPTET project [1].

5.5.12 References

[1] OPTET Project: www.optet.eu

6 Network management and virtualisation isolation enablers open specifications

6.1 Access control mechanisms enabler: open specification

6.1.1 Preface

In 5G, a much stronger adoption of software-defined networking (SDN) is expected than in current mobile networks. It is also expected that various network applications will run at the network's control plane on top of the controller. These applications will manage the network's data plane and offer a wide range of network services. Examples of such applications are routing applications, load balancer, and monitoring and analysis tools for network traffic. The diversity of network applications and their large-scale deployment actually applies to SDN in general. The network applications, however, might not be trusted by the network operator. Reasons for this are: (1) they might be from different network tenants or service providers, (2) they might be developed by third parties, or (3) they might contain bugs—as any complex software—and the control plane is therefore vulnerable to various kinds of attacks. Note that even if the network applications run in separate virtualized networks or network slices, they still indirectly access the same physical network resources.

6.1.2 Status

A prototype of the enabler is currently developed; the specification of the enabler is a preliminary one.

6.1.3 Copyright

The enabler is owned by NEC. NEC is currently the only contributor to this enabler.

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6.1.4 Legal notice

The Legal Notice that applies to this specification is given in Annex A.

6.1.5 Terms and definitions

ONF	Open Networking Foundation
OpenFlow	Protocol standardized by the Open Networking Foundation (ONF) for controller-switch communication.
SBI	Southbound Interface
SDN	Software-Define Networking
NBI	Northbound Interface

6.1.6 Overview

Current SDN controllers fall short in restricting the access of network applications to network resources. The security enabler of this section applies the principle of least privilege to the network applications, that is, the enabler enforces that each network application must be able to only access the information and resources that are necessary for performing its tasks. To this end, a reference monitor is added to the network's control plane as a component of an SDN controller. The reference monitor permits and denies access to network resources according to a given access control policy. In particular, the reference monitor targets the controller's southbound interface, i.e., it restricts the OpenFlow messages a network application can send to and receive from the components at the network's data plane.

6.1.7 Basic concepts

SDN separates the control plane from the data plane. The control plane comprises a (logically centralized) controller. It interacts via its southbound interface (SBI) with the data plane components (e.g., switches). The most widely used SBI is the OpenFlow protocol [McKeown et al., 2008]. On top of a controller run network applications. Examples of such applications are network traffic routing applications and network monitoring applications. A network application indirectly accesses the data plane components by interacting with a controller's northbound interface.

An access control policy stipulates which subjects (e.g., the network applications) can access which objects (e.g., the switches) and how. A reference monitor enforces a given access control policy, i.e., it permits or denies an access request. For example, a reference monitor denies a network monitoring application to modify the flow rules of a switch, while reading the counters' of the flow rules are permitted.

6.1.8 Main interactions

6.1.8.1 Use cases

Widely used APIs and the resulting deployment of various third-party applications pose new security threats in SDN. Indeed, "malicious" network applications can leverage such an API and infiltrate the network. These threats become even more evident when the network owner "leases" network slices, which are administrated by the leasing tenants, which in turn might install their own, possibly third-party, network applications on top of the network owner's controller. Since the leasing tenants might have competing objectives, access to the shared network resources must be appropriately handled and secured. Cf. the use case 5.2 of [Deliverable 2.1, 2016].

Note that by using network virtualization the network owner can provide an isolated view on the network to each leasing tenant. However, the different tenants still share the data plane's network resources, which they indirectly access whenever they access one of their virtual network components. Furthermore, accessing a virtual component might result in accessing several data plane components, e.g., when a virtual component comprises multiple components of the data plane as in the "one-big-switch" abstraction. The access translation can be non-trivial and the controller's compiler implementing the translation might be incorrect because of software bugs or controller misconfigurations. This in turn can lead to incorrect updates of the switches' forwarding logic and such vulnerabilities of the controller can be exploited to launch attacks to the network.

Enhancing the network owner's controller (i.e., the controller that directly interacts with the network components at the physical data plane) with a mechanisms that control and restrict the access of the network users (i.e., the network owner and the leasing tenants) and the applications to the network components at the data plane would reduce the network's attack surface and protect the network resources. This enabler adds a reference monitor—similar as in an operating system [Anderson, 1973]—as an additional controller component.

6.1.8.2 Components and interaction overview

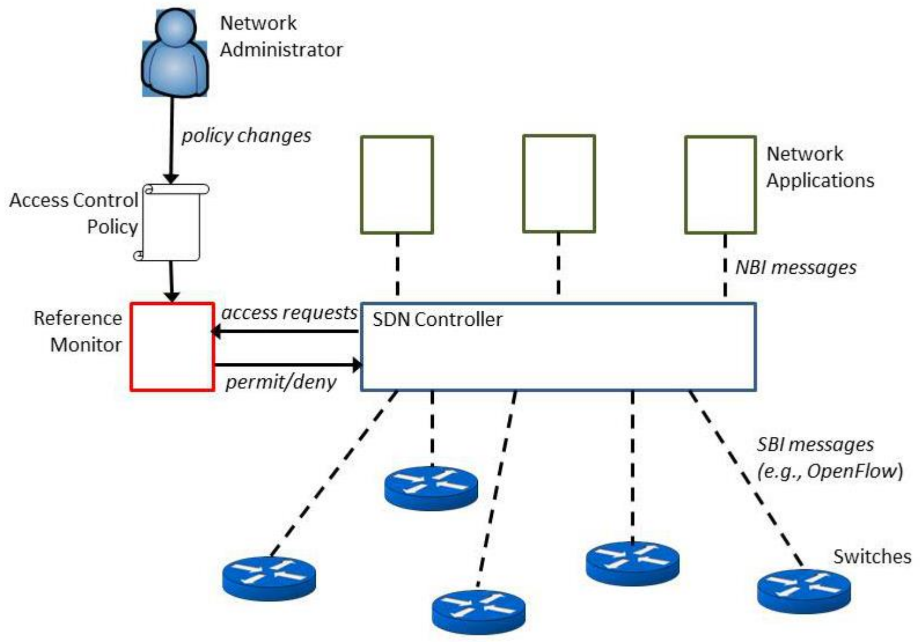

Figure 59: Components and their interactions

The main component of the enabler is the reference monitor. Its inputs are an access control policy and access requests. For each access request it outputs a permit or deny. See Figure 59 for illustration.

The access requests are initiated by network events. For example, a network application requests to install new flow rules in a switch, or a switch receives a network packet that does not match any of its flow rules and is thus forwarded to the controller. In the first case, the controller requests to send OpenFlow messages of the type OFPT_FLOW_MOD to a switch, which, e.g., originate from a NBI message send from a network application to the controller. In the second case, the controller receives an OpenFlow message of the type OFPT_PACKET_IN from a switch and requests to forward the message to a network application.

The decisions of the reference monitor are according to the given access control policy. The network administrator can make changes to this policy. The network applications can also make policy changes. However, their changes are limited and only concern the objects that they own. For example, a network application A can allow another network application B to read the counters of a flow rule that A owns (i.e., created).

6.1.9 Architectural drivers

6.1.9.1 High-level functional requirements

The reference monitor must check for each access request whether the access is compliant according to a given access control policy. That is, it must either permit or deny an access. The decision must be according to the given access control policy.

6.1.9.2 Quality attributes

The overhead for the SDN controller of including a reference monitor must be low. In particular, the reference monitor must not significantly decrease the controller’s performance. This means, the reference monitor must efficiently decide whether a requested access is permitted or denied with respect to the given access control policy. Furthermore, the reference monitor should be tamper proofed and verifiable.

6.1.9.3 Technical constraints

The enabler must be integrated as a separate component to the SDN controller. The reference monitor must be invoked by the controller on every OpenFlow message that is sent to the control plane and that is received from the control plane.

6.1.9.4 Business constraints

There are no business constraints for this enabler.

6.1.10 Detailed specifications

6.1.10.1 Introduction

The enabler is “SDN generic,” i.e., the reference monitor is a component of an SDN controller. In the first release, we opted for access control mechanisms (access control policies and reference monitor) that are simple, focused, and close to the SBI of the controller, which interfaces directly with the switches using the OpenFlow protocol. The rationale behind this design decision is as follows. First, it supports one to build a tamperproof and verifiable reference monitor. This is based on the scheme’s simplicity and since it is focused. Furthermore, since the controller only communicates via OpenFlow messages with the switches, we obtain complete mediation by permitting or denying OpenFlow messages by the reference monitor before they are sent. These are essential principles for a reference monitor [Anderson, 1973].

Rendering the reference monitor tamperproof from the applications running on top of the controller can be achieved by simple OS-level techniques (different process, different user). Note that the reference monitor is a separated component. Increased isolation can be achieved by using containers or VM separation. However, the increased isolation might not justify the performance degradation due to additional context switches, system calls, and so on.

We expect that future NBIs in SDN will support multiple different abstractions of the network at the control plane. Any such interface will be built on top of the interface provided by OpenFlow, which directly interacts with the network components. Access control at higher layers will utilize our access control scheme and complement it.

In the following, we specify the reference monitor’s input in more detail.

6.1.10.2 Conformance

An implementation to be reported as conformant should comply with the open specification here stated for the enabler.

6.1.10.3 API specifications

*Methods.*In order for the reference monitor to check that the SBI traffic conforms to the policy, it needs to be hooked on all calls delivering messages to or from the switches.

When a message arrives from the switch, the following method should be called:

```
Boolean RequestReceiving(Switch src, Application dst, OpenFlowMessage msg)
```

where src indicates the source switch from which the message originates from, dst is the application to which the controller intends to distribute the message, and msg is the OpenFlow message itself. As is the case for other information coming from the controller's NIB, it is assumed that the controller already authenticated the information. For example, in the case of switch source, the controller guarantees the authenticity of the switches and TLS can be used for the OpenFlow communication between the controller and the switches.

To avoid bypassing the reference monitor, the controller has to cover all possible delivery scenarios. This might include direct relay to a specific application for a certain message type (e.g., link discovery messages go to an LLDP application), a pipeline in which all applications read the message sequentially or a store in which subscribed applications are notified. These and any other means of delivering messages to the application have to be instrumented such that the RequestReceiving hook is called.

After evaluating the message, source and destination against the policy, the method returns a Boolean value, where true means that receiving the message is permitted and false means that receiving the message is denied. To address in the future more complex scenarios, a binary permit/deny decision might not be enough. In particular, in multitenant networks where multiple policies have to be composed, the decision of a reference monitor could also be "don't know," a third truth value. Furthermore, in addition to the reference monitor's decision, the reference monitor could return information explaining its decision. In particular, when denying the request, such information can be helpful for the source. However, such extensions are currently not considered for the enabler.

In the other direction, before sending messages to the switches the following method should be first called:

```
Boolean RequestSending(Application src, Switch dst, OpenFlowMessage msg)
```

where src is the originating application, dst is the affected switch, and msg is the OpenFlow message.

Similar to delivering messages to applications, sending messages to switches must cover all check points in the controller to avoid bypassing the reference monitor.

As for the method RequestReceiving, RequestSending's return value specifies whether the sending request is policy compliant (true) or noncompliant (false).

In order to support dynamic policy changes, the following method allows the administrator to modify or replace the policy:

```
Boolean UpdatePolicy(Policy pol)
```

where pol is either an entirely new policy replacing the old one or a fragment that is incorporated in the existing policy to extend, restrict or otherwise modify the behaviour. If the method's return value is true, the update was successfully applied and new requests will be processed according to the new policy. Otherwise, there was an error applying the new policy.

A separate method might be used by applications to refine the policy concerning resources that they own:

```
Boolean UpdateAppPolicy(Application app, Policy pol)
```

where app is the application wishing to extend or restrict how other applications might interact with resources it owns (i.e.: give read only access to counters of flows that it installed).

*Messages.*The messages that are permitted or denied to transit the SBI correspond to OpenFlow messages. Depending on the controller, they might be decorated with additional fields. The kinds of fields likely to be used in a policy include but are not limited to:

- DPID – switch identifier (Data Path ID),
- ingress port – the port on which the message was received,
- source – e.g., MAC or IP address of the source,
- destination – e.g., MAC or IP address of the destination, and
- flow entry – the entry to modify in case of a flow mod.

The available fields depend on the message type (e.g., OFPT_PACKET_IN for a message received by an application and OFPT_FLOW_MOD for a message sent by an application). Apart from the information about encapsulated layers (e.g., IP address or TCP port) that the controller extracts when it deserializes an OpenFlow message, other network information can be used inside policies. Controllers regularly collect facts about links, switches, and other network resources that they store in a network information base (NIB). The NIB can be augmented with an *ownership tag* that can be used by applications to delegate permissions (see UpdateAppPolicy method). Depending on the expressiveness of the policy, other tags could be associated with resources stored in the NIB. When communicating with the reference monitor, this extra information could be part of the OpenFlow message object or it could be passed as an additional context parameter.

6.1.11 Re-utilised technologies/specifications

The reference monitor will be integrated into the ONOS controller [Berde et al., 2014]. Some of the concepts of this enabler have been described by Klaedtke et al. [2014] and [2015].

6.1.12 References

[1] 5G-Ensure Consortium, Deliverable 2.1 Use Cases, [Online]. Available: http://www.5gensure.eu/sites/default/files/Deliverables/5G-ENSURE_D2.1-UseCases.pdf, 2016.

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[8] Open Networking Foundation (ONF). OpenFlow switch specification – version 1.3.0 (wire protocol 0x04). 2012.

6.2 Interaction audits enabler: open specification

6.2.1 Preface

Networks comprise multiple components, e.g., endhosts and switches, and a controller in case of an SDN network. Policies specify how these components must and must not behave. There is a wide spectrum of policies, targeting various aspects of a network like correctness, performance, quality of service, reliability, and security. Detecting noncompliant behavior of components with respect to a given policy is an important task to ensure the correct and safe operation of a network. In particular, in a network in which physical and virtual components are managed by different tenants (e.g., a network with multiple network or service providers), the detection of noncompliant behavior of a component is a major concern for the network operator. It helps the operator to protect the network, e.g., against misbehaving components and misconfigurations.

6.2.2 Status

A prototype of the enabler is currently developed; the specification of the enabler is a preliminary one.

6.2.3 Copyright

The enabler is owned by NEC. NEC is currently the only contributor to this enabler.

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6.2.4 Legal notice

The Legal Notice that applies to this specification is given in Annex A.

6.2.5 Terms and definitions

NTP	Network Time Protocol
ONF	Open Networking Foundation
OpenFlow	Protocol standardized by the Open Networking Foundation (ONF) for controller-switch communication.
SDN	Software-Define Networking

6.2.6 Overview

The scope of the enabler is to check the interactions between network components against a given policy, which specifies how components must and must not interact with each other. The checking can be done online, i.e., while the components are running, or offline during an audit. The enabler supports a rich formally defined specification language for expressing a large variety of policies. It is not in the scope of the enabler to perform corrective actions in case the network components interactions are not policy compliant.

6.2.7 Basic concepts

A *policy* is an informal or formal document consisting of rules that stipulate, for instance, when performing an action is allowed and who is allowed to perform the action. A (*policy) violation* is a behavior that violates one of the policy rules. A behavior is *(policy) compliant* if no rule of the given policy is violated by the behavior.

A *(network) component* is an entity of a system (network) that performs actions. For example, a switch processes network packets and forwards packets to ports. Components usually *interact* with each other. The interaction is according to a given protocol and usually asynchronous. For example, the controller of an

SDN network interacts with the switches by sending and receiving OpenFlow messages [McKeown et al., 2008]. Note that a controller can be composed out of several smaller components, which again interact with each other. It depends on the given policy on which abstraction level the system is considered.

A *compliance checker* monitors the components, in particular, their performed actions. With respect to a given policy, it reports compliant and noncompliant behavior by outputting verdicts, e.g., explaining when the policy was violated and which action caused the violation.

6.2.8 Main interactions

6.2.8.1 Use cases

One use case of this enabler is to increase the resilience of the network. For this, the network administrator deploys the compliance checker into the network. Furthermore, he instruments some of the network components such that they send messages describing their performed actions to the compliance monitor. A policy specifies how these components should behave, e.g., how they must and must not react to certain network events. Whenever the policy is violated, the network administrator is notified by the compliance checker and can take countermeasures against this noncompliant behavior. Policy violations can for example be caused by a wrongly configured component or a malicious component. Cf. the use case 5.2 of [Deliverable 2.1, 2016].

Another use case is where the network administrator deploys a new component to the network. Similar to the first use case, the performed actions of this new component are checked against a policy and noncompliant behavior is detected and reported to the network administrator. For instance, a new component might behave not as intended because of a software bug or a misconfiguration, which are then detected by the compliance checker. Note that buggy software and misconfigurations might make the network vulnerable to attacks. Cf. the use case 5.4 of [Deliverable 2.1, 2016].

6.2.8.2 Components and interaction overview

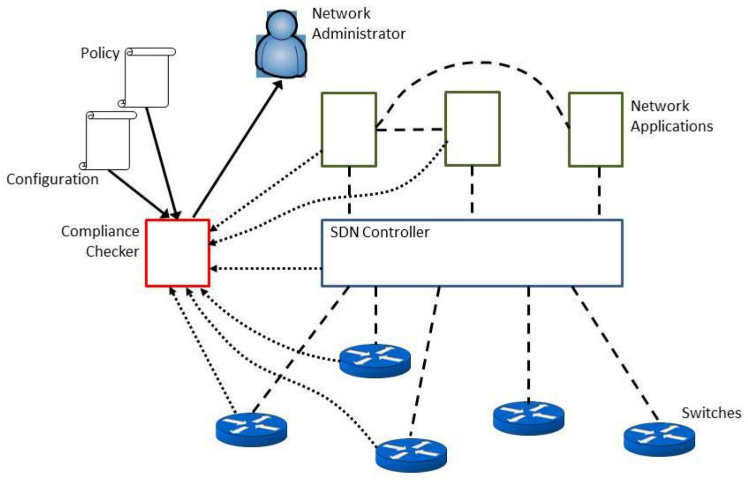

Figure 60: Components and their interactions

Figure 60 provides an overview of the involved components and illustrates with whom the enabler interact and how. Recall that a switches, controllers, and network applications are network components. Note that this list is not exclusive. Furthermore, note that the network components interact with each other. For example, in an SDN network, the controller sends OpenFlow messages to the switches. An OpenFlow message can, e.g., be initiated by a network application. The main component of the enabler is the compliance checker. The interactions between the network components are illustrated in Figure 60 by the dashed lines.

In the following, we explain the compliance checker's input and output in more detail. The inputs to the compliance checker are of two kinds. In Figure 60, they are illustrated as solid and dotted ingoing arrows.

- The first kind of input (the solid ingoing arrows in Figure 60) is static and provided by the start of the compliance checker. These inputs are the policy and the configuration. The configuration describes the network components that should be monitored and the format of the messages that describe the components' performed actions. The policy specifies the interactions between the network components that are allowed.
- The second kind of input (the dotted ingoing arrows in Figure 60) are the messages from the network components that describe their performed actions. When using the compliance checker online, the monitored networks components send messages describing their performed actions to the compliance checker. Note that when using the compliance checker offline, these messages are logged (either directly by the component or by a log server) and the obtained logs are, e.g., merged and processed by the compliance checker during an audit.

The output of the compliance checker are verdicts. They are sent to the network administrator, or some other entity, which may want to take corrective actions when the given policy is violated. These corrective actions, which are not in the enabler's scope, may depend on the frequency a policy is violated. The enabler's focus is on detecting policy violations. Note that verdicts are sent while the compliance checker processes the messages from the network components.

We remark that the network components are distributed, the components act concurrently, and the communication between the components is asynchronous. When using the compliance checker online, it can be seen as yet another network component, which receives and processes messages from other components. The messages that are sent to the compliance checker can arrive at any order. Furthermore, components can crash, including the compliance checker, and recover later.

Furthermore, we remark that the current version of the enabler assumes that: (1) messages are not tampered with, and (2) components correctly report their actions and do not send bogus messages. The first assumption can be easily discharged by adding information to each message such as a cryptographic hash value, which is checked by the compliance checker when receiving the message. To discharge the second assumption additional mechanisms need to be deployed. For example, a message contains a timestamp when the action is performed. To ensure the correctness of the timestamp a trustworthy clock must be used that signs the timestamp. The compliance checker can then check the validity of a timestamp by checking its signature. For ensuring that a reported action was performed or a non-reported action did not take place, one could deploy additional monitors or "traps" that check this. Such monitors or "traps" are, however, action and component dependent and not in the scope of the current version of the enabler.

6.2.9 Architectural drivers

6.2.9.1 High-level functional requirements

Policies are formally specified as formulas of a temporal logic. The main functionality of this enabler is to monitor network components, in particular, their performed actions, and detect and report all the performed actions that are noncompliant with respect to the given policy. The enabler's output, i.e., the verdicts it outputs should be sound and complete. Soundness means here that the enabler only outputs verdicts that correspond to policy violations. Completeness means here that the enabler outputs a verdict for every policy violation.

Note that the enabler might not have complete knowledge about all the performed actions. For example, the performed action has not yet been received by the monitor due to message loss. In this case, the enabler should not output any verdict.

6.2.9.2 Quality attributes

When using the compliance checker online, it should be capable of processing the received messages at the speed of the network that performs these actions. That is, the compliance checker's throughput of processing messages should be most of the time has high as the number of the (policy-relevant) actions that are performed by the network components. Otherwise, the compliance checker would lag behind and output verdicts late. Note that the compliance checker can store unprocessed messages in a queue in case it receives many messages in a short time. In this case, it might lag behind of outputting verdicts for some time. However, this should only rarely happen and the compliance checker should quickly "catch up". Even in an offline use, logs should be processed efficiently.

6.2.9.3 Technical constraints

The network components must be instrumented such that they inform the compliance checker about their actions that are policy relevant actions. For this, we require that the actions must only be performed via trustworthy subcomponents.

The format describing these actions must be standardized. The compliance checker needs to be configured appropriately. Currently, the compliance checker focuses on the network components that interact via OpenFlow messages, i.e., the interaction between switches and SDN controllers.

Furthermore, the network components need to timestamp their actions. The timestamps are used by the compliance checker to relate the received actions timewise. Because of clock drifts, the network components must synchronize their clocks regularly, e.g., by the Network Time Protocol (NTP) [Mills, 1995]. The verdicts of the compliance checker are only correct with respect to the provided timestamps.

6.2.9.4 Business constraints

There are currently no business constraints.

6.2.10 Detailed specifications

6.2.10.1 Introduction

The enabler is "SDN generic," i.e., the compliance checker is a network component at the control plane of an SDN network. It runs separately to the other control plane components (e.g., controller and network applications). The interaction with the other components is "one way." In particular, in its online use, it only receives over a socket messages from the other network components, both at the data plane and control plane. The compliance checker does not directly impact the network traffic and the network configuration. Nevertheless, it might indirectly impact the network configuration, since it outputs verdicts, on which a network administrator, e.g., can take corrective actions. In the following, we specify the compliance checker's input, and also its output, in more detail.

6.2.10.2 Conformance

An implementation to be reported as conformant should comply with the open specification here stated for the enabler.

6.2.10.3 API specifications

*Messages.*The messages that are sent to the compliance checker and describe the monitored components' performed actions must be timestamped. The timestamp of a message describes when the action was carried out. The enabler assumes the timestamp as Unix time (with integral part and a possibly fractional part). Furthermore, the message must specify the sender and a sequence number. The sequence number is the number of messages that the sender has sent so far to the compliance checker. With the sequence numbers the compliance checker can determine whether it has received all messages up to a given time. Finally, the message must describe the performed action. Overall, the fields of a message are as follows.

timestamp	sender identifier	sequence number	description of performed action

For interpreting the received messages, a configuration file must be provided to the compliance checker. This configuration file consists of rules with regular-expression matching to identify the performed action and to extract relevant data values. The first matching rule determines the interpretation of the message. One can think of these rules as an if-then-else program.

As an example, consider the rule

```
[event matches "OFPT_FLOW_MOD", event matches " \(xid=0x(?P<xid>[0-9abcdef]+)\)"]
=>
 flow_mod(<xid>)
```

for an SDN controller like Ryu. It matches a message that contains the string OFPT_FLOW_MOD and a string of the form (xid=0x*hexnumber*). The interpretation is that the controller's performed action is the sending of an OpenFlow message of the type OFPT_FLOW_MOD with the xid *hexnumber*. The specified policy, which we describe next, can refer to predicates like flow_mod. See also Section 6.2.10.4.

Policy specification language. The enabler uses a temporal logic to express and formalize policies. We refer to Alur and Henzinger [1992], Baier and Katoen [2008], and Basin et al. [2015] for background. The core grammar of the enabler's policy specification language is given by the following grammar.

spec	::=	TRUE
	|	p(x1, …, xn)
	|	(NOT *spec*)
	|	(*spec* OR *spec*)
	|	(*spec* SINCE[a,b] *spec*)
	|	(*spec* UNTIL[a,b] *spec*)
	|	(FREEZE x1[r1], …, xn[rn]. *spec*)

Here, p is a predicate symbol, x1, …, xn range over variables, a and b are nonnegative integers, and r1, …, rn range over data registers.

- TRUE specifies the trivial policy that any behavior satisfies.
- p(x1, …, xn) specifies the policy that a behavior satisfies at time t whenever in (x1, …, xn) are in the relation p at time t.
- (NOT spec) specifies the policy that a behavior satisfies whenever it does not satisfy spec.
- (spec1 OR spec2) specifies the policy that a behavior satisfies whenever it satisfies spec1 or spec2.
- (spec1 SINCE[a,b] spec2) specifies the policy that a behavior satisfies at time t whenever the behavior satisfies at some time s<=t, with a<=t-s<=b, the policy spec2, and since s, the behavior satisfies the policy spec2.
- (spec1 UNTIL[a,b] spec2) specifies the policy that a behavior satisfies at time t whenever the behavior satisfies at some time s>=t, with a<=s-t<=b, the policy spec2, and until s, the behavior satisfies the policy spec2.
- (FREEZE x1[r1], …, xn[rn]. spec) specifies the policy that a behavior satisfies at time t whenever the behavior satisfies the policy spec, where x1 to xn are assigned to the register values x1 to xn at time t.

Various additional syntactic sugar can be defined. For example, (spec1 AND spec2) abbreviates (NOT ((NOT spec1) OR (NOT spec2))). As expected, (spec1 AND spec2) specifies the policy that a behavior satisfies whenever the behavior satisfies the policy spec1 and the policy spec2. (spec1 IMPLIES spec2) is syntactic sugar for ((NOT spec1) OR spec2); its meaning is as expected. Another example is (ONCE[a,b] spec) that abbreviates (TRUE SINCE[a,b] spec). A behavior satisfies the policy (ONCE[a,b] spec) at time t whenever the behavior satisfies spec at some time s, with a<=t-s<=b.

The connectives are assigned to different binding strengths, which allow one to omit parenthesis. We use the standard conventions here. For example, NOT binds stronger than OR. By this convention, NOT spec1 OR spec2 abbreviates ((NOT spec1) OR spec2). Finally, we also allow open intervals and half-open intervals as metric temporal constrains like (a,b) and [a,b), for integers s a and b with 0<=a<b. In these two cases b could also be infinity to specify an unbounded interval. A time unit (e.g., ms, s, and m) can be attached to the numbers. If no time unit is given the numbers are interpreted as seconds.

We refer to Alur and Henzinger [1992] for details, in particular, for the underlying temporal model and the semantics of the specification language. Examples for expressing policies are given in Section 6.2.10.4.

Verdicts. The verdicts that the enabler's output specify the time when the policy is violated. Note that this time corresponds to a message that the compliance checker has received previously. Additional information can be included to a verdict, e.g., the message that caused the policy violation. The verdicts are either written to a log file or they are sent over a socket to another program.

6.2.10.4 Examples

For illustration of the use of the compliance checker in general and the policy specification language in particular, consider a setting in which an SDN network has multiple controllers. One of them is the master controller and the others are the slave controllers. The master controller is responsible for tracking the liveness of the links between adjacent switches. However, the master controller must be elected among the controllers. Such an election takes place, for example, after a reboot of a controller (e.g., because it crashed previously). The election protocol of the ONOS controller contained a flaw, which could result in the state that no controller is tracking the liveness of the network links. See Scott et al. [2014].

By monitoring the relevant actions of the two monitors for the election process, the compliance checker could detect the harmful situation when no controller would track the liveness of the network links. The following formula expresses that whenever there is a controller election then, within 1 second, one of the controllers is the master controllers.

```
ALWAYS ControllerElection() IMPLIES
   EVENTUALLY[0,1s] FREEZE c[election_outcome]. MasterController(c)
```

Note that EVENTUALLY[a,b] spec is syntactic sugar for TRUE UNTIL[a,b] spec, and ALWAYS spec is syntactic sugar for NOT EVENTUALLY[0,infinity] NOT spec.

Furthermore, note that the above formula however does not account for the case in which more than one controller is elected as the master controller, which is also an unwanted state, which could be expressed by a second formula. For example, the following formula expresses that whenever c is elected as the master controller then there are no other controllers elected as the master controller (at most 1 second before c's election).

```
ALWAYS FREEZE c[election_outcome]. MasterController(c) IMPLIES
                NOT (ONCE(0,1s] FREEZE d[election_outcome]. MasterController(d) AND d /= c)
```

The network controllers must be instrumented to send messages about their policy-relevant actions. Here, the relevant actions are (a) when a controller initiated an election of the master controller, and (b) when a controller starts acting as the master controller. In the latter case, a controller would send a message of the form

```
1461144315.2435@[ONOS:199.37.70.30] (346): start acting as master
```

where the first decimal number is the timestamp of the performed action, the text in square brackets specifies the sender, the number in parentheses is the sequence number of the sender, and the text after the double column describes the action. Such a message is interpreted by the compliance checker according to the given configuration file. For example, with the rule

```
[component matches "ONOS:(?P<election_outcome>[0-9]+\.[0-9]+\.[0-9]+\.[0-9]+)",
 event matches "start acting as master"]
=>
{MasterController(<election_outcome>)}
```

the compliance checker extracts the information that the predicate MasterController(ONOS:199.37.70.30) is true at (Unix) time 1461144315.2435 from the above message.

6.2.11 Re-utilized technologies/specifications

The compliance checker is based on an extension of the monitoring approach described by Basin et al. [2015]. The extension comprises an online algorithm that handles a richer policy specification language as described in Section 6.2.10.3, and will be described and analyzed in detail in a forthcoming paper.

6.2.12 References

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6.3 Bootstrapping Trust in SDN deployments: open specification

6.3.1 Preface

The physical infrastructure supporting 5G networks will be multiplexed among multiple tenants with own environments, similar to a cloud infrastructure model. In this model, SDN allows tenants to configure complex topologies with rich network functionality, managed by a network controller [1]. The availability of a global view of the data plane enables advanced controller capabilities – from pre-calculating optimized traffic routing to managing software applications that replace hardware middleboxes. However, these capabilities also turn the controller into a valuable attack target: once compromised, it can provide the adversary with complete control over the network [2]. Furthermore, the global view itself is security sensitive: an adversary capable of impersonating network components – such as virtual switches -- may distort the controller's view of the data plane and influence the network-wide routing policies. Virtual switches are security sensitive elements in SDN deployments. They run on commodity operating systems (OS) and are often assigned the same trust level and privileges as physical switches – specialized, hardware components with compact embedded software. Commodity OS with large code bases are likely to contain multiple security flaws which can be exploited to compromise virtual switches. For example, their configuration can be modified to disobey the protocol, breach network isolation and reroute traffic to a malicious destination or hijack other network edge elements through lateral attacks. Such risks are accentuated by the extensive control a cloud provider has over the compute, storage and networking infrastructure of its tenants.

This enabler aims to reduce the risk to the integrity of the virtual switches in the SDN deployment, as well as to the integrity and confidentiality of the communication between the virtual switches and network controller in the deployment.

6.3.2 Status

A prototype of the enabler is currently under development.

6.3.3 Copyright

The enabler is owned by SICS.

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6.3.4 Legal notice

The Legal Notice that applies to this specification is given in Annex A.

6.3.5 Terms and definitions

OpenFlow	Protocol standardized by the Open Networking Foundation (ONF) for controller-switch communication.
SDN	Software-Define Networking
TEE	Trusted Execution Environment
ISA	Instruction Set Architecture
PSK TLS	Pre-shared key Transport Layer Security
ABI	Application Binary Interface
FIB	Forwarding Information Base

6.3.6 Overview

The *Bootstrapping Trust* enabler allows to create a system where tenants can securely deploy virtual switches in trusted execution environments and set up virtualized network topologies in a cloud environment, under the adversary model described in [3]. Furthermore, the enabler allows tenants to establish trust in the topology of the SDN deployment using attestation and enrolment procedures. Thus, only virtual switch instances running in TEEs and attested by the network controller are considered enrolled in the topology of the SDN deployment.

Furthermore, following the enrolment, all communication between the network controller and the virtual switches is confidentiality and integrity protected. Such communication includes both the unmatched packets sent from the virtual switches to the network controller, as well as updates to the forwarding information base (FIB) made by the network controller. This prevents the adversary from learning the contents of the virtual switch FIB, thus preventing topology and traffic fingerprinting.

6.3.7 Basic concepts

The main principles of this enabler are presented in Figure 61 and described below.

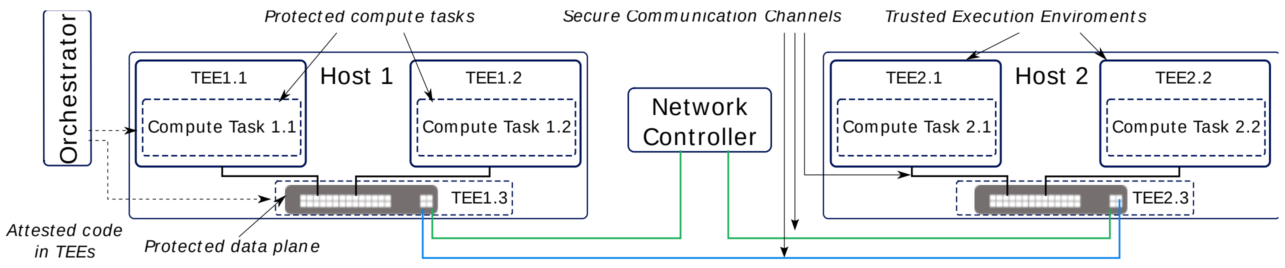

Figure 61: Principles of the Bootstrapping Trust enabler

Trusted Execution Environments (TEEs) guarantee isolated execution in the given adversary model, assuming correct implementation of the CPU and of the executed code. The TEE can be located on the same platform or on other platforms within the deployment.

Attested code in TEEs: Integrity of the code and data deployed in the TEEs is attested before any keys or key material is provisioned to the respective TEE. An orchestrator running under the control of the tenant performs the attestation of the TEE.

Protected Compute Tasks: Security sensitive compute tasks may be deployed in TEEs. In this context, such tasks include all operations – and their results – that tenants aim to protect from an untrusted cloud provider.

Protected Data Plane: Switches (partly or fully) deployed in TEEs forward traffic between compute tasks according to routing policies specified by a network administrator and compiled into discrete forwarding rules maintained in the forwarding information base.

Secure Communication Channels: The enabler protects communication channels between compute tasks, as well as communication channels between virtual switches and the network controller. Communication security is ensured using confidentiality and integrity protection keys provisioned to TEEs and only used by the authenticated network components and endpoints.

6.3.8 Main interactions

6.3.8.1 Use cases

In this section we describe two typical use cases for the "Bootstrapping trust" enabler. Use cases are described in the "fully-dressed" format [6].

ID	BT-1
Title	Attest integrity of a virtual switch in the SDN deployment
Description	Administrator obtains a quote of the virtual switch enclave code and data, verifies its authenticity and verifies that it matches the expected values.
Primary Actor	Administrator
Preconditions	Virtual switch is (partly or fully) deployed in a trusted execution environment
Postcondition	Administrator has obtained a statement of whether the enclave code and data match the expected values
Main success scenario	1. Administrator requests a quote of the virtual switch enclave 2. Virtual Switch Enclave produces the quote 3. The "Quoting Enclave" (QE) on the respective platform signs the quote and returns to the administrator. 4. Administrator verifies quote signature against the known public key of the host QE 5. Administrator matches quote against expected values for the virtual switch.
Extensions	4a1. The signature verification step shows that the quote signature is invalid. 4a2. Administrator either retries operation or excludes the virtual switch on the respective host from the list of switches in the deployment.
Frequency of Use	At each deployment of the SDN infrastructure or as required for audit purposes.
Status	Implementation on-going
Owner	SICS Swedish ICT

ID	BT-2
Title	Enrol virtual switch into SDN deployment
Description	For an attested virtual switch enclave, the orchestrator provisions the necessary key material to establish a protected communication channel with the network controller and updates the list of virtual switches in the deployment.
Primary Actor	Software Orchestrator
Preconditions	Virtual switch is (partly or fully) deployed in a TEE and its integrity has been attested
Postcondition	The virtual switch enclave has established a secure communication channel to the network controller.
Main success scenario	1. Orchestrator locates virtual switch enclave identity and its public key in the list of attested virtual switches enclaves. 2. Orchestrator generates an "enrolment message" containing necessary certificates and a pre-shared key. 3. Orchestrator confidentiality and integrity protects the "enrolment message" using the public key of the switch enclave. 4. Orchestrator provisions *enrolment message* to virtual switch enclave. 5. Virtual switch enclave uses contents of the *enrolment message* to establish a PSK TLS session with the network controller.
Extensions	None
Frequency of Use	At each deployment of the virtual switch enclave.
Status	Implementation on-going
Owner	SICS Swedish ICT

6.3.8.2 Components and interaction overview

In this section we describe the high level overview of the enabler components and their interaction.

Figure 62 illustrates the interaction between the main actors in the *Bootstrapping Trust enabler*. The subjects of the interaction are the Administrator and the Orchestrator, the signature verification service and the application fingerprint store. The subjects of the interaction are the network deployment components – the virtual switches on the hosts within the deployment and the SDN network controller. The below description follows the numbered steps illustrated in Figure 62.

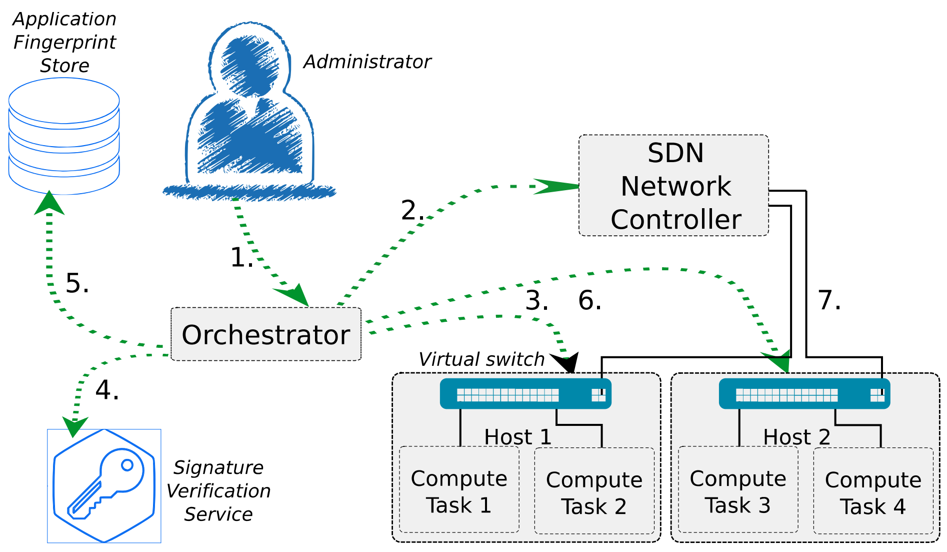

Figure 62: High-level components and interactions

In step (1), the *Administrator* initiates the deployment of the network infrastructure components, which is performed by the *Orchestrator*. Next, the orchestrator deploys (2) the *SDN network controller* (we assume that the network controller is deployed on a trusted host under the control of the administrator), as well as (3) the virtual switches on the host in the deployment. The code and data for the virtual switches, along with a bootstrap application, are first deployed on the host. Next, the bootstrap application initializes a TEE and deploys the virtual switches in the TEE.

Step (3) also includes the Orchestrator's request for a quote of the TEE. A *quoting enclave* signs the quote prior to being returning it to the Orchestrator. This signature is required in order to prove – while presenting the privacy of the platform – that the TEE is executing on a genuine platform capable to create a TEE (we assume in this specification that the TEE is implemented using Intel SGX [7]).

Next the Orchestrator verifies the signature of the quote message (4), and then attests (matches) the quote message against an application fingerprint store. If the quote message matches the respective entry in the application fingerprint store, the orchestrator enrols the virtual switches by sending it an enrolment message (6). The enrolment message contains the data necessary to establish a protected communication channel between each of the virtual switch enclaves and the network controller (7), as well as among the virtual switches themselves.

In this scenario, it is critical that the signature verification service is reliable enough to detect attempts to modify or forge the quote messages; it is also essential to ensure the integrity of the application fingerprint store. However, these aspects are out of the scope of Bootstrapping trust enabler.

6.3.9 Architectural drivers

6.3.9.1 High-level functional requirements

Authentication All communication between control plane components must the authenticated, and a secure enrolment mechanism for management applications and data plane components must be in place.

Topology integrity: The network controller must be protected from network components that attempt to distort the visible global network view. This applies both to centralized and distributed network controllers.

Component integrity: Integrity of the data plane components must be verified prior to enrolment and the cryptographic material required for their network access must be protected with a hardware root of trust.

Confidentiality protection of domain secrets: Network domain secrets – such as VPN session keys – should not be revealed in plaintext even if the adversarysucceeds in compromising the software stack on the host.

Confidentiality and integrity of network communication: All network communication in the tenant domain must be confidentiality and integrity protected.

6.3.9.2 Quality attributes

Several *preliminary* quality attributes have been defined for the *Bootstrapping trust* enabler. The quality attributes below have been defined following the currently assumed use cases and the principles of network virtualization:

- Virtual switches deployed in TEEs using the *Bootstrapping trust* enabler should forward packets at a rate similar to virtual switches deployed outside of TEEs.
    - **Clarification**: Intra-host virtual switching is near instant, as packets are matched against policies and transferred in memory and use of TEEs should not induce a significant overhead. Implementation should be done with TEEs that offer native performance. Failure to keep up with the required performance would transform virtual switches deployed in TEEs into bottlenecks and would prevent their adoption.
- Virtual switches deployed in TEEs using the *Bootstrapping trust* enabler should be easily upgradable and interoperate with other commodity components and common protocols.
    - **Clarification:** Radical changes in the software architecture or operation of the virtual switches deployed in TEEs could limit their maintainability or require the use of implementation-specific protocols. This in turn would the prevent adoption of virtual switches deployed in TEEs.

As the enabler is currently in development, the specified quality attributes may change at a later stage.

6.3.9.3 Technical constraints

The *Bootstrapping Trust* enabler introduces a number of technical constraints and prerequisites, on the platform, software and protocol level.

On hardware level, the virtualization platforms must have support for Intel Software Guard Extensions (SGX) or other technology for creating TEEs with properties comparable to SGX enclaves. In the absence of such support, emulation software – such as OpenSGX [4] – can be used. While it is helpful or even essential for development and testing, an emulator cannot be used in practical deployments, as this would moot any security guarantees expected from a TEE.

Software applications may need modification in order to add support for executing in a TEE. In most cases, this excludes closed-source software from the list of potential software applications to be used by the enabler (unless the vendor itself adds the required support). Additionally, software orchestrator software must be extended in order to add support for TEE attestation functionality.

Finally, on the protocol level, it is desirable that the OpenFlow protocol [1] supports pre-shared key (PSK) cipher suites for transport layer security (TLS).Considering that SDN infrastructure offers a controlled environment, the use of PSK TLS to establish communication secure channels can significantly reduce the

TLS handshake overhead compared to the use of other TLS modes [8]. PSK TLS communication can be established using a key provisioned at deployment time.

6.3.9.4 Business constraints

No business constraints have been found at this point.

6.3.10 Detailed specifications

6.3.10.1 Introduction

The purpose of the *Bootstrapping trust* enabler is to deploy and operate a trusted SDN infrastructure, given that the physical security is ensured and that the underlying roots of trust – in this case the platform processor and the code and data of the network components deployed in TEEs – have been implemented correctly.

The enabler aims to be implementation-agnostic and one should be able to implement the principles of the enabler using different technologies. However, for the sake of clarity, the specification uses – where needed – concrete technologies and software applications.

The *Bootstrapping trust* enabler aims specifically to allow tenants securely deploy virtual switches in trusted execution environments and set up virtualized network topologies in a cloud environment. While, this addresses some of the threats towards SDN infrastructure deployments, as described in [3, 5], it *does not* protect the SDN deployment from exploits of vulnerabilities in the implementations of the network controller, network management applications or virtual switches. The *Bootstrapping trust* enabler is a mechanism to deploy the virtual switch code and data in immutable TEEs and attest that its integrity has been maintained in the process.

Another important aspect is that executing software in a TEE such as Intel SGX enclaves requires certain adaptations to the ABI available to SGX enclaves. To minimize the effort required for enabler implementation, one may choose to only place *security sensitive* parts of the application in TEEs. The definition of which parts are security sensitive is application specific and out of the scope of this specification.

Finally, it must be noted that the current API specification is likely to change both as the enabler itself matures, and in case the enabler will be implemented for platforms with available SGX support. Currently no such platforms are widely available and the enabler will be developed using an emulator, OpenSGX[9].

6.3.10.2 Conformance

The enabler requires the use of SDN and support for trusted execution environments, and various TEE implementations. This particular enabler implementation uses Intel SGXs to create the required TEEs.

Once the SDN components (namely the virtual switches) have been deployed in TEEs, various approaches for establishing a secure communication channel can be used. This particular enabler implementation uses PSK TLS to establish a secure communication session between the components.

In order to be conformant, an enabler should comply with all the specifications described below.

[9] OpenSGX project page: https://github.com/sslab-gatech/opensgx

6.3.10.3 API specifications

Below is a preliminary API specification of the enabler.

Each API call is described with title, the set of expected inputs, the set of expected outputs and a clarification comment. As the enabler is under development, this API is preliminary and may – with a high probability – be changed. As the enabler implementation will mature, a more detailed API will be made available.

1. ***Deploy switch enclaves***
    a. **Input**
        i. List of target hosts (ip addresses/hostnames)
        ii. Url to repository with enclave-capable virtual switch application code
        iii. Url to repository with bootstrap application code
    b. **Output**
        i. Tuple list of <target host, enclave identity> (for hosts where deployment was successful)
        ii. Tuple list of <target host, error message> (for hosts where deployment has failed)
    c. **Comment** This API command is intended to the initial deployment of virtual switch application code on the virtualization hosts (or bare-metal hosts) within the domain of the tenant, specified by the list of target hosts. On each target host, upon receiving the command, the bootstrap application retrieves the virtual switch code and interacts with the host-local SGX driver (or OpenSGX emulator software) to create an enclave and deploy the enclave-capable virtual switch application code. As a result, on each target host, the bootstrap application either obtains an enclave identity of the created enclave, or an error code in case of failure. These results are returned to the caller.
2. ***Quote switch enclaves***
    a. **Input**
        i. Tuple list <target host, enclave identity>
    b. **Output**
        i. Tuple list <target host, quote message> (for cases when the signature of the quote has been successfully validated)
        ii. Tuple list <target host, error message> (for cases when the quote signature validation failed)
    c. Comment Quoting a switch enclave allows to reliably obtain a snapshot of the virtual switch code executing in the created enclave. The trustworthiness of the quote depends upon the properties of the trusted execution environment (in this implementation – Intel SGX enclaves) and on the security of the signing keys (the signing keys are provided by the vendor and never leave the trusted execution environment of the platform). The signature of the *quote message* is then validated against the public key of the platform in order to ascertain its integrity and authenticity. Failure to do so invalidates any trust expectations on the respective enclave.
3. ***Attest switch enclave***
    a. Input
        i. Tuple list <Enclave identity, Quote>
    b. Output
        i. Tuple list <Enclave identity, Attestation Result>

c. **Comment** Attestation allows to verify whether the code and data executing in the switch enclave has not been modified and its fingerprint is identical to the expected values. This is a simple matching operation with a binary answer – the fingerprint either matches or does not. If the fingerprint matches, the switch enclave is executing the expected code and data (assuming trust in the implementation of the platform). If the fingerprint does not match, nothing can be said about the integrity of the enclave.

4. ***Enrol switch enclave***
   a. **Input**
      i. Tuple list <Enclave identity, Enrolment message>
   b. **Output**
      i. Updated list/view of the switches in the topology
   c. **Comment** Successfully attested virtual switch enclaves (i.e. with a matching fingerprint) are included in the topology. The enrolment message sent to each switch enclave is confidentiality and integrity protected (using the public key of the switch enclave, which was earlier communicated as part of the quote message), and contains the keying material used to establish a protected communication channel between the network controller and each individual switch, as well as among the switches in the same domain or segment (multiple such domains are possible). The details of the enrolment message will be specified in a later version of this API.

6.3.11 Re-utilized technologies/specifications

The bootstrapping trust enabler uses the Ryu SDN controller and the "Open vSwitch" virtual switch. Both are modified where necessary for the purposes of the enabler. In addition, the enabler utilizes the OpenSGX emulator software.

6.3.12 References

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6.4 Micro-segmentation Enabler: open specification

6.4.1 Preface

The upcoming 5G networks are currently being designed and the general vision is that 5G will be software-defined and virtual. There will be a new mobile ecosystem that consists of heterogeneous services, applications, networks, users and devices.

The security of 5G will be critical, as multiple different players will be included in the 5G ecosystem, such as Massive Machine-Type Communications (mMTC), Machine to Machine (M2M) or Industrial Internet based companies. In the case of a cyber-attack, the consequences could be dramatic.

Consequently, the role of isolation, virtualization and network management is going to be important. Applications or services requiring high level of security need to be clearly isolated and secure from the rest of the network. Network slicing has been introduced before to provide network isolation and this work presents the concept of micro-segmentation into 5G network security.

6.4.2 Status

These are preliminary open specifications of Micro-segmentations focusing on enabler in R1 (v1.0).

6.4.3 Copyright

The enabler is owned by VTT. VTT is currently the only contributor to this enabler.

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6.4.4 Legal notice

The Legal Notice that applies to this specification is given in Annex A.

6.4.5 Terms and definitions

AAA	Authentication, Authorization, Accounting
IoT	Internet of Things
LTE	Long Term Evolution
MME	Mobile Management Entity
NFV	Network Function Virtualization
PCRF	Policy Control Resource Function
PGW	Packet Data Network Gateway
SGW	Serving Gateway
VMNO	Virtual Mobile Network Operator

6.4.6 Overview

The micro-segmentation enabler describes how network virtualization can be used to secure the network, users, and their traffic effectively against cyber-attacks.The enabler allows creating secure segments into the 5G network in which granular access controls and strict security policies can be enforced.

Network slicing [1]-[4] is said to be a key component of 5G networks. Network slices provide a dedicated, logical network for a specific application, such as IoT. In other words, they provide all necessary functionality for a service and basic isolation. All other functionality is thus avoided in order to minimize the internal complexity of the slice. In general, it can be seen that network slices provide basic network security.

Micro-segments[10] can be viewed as a further sub-partition of slices into parts with more specific security properties. They are meant to complement network slicing by providing customizable security settings that can be modified to fit the purpose of the used service or application. In other words, they are an extra option for network slices.

Table 9 shows a general comparison of network slicing and micro-segmentation. Compared to network slices, micro-segments are in general more dynamic and hold smaller number of subscribers. They can be created, deleted, merged, and split on-demand while network slices are more static and hold larger number of subscribers. Micro-segmentation places more emphasis on security compared to general network slices. Of course, secure slices may be implemented but micro-segmentation is a cost-effective solution for the mobile network security control as methods such as next generation firewalls and reactive counter-measures based on complex event processing may not be practical in large scope.

Table 9 Network slicing and micro-segmentation comparison

Property	**Network Slicing**	**Micro-segmentation**
General	Provides necessary functionality for a particular service by the use of network virtualization.	Provides flexible security mechanisms that can be modified to fit user needs and different use cases and applications. Network virtualization is used.
Size	Larger number of subscribers and more heterogeneous environment.	Smaller number of subscribers and more homogeneous environment.
Dynamics	More static than micro-segments.	Dynamic and flexible.
Security	Provides a high level of security and isolation.	Provides granular, flexible, autonomous and cost-effective security.

Generally there are three entities regarding the micro-segmentation concept: micro-segment provider, micro-segment subscriber, and security inference provider. Micro-segment provider is an entity who controls the switches and SDN controllers in micro-segments and collects event information, e.g. network statistics. This actor is typically the Mobile Network Virtual Operator (MVNO).

Security inference provider is an entity that acquires security information from micro-segments through the APIs of the micro-segment provider. This information is used for analytics and controlling the micro-segment. The actor can be a micro-segment provider, a third-party, or the micro-segment subscriber. Micro-segment subscriber is an organization, company requiring isolated 5G network services (and monitoring) for a particular application.

Figure 63 shows an example of the micro-segmentation approach in a single domain (single operator) that could be built on top of existing 4G architecture. Network slices and micro-segments are created by the use

[10] Another term that could be used is a sub-slice (i.e. a small network slice) or a secure network slice. In this document we use the term micro-segments, used previously in data centres, to put more emphasis on network security.

of virtualization. For example, there could be one general network slice for “IoT”, but two micro-segments for “smart metering” and “personal health”. The subscriber of a micro-segment is typically an organization, service provider or a Virtual Mobile Network Operator (VMNO). The overall control of the micro-segments would be by (virtual) operators. The organizations and service providers that use the micro-segments may also have some control, especially related to the security functionalities within the micro-segment. Individual end-users would not have control over a micro-segment. Within a single domain, the segments should typically lay within a single network slice.

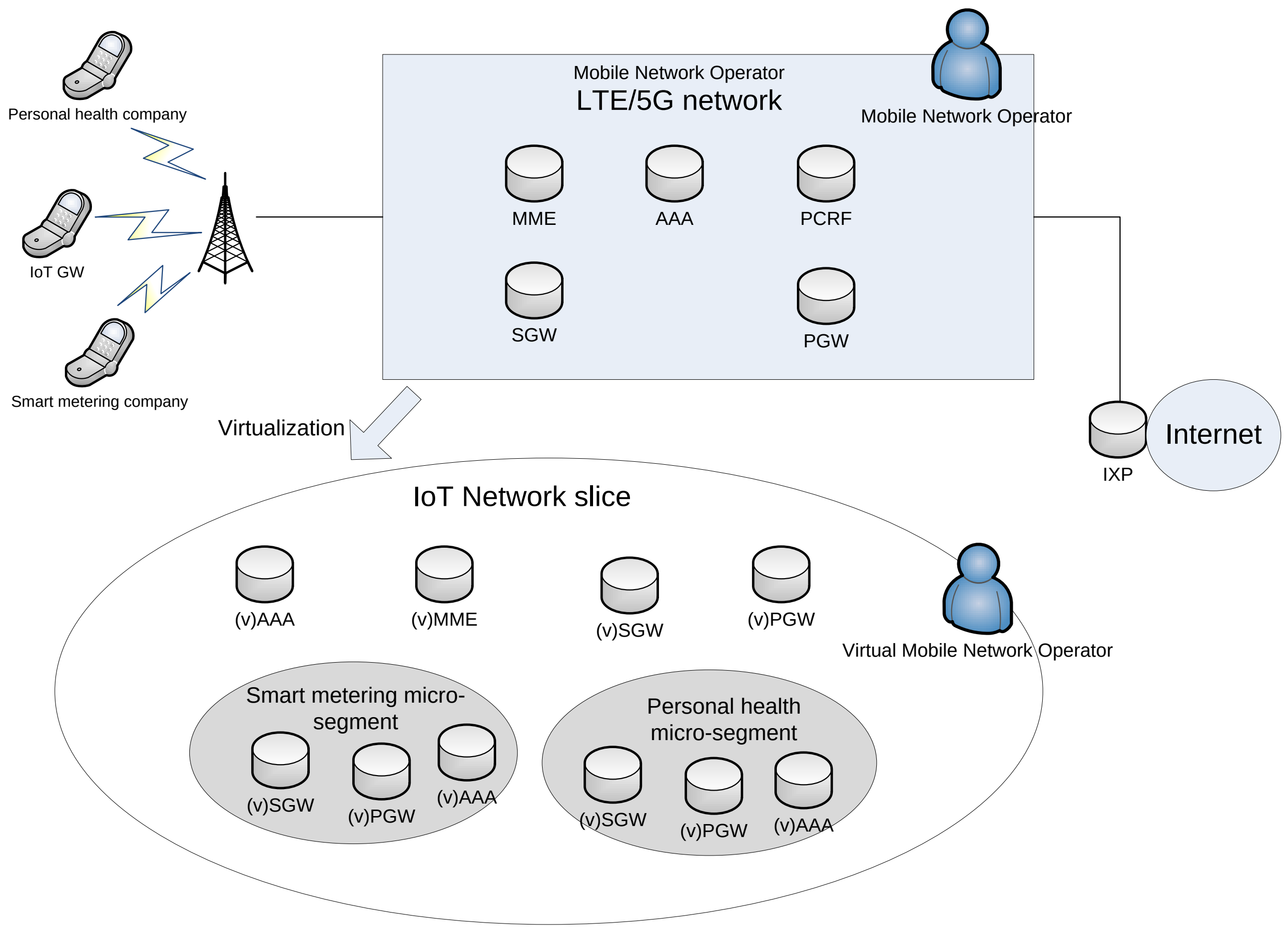

Figure 63: Micro-segmentation in a single domain network.

6.4.7 Basic concepts

The specific components that are included in a network slice or micro-segment depend essentially on the used application or service. What kind of functionality from the mobile core network is needed to run the service or application? By discarding unneeded functionality, the complexity of a micro-segment can be reduced.

In a 4G LTE network, the minimum requirements could be to include virtualized instances of both the Serving Gateway (SGW) and the Policy Control Resource Function (PCRF) in a network slice or micro-segment. For applications or services requiring Internet access, the network slice or micro-segment should include also the Mobile Management Entity (MME) and the Packet Data Network Gateway (PGW). Each network slice and micro-segment could also have its own AAA entity, but the AAA functionality of a micro-segment should not be too heavy to avoid the complexity. All these components would be virtualized resources or functions, i.e., Network Function Virtualization (NFV) would be used.

A micro-segment instance is, however, not necessarily required to form a complete logical network. Typically some parts of the functionalities of network slices can be inherited by micro-segments and a single micro-segment instance includes only a part of the subscribers of a network slice.

For instance, a massive Internet of Things (IoT) service may not necessarily require features such as handover or location update, which are being used with mobile devices. This is because the IoT service connects with a large number of immobile sensors that measure different parameters, such as humidity, precipitation, etc. and mobility is thus not considered. However, security for the service is critical.

Micro-segmentation needs to take into account different trust models for different micro-segments. Some micro-segments may require a Zero Trust model, which states that all nodes should be authenticated before attaching them into the micro-segment. The main principle of Zero Trust is “Never trust, always verify and authenticate”. Zero Trust employs a least privilege and unit-level trust model that has no default trust level for any entity or object in the network. Such a trust model can be, e.g., provided to micro-segments with critical services. Such a case could be an authority network in a crisis situation, in which trust would not be self-evident and the micro-segment should be highly secure. Other possible use case includes networks related to critical infrastructures, such as electricity distribution.

6.4.8 Main interactions

6.4.8.1 Use cases

Potential customers for the micro-segmentation approach in 5G networks include hospitals, factories, Industrial Internet and IoT based companies. An IoT company that is using the 5G network needs to gather data from different sensors reliably and securely. The delay may not need to be small but security is of high concern. Hospitals would also benefit from a dedicated micro-segment from the 5G network that is highly secure since e.g. gathering patient information from various sensors needs to be extremely private.

6.4.8.2 Components and interaction overview

Figure 64 depicts the micro-segmentation concept in an SDN network. The physical topology consists of two micro-segment subscribers, i.e. organizations or companies, connected to SDN switches and a SDN virtualization controller. The micro-segments are virtual networks that consist of a virtual SDN controller and several virtual SDN switches. The physical users are connected to one micro-segment while the physical SDN switches may be connected to both micro-segments. The virtual SDN controller is responsible for controlling the traffic inside the micro-segment and the SDN virtualization controller used for creating the two micro-segments A and B by the use of OpenVirteX [5] virtualization software. The virtual SDN controllers may hold applications for AAA and Security monitoring. Each micro-segment thus can have its own AAA entity for authenticating and authorizing users and accounting.

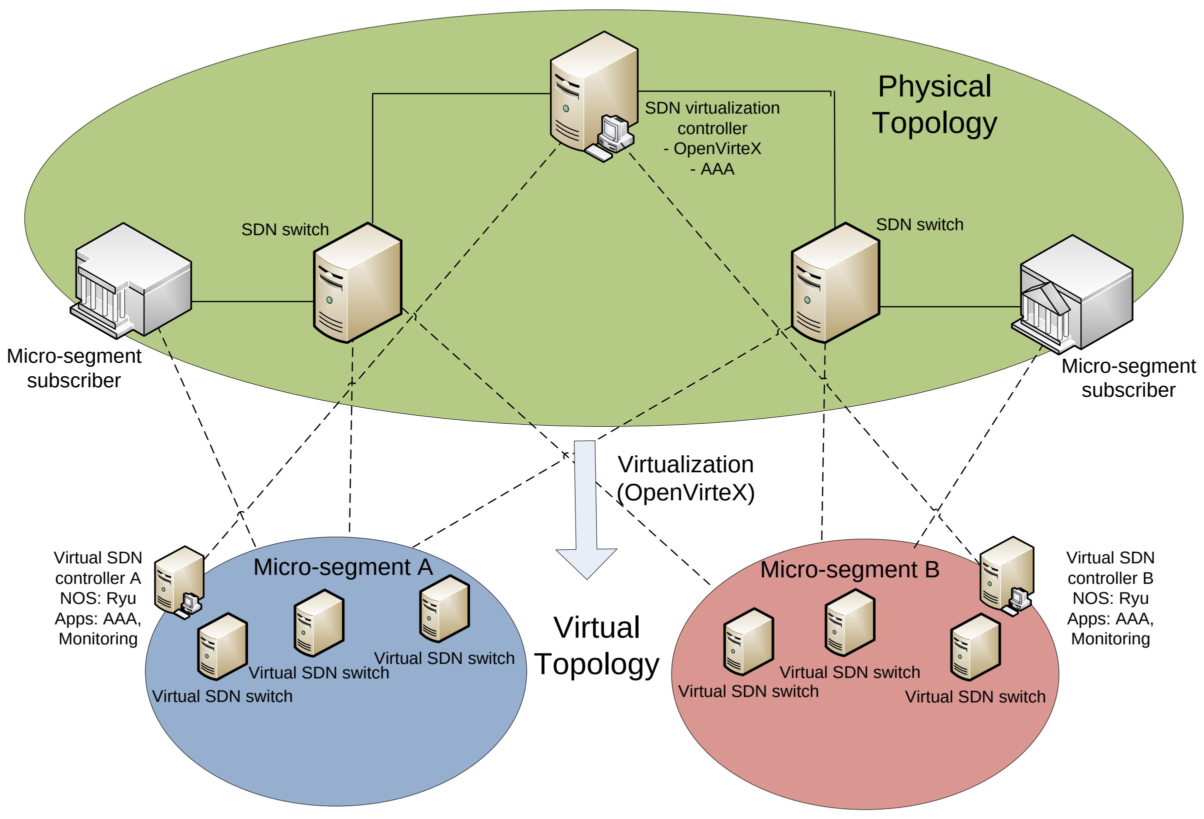

Figure 64: Micro-segmentation in an SDN network.

Figure 65 shows the architectural diagram of the micro-segmentation enabler. As can be seen from the figure, the enabler is related to a Security framework that consists of Security monitoring enabler and Trust metric enabler. Security framework needs information about micro-segments in order to modify micro-segment contents. The trust metric enabler also needs information about micro-segments to calculate a trust metric value for a micro-segment. Also, micro-segmentation enabler needs information from the SDN controller. Each time a certain change happens in the system, the micro-segmentation enabler informs the Security framework about it by sending an event (micro-segment created, micro-segment deleted, micro-segment modified).

In the release 1, the enabler shall be functioning independently without a connection to the Security framework. This means that the enabler will be able to create micro-segments, delete micro-segments, add nodes to micro-segment, and delete micro-segments without control from the Security framework.

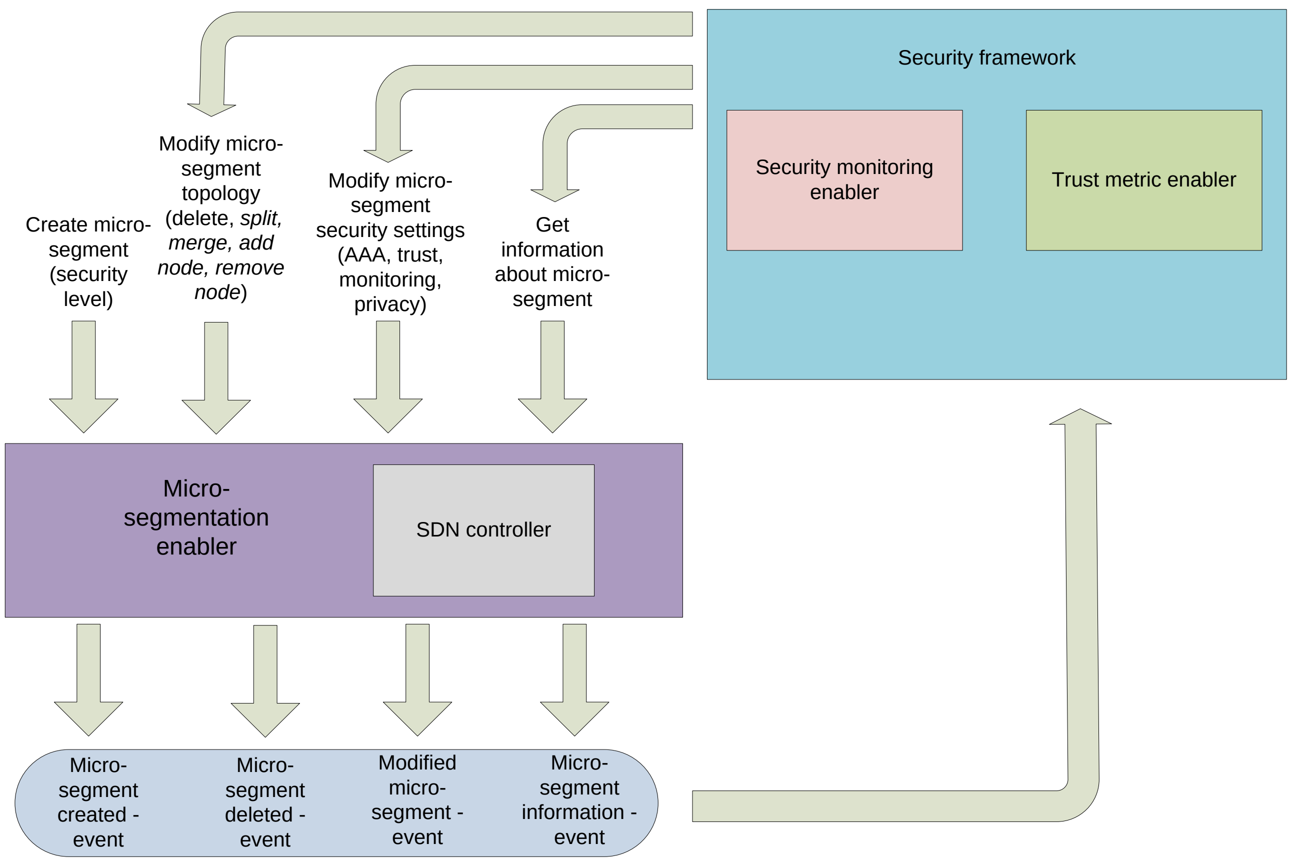
Security framework
Security monitoring enabler
Trust metric enabler
Create micro-segment (security level)
Modify micro-segment topology (delete, *split, merge, add node, remove node*)
Modify micro-segment security settings (AAA, trust, monitoring, privacy)
Get information about micro-segment
Micro-segmentation enabler
SDN controller
Micro-segment created - event
Micro-segment deleted - event
Modified micro-segment - event
Micro-segment information - event

Figure 65: Architectural diagram of the micro-segmentation enabler.

6.4.9 Architectural drivers

6.4.9.1 High-Level functional requirements

The enabler will in general create, delete, split, and merge micro-segments, which are isolated parts of the 5G network. In other words, micro-segments are virtualized, logical instantiations of the network that are highly isolated and secure.

Micro-segmentation will in effect provide a more homogeneous and smaller environment for security monitoring in order to respond better to abnormal behavior or attacks. Consequently, the threat landscape becomes smaller.

6.4.9.2 Quality attributes

When using the micro-segmentation enabler, it should be able to provide up-to-date information to the security framework in order to do appropriate decisions. Also, when deployed in the 5G network, the enabler should not degrade the performance of the running applications or services in the micro-segment, i.e., the Service Level Agreements (SLAs) should be guaranteed.

6.4.9.3 Technical constraints

It needs to be investigated how the micro-segmentation approach can be implemented into the 5G network architecture. For example, what network functions of the architecture can be included in a micro-segment, which is a virtualized part of the mobile core network? Are there any limitations in virtualizing mobile network functions? Should micro-segments have common network functions?

6.4.9.4 Business constraints

The enabler is built on existing open source software that can be quite easily integrated together. This facilitates the applicability of the solution to other environments.

6.4.10 Detailed specifications

6.4.10.1 Introduction

In order to implement micro-segmentation, SDN and virtualization technologies are needed. Figure 64 showed the micro-segmentation concept in an SDN network that showed how micro-segments are in general created. There needs to be an SDN virtualization controller that is able to create virtual networks that are isolated from the physical network. In our scenario, the virtualization is done by OpenVirteX software [5]but other network virtualization hypervisors are possible. A detailed review of different hypervisors can be found here [6]. The SDN virtualization controller may also have its own AAA application.

For controlling the traffic inside the micro-segment, a virtual SDN controller is needed. In our case we are using the Ryu SDN controller [7]but other type of SDN controller is plausible. The virtual SDN controller needs to have SDN applications for AAA and security monitoring. The AAA application will be used for authenticating and authorizing users and monitoring user statistics, i.e., accounting. In the first phase, the authentication will be based on Extensible Authentication Protocol over LAN (EAPoL).

Micro-segments may support and require particular authentication mechanisms. For example, if the mobile device has been authenticated strongly to the mobile network by the use of USIM, it can be authorized to use the micro-segment. However, if lighter authentication methods have been used in the mobile network, the device needs to be authenticated using stronger or second-factor mechanismto authorize use of the micro-segment. The security monitoring application will be used for monitoring traffic inside the micro-segment and responding to threats, attacks, and anomaly behaviour. The monitoring enabler is a separate entity from the SDN controller and it tries to gather information from a wide perspective in addition to the network traffic information that can be obtained through the SDN controller.

In order to test micro-segmentation with mobile networking architecture, there needs to be a way how to integrate the different functions of mobile networks (e.g. PGW, SGW, MME, PCRF) with SDN and network virtualization technologies. One possible solution could be to use the OpenEPC [8] that covers all the functional elements in the 3GPP Evolved Packet Core (EPC) and Systems Architecture Evolution (SAE) technologies up to 3GPP Release 12. Another alternative is the OpenAirInterface [9].

6.4.10.2 Conformance

The enabler needs SDN and virtualization technologies for implementation and these two are the building blocks of the enabler. For SDN, an SDN controller is needed that can be chosen quite freely. In this work we are currently using the Ryu SDN controller[7].For network virtualization, OpenVirteX software [5]is used, but another type of network hypervisor is plausible.

For AAA methods, the selection depends on the used application. If a high level of security is needed, then perhaps a strong authentication method is in place. The AAA methods can be therefore chosen quite freely.

6.4.10.3 API specifications

Figure 65 showed the architectural diagram of the micro-segmentation enabler, which takes the following input actions:

- ***Create micro-segment based on the needed security level***. The security level can depend on the following entities: AAA (e.g. how are the end users authenticated?), security monitoring (e.g. what kind of monitoring is needed?), anomaly detection (e.g. what kind of anomaly detection is needed?), intrusion detection (what kind of intrusion detection is needed?), and prevention mechanisms (e.g. what kind of prevention mechanisms are needed? E.g. Deep Packet Inspection?).
- ***Modify micro-segment topology***. This can be done by either splitting a single micro-segment into several micro-segments or merging several micro-segments into single micro-segments. Modification of the micro-segment also includes adding and deleting nodes from the micro-segment. Micro-segment can also be deleted.
- ***Modify micro-segment security settings***. This includes modifying AAA, trust, monitoring and privacy settings.
- ***Get information about a micro-segment*****.** This action is used for getting general status of the micro-segment: what are the nodes connected to the micro-segment, statistics, network traffic, etc. This can be retrieved from the SDN controller.

The enabler produces the following outputs based on the input actions:

- Micro-segment created based on the needed security level.
- Micro-segment is deleted.
- A modified micro-segment is generated based on the input action (split, merge, add node, remove node).
- General information about a micro-segment is sent forward.

The specific technical details of the API depend on the selection of the network hypervisor and the SDN controller. For example, in this work OpenVirteX is used as the network hypervisor that does the network virtualization and Ryu SDN framework is used as an SDN controller. Apache Kafka[10] could be used as an API that produces events coming from the enabler while REST API could be the way how commands are sent to the enabler. Information needed from the Ryu SDN controller can be retrieved via REST API.

In release 1 of the micro-segmentation enabler, creation of micro-segments, deleting micro-segments, adding nodes to micro-segment, and deleting nodes from micro-segment shall be implemented. Next releases will include other functionalities (merge, split) and integration with the Security framework.

6.4.10.4 Examples

Micro-segments can be provided by Mobile Virtual Network Operators (MVNOs) to subscribers, such as hospitals, factories, Industrial Internet and Internet of Things (IoT) based companies. Initially, the micro-segment subscriber informs the MVNO that a micro-segment with a certain security level is needed. The security level can depend on the used AAA methods, type of security monitoring, privacy, and trust. Ultimately, micro-segments are customizable. Subsequently the micro-segment is created based on the subscriber input. A micro-segment created – event is sent to the security framework module to inform of a new micro-segment in the system.

The security framework gathers information from the micro-segmentation enabler about micro-segments, possibly via Apache Kafka API. This information is gathered via the SDN controller of a micro-segment through REST API. The controller sees all the switches and nodes in the micro-segment, micro-segment topology, and status information about amount of packet/bit network traffic.

The security framework also provides actions to the micro-segment enabler to modify micro-segment topology or modify micro-segment security settings. This could be done via REST API. Modifying the topology can happen when nodes need to be removed or added to the micro-segment or micro-segments need to be deleted, split or merged. Deleting a micro-segment can happen when the subscribers are no longer using the micro-segment. Merging happens when two micro-segments need to be combined together and splitting divides a single micro-segment into several micro-segments. All of these events are subsequently provided to the security framework to handle up to date information about micro-segments and nodes in micro-segments.

6.4.11 Re-utilised Technologies/Specifications

The enabler uses the OpenVirteX software for network virtualization and the Ryu SDN controller for management of micro-segments. Both of these are modified to fit the purpose of the enabler.

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6.4.13 Acknowledgements

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7 Conclusions

In this document the open specifications of 5G-ENSURE security enablers planned to compose the first release (i.e. v1.0) as per Technical Roadmap reported in D3.1 have been presented and detailed. Each of these enablers is now under development and is expected to be delivered on due time by M11 (i.e. September 2016) in the context of the next deliverables to come (namely D3.3 security enablers sw release (v1.0) and D3.4 security enablers documentation). Work reported here was performed in close collaboration with other technical work packages and exploited the deliverables already produced by the project, especially D2.1 on Use Cases and D3.1 on Technical Roadmap. It is also input to other technical works, especially the ones on the 5G Security architecture from WP2, but also the 5G Security testbed from WP4. It is an input for the 5G Security architecture, since it provides details to map enablers targeted to 5G security architectural components according to specified design. On the other hand it is also input for 5G security testbed, since through detailed specifications of enablers, it provides material to figure out what is requested to get them hosted and/or tested in the context of relevant use cases.

Most of the enablers here specified are expected once released in v1.0 to be continued and/or completed in the context of the next release (i.e. v2.0 due on M22).

These open specifications are also expected to be shared with 5G-PPP community at large starting first and foremost with 5G-PPP Security community through 5G-PPP Security WG activities performed.

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