ICT-56-2020 "Next Generation Internet of Things"

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IntelliIoT

Deliverable D4.8
Trust mechanisms (final version)

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1 INTRODUCTION

This deliverable, being the final output of Task 4.4 ("Trustworthy infrastructure by design"), aims to provide details on the design and development of the second (and final) version of the trust mechanisms that are an integral part of the IntellIoT framework. These mechanisms, and the associated enablers, jointly provide trust-by-design, safeguarding the security and privacy of IntellIoT and its target deployment (e.g., use case deployment), ultimately building trust into IntellIoT and the application deployment as a whole.

1.1 Overview of IntellIoT's Trust-related efforts

From a high-level perspective, IntellIoT's Trust Mechanisms and the associated components can be grouped into three pillars:

- Continuous Security Assurance, centred around the provision of evidence-based assessments of the security and privacy posture of IntellIoT and its deployment;
- Security, Privacy & Trust primitives, including innovative enablers such as trust-based intrusion detection, moving target defences, and Distributed Ledger Technologies (DLT), and;
- Multi-layer Security Monitoring, provided by heterogeneous, purpose-developed event captors that are deployed across IntellIoT deployment layers and which cover core components and processes.

These three pillars and their interplay are visualised in Figure 1.

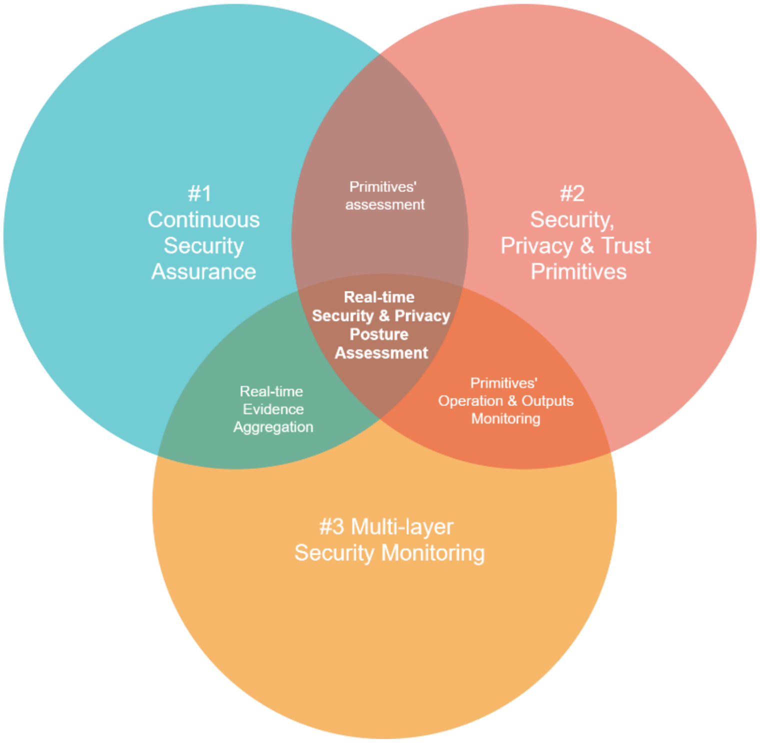


Figure 1. The three implementation-level trust pillars of IntellIoT

From a component development perspective, details on the individual enablers comprising the above three pillars, and how they all fit together, have been documented in deliverable D2.6 - "High level architecture (final version)", whereby a separate subsection dedicated to these "Trust Enablers" has been included in all 4 views of IntellIoT's architecture that said deliverable provided. Figure 2 highlights these enablers, as identified in the final version of IntelliIoT's high-level, logical architecture, documented within D2.6.

Updates to the architecture (compared to what was defined in D2.3) & the enablers themselves (compared to what was delivered in Cycle 1; D4.4) include a richer feature set, as was anyway typically anticipated on the initial delivery plan of each component, but also integrate changes based on feedback from Cycle 1 of the project (see Cycle 1 demonstration activities of Task 5.2, documented in D5.2 & following evaluation activities of Task 5.3, documented in D5.3). These provided valuable inputs for the design and implementation of the final components of Task 4.4.

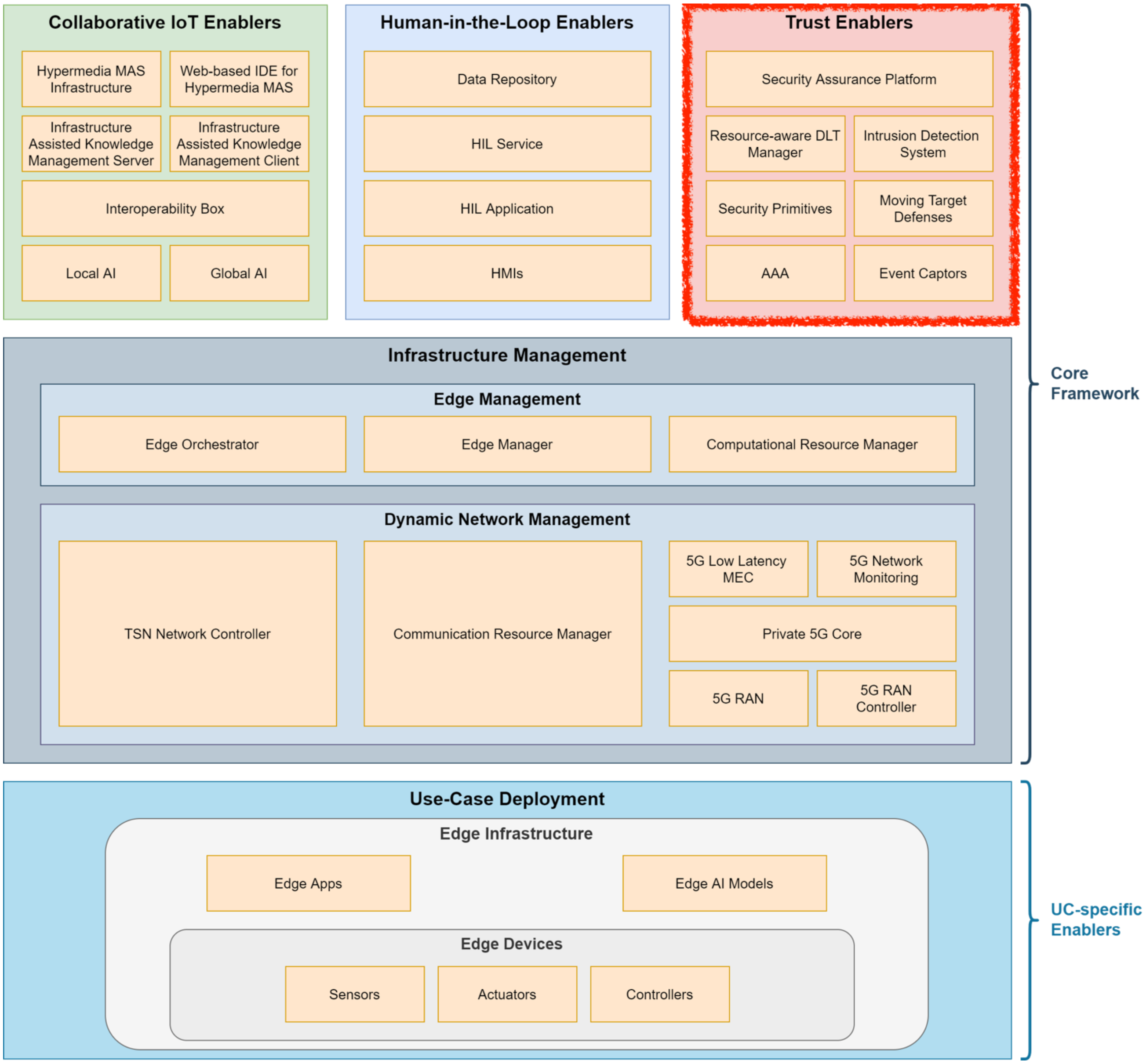


Figure 2. Core trust enablers (top right) within the final version of IntelliIoT's architecture

Finally, from a work plan perspective, and being the final (i.e., Cycle 2) output of Task 4.4 - this deliverable provides details on the final versions of the trust mechanisms and components, as planned to be integrated into the final release of IntellIoT. Said version is to be delivered through D5.4 – "Integrated IntellIoT framework & use case implementations (final version)", of Task 5.1 ("Integration & implementation"). This is in line with the overall work plan, whereby Task 4.4 outputs its results mainly to Task 5.1.

More details on the interplay of Task 4.4 with other tasks within the project are shown in Figure 3.

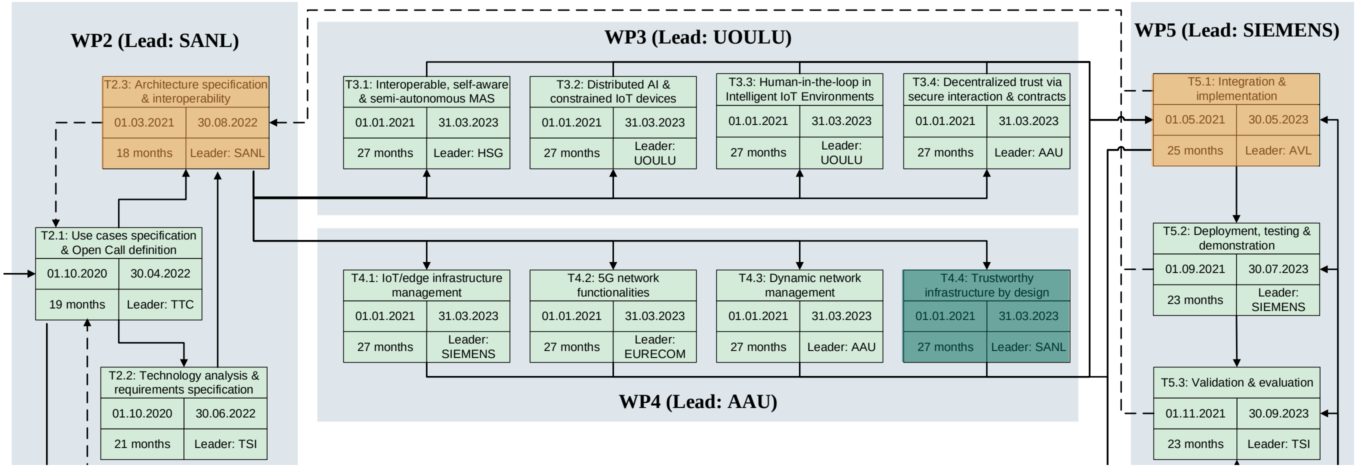


Figure 3. Task 4.4's interplay with other WPs and Tasks of IntellIoT

1.2 Relation to Objectives & KPIs

The efforts presented herein are aligned with the project's 4th Objective: *"Enable security, privacy, and trust by design with continuous assurance monitoring, assessment and certification as an integral part of the system, providing trustworthy integration of third party IoT devices and services"*.

The fulfilment of this objective is verified through the KPIs appearing in Table 1 below.

Table 1. Trust-related IntellIoT KPIs, mapped to Objective 4

KPI ID	KPI Description	Validation
4.1	Delivery of **a continuous assurance and certification component** supporting: (a) individual risk assessment schemes; (b) incremental risk assessment schemes, and; (c) hybrid risk assessment schemes to estimate risk by combining the outcomes of the schemes in (a) and (b).	D4.8; Delivered through Continuous Assurance & Certification solution detailed in Section 2 below.
4.2	Delivery of **at least 2 DLT implementations** that can adjust level of trust to capabilities of devices, can integrate proxies, and can conform to certain latency and reliability requirements, such that the level of decentralization of device participation is proportional to its computation-communication capabilities.	Delivered through DLT component developed within Task 3.4 (deliverable D3.8), but also briefly described and integrated with other Trust enablers; See Subsection 6.3 below.
4.3	Delivery of **at least 2 trust-based secure routing algorithms**, applicable for the IoT system, which cover the design requirements of i) relatively static networks with low mobility and ii) open networks with high mobility nodes, respectively.	Mapped to Trust-based Secure Routing component described in Section 4 herein.

4.4	Development of **at least 2 MTD algorithms** for: i) local decision making by an individual agent for its underlying system, and; ii) horizontal incorporation of trusted agents in the IoT system.	Delivered through MTD component detailed in Section 5 herein.

1.3 Deliverable outline & delta compared to previous version.

To present the above building blocks, this deliverable is organised as follows:

- Section 2 presents the Security Assurance Platform (referred to as SAP), i.e., the main enabler of the continuous assurance pillar mentioned above.
- Sections 3, 4 and 5 provide details on core security, privacy, and trust primitives, including the Authentication, Authorisation and Accounting (AAA) solution adopted for IntellIoT, and the novel Trust-based Intrusion Detection System (IDS) and Moving Target Defences (MTD) approaches, respectively.
- Section 6 is dedicated to presenting the integration and collaboration between all of IntellIoT's Trust Enablers through the dedicated message broker, including the integration between SAP-MTD-IDS and the integration between the SAP and the DLT -based trust primitives, mostly developed within Task 3.4 ("Decentralized trust via secure interaction & contracts").
- Section 7 documents additional security, privacy, and trust efforts within Task 4.4, including the development of multi-layer monitoring capabilities that enable the corresponding third pillar mentioned above, as well as other security provisions adopted, encompassing 5G security, and the adoption of best practices and state-of-the-art approaches for cryptographic primitives and secure-by-default and fail-secure device configuration.
- Finally, Section 8 provides the concluding remarks.

Considering the changes compared to the previous version of the deliverable, i.e., D4.4 - "Trust mechanisms (first version)", the new content presented within this final Task 4.4 deliverable includes:

- Minor updates to the Sections 1 (Introduction) & Section 8 (Conclusions) sections, to bring them up-to-date with the current deliverable, as the last output of Task 4.4. The Introduction section now also presents the differences with the previous version of the deliverable.
- A major update of the Security Assurance Platform description in Section 2, to more accurately present SAP's final set of features, notably including the Incident Response Orchestration & Automation subcomponent and the relevant executable "Playbooks", as well as more detailed information on the Hybrid Assessments; both key features released in Cycle 2.
- An update to Section 3, detailing the AAA solution integrated within IntellIoT, with updates to reflect the final status of the component & its enhanced integration with IntellIoT components.
- An update to Section 4, documenting the Trust-based Intrusion Detection component of IntellIoT, with updates to reflect the Cycle 2 (final) set of features of the component.
- An update to Section 5, describing the Moving Target Defence enablers of IntellIoT, with updates to reflect the Cycle 2 (final) set of features of the component.
- A minor update to Section 6, to present the final integration of the Trust enablers more accurately, considering the adjustments that have been made from the Cycle 1 to the Cycle 2 release (& integration) of said enablers.

Finally, in addition to the above, other minor updates were made throughout the deliverable (e.g., editing, language).

2 CONTINUOUS ASSURANCE AND CERTIFICATION

2.1 Overview

The Security Assurance Platform (SAP) is an integrated framework of models, processes, and tools to enable the continuous assurance and certification of the security properties of the devices across the IntellIoT infrastructure. It uses different types of evidence to demonstrate the support for the required properties and award the corresponding certificate. These include hybrid assessments that consider different attacks surfaces and attacker capabilities by gathering contextual information (e.g., configuration changes, network, and middleware behaviour), as well as an up-to-date view of all known vulnerabilities across the IntellIoT deployments, from field to backend. The Security Assurance Platform:

- Combines runtime monitoring and dynamic runtime testing to ensure correct and effective operation of security controls.
- Can be hooked to different systems programmatically through appropriate probes (e.g., event captors, test tools) to obtain the monitoring and/or test evidence required for assurance and/or certification assessments.
- Operates based on models that determine the operational evidence that should be captured from systems and how it should be assessed (e.g., what conditions it should satisfy) to assess the correctness and effectiveness of implemented system security controls.
- Enables the runtime assessment of temporal event patterns and rules that can express signature or anomaly-based patterns.

2.2 Internal Architecture

As shown in Figure 4, internally the SAP is comprised of five main modules:

1. **Cyber System Asset Loader**: The component responsible for receiving the Security Assurance Model for the target organization. This model includes the assets of the organization, security properties for these assets, threats that may violate these properties, and the security controls that protect the assets and is based on STS's Assurance Model.
2. **Vulnerability Analyzer**: The Vulnerability Analyzer is responsible to identify known vulnerabilities of assets defined within an organisations' asset model. This component automatically constructs the Common Platform Enumeration (CPE[1], a structured naming scheme for information technology systems, software, and packages) per asset and then retrieves the relevant Common Vulnerabilities and Exposures (CVE[2], a reference-method for defining unique, common identifiers for publicly known information-security vulnerabilities and exposures) entries, by searching in a local copy of the National Vulnerability Database (NVD[3], a U.S. government repository of standards-based vulnerability management data, maintained by the National Institute of Standards and Technology, NIST[4]). This copy is continuously updated by utilising an in-house component that fetches the latest known CVEs from NVD's JSON files.
3. **EVEREST**: A runtime monitoring engine, built-in Java, that offers an API for establishing the monitoring rules to be checked. This module is composed of two submodules: (a) the monitoring database and (b) the monitor. The role of the module is to forward the runtime events from the application's monitored properties and finally

[1] https://nvd.nist.gov/products/cpe
[2] https://cve.mitre.org/
[3] https://nvd.nist.gov/
[4] https://www.nist.gov/

obtain the monitoring results. **EVEREST** basic implementation is based on Drools logical language, while it is modelled in Event Calculus, a first order temporal logic that can both represent and reason actions and their effects over time. By abstracting the above concepts, Event Calculus basic elements are comprised of events and fluents. **EVEREST** performs continuous assessments and is based upon these core logic factors of Event Calculus in terms of comprising the rules continuously checked in a system.

4. **Event Captors**: The Event Captor is a tool, implemented In Java, that based on collected data and triggering events, formulates a rule or a set of rules and pushes the latter towards the monitoring module for evaluation. Data and events are mostly collected through Elastisearch[5] based on lightweight shippers (namely Beats), such as Filebeat[6], Metricbeat[7], Packetbeat[8], etc., that forwards and centralizes log data. Data can also be collected through Logstash, an open server-side data processing pipeline that ingests data from a multitude of sources transforms it, and then sends it to Elasticsearch. The Event Captor is initiated through the respective REST calls from the monitoring module. In addition, Elasticsearch provides build-in mechanisms to support the secure communication with SSL communication and hence the interaction is performed via the HTTPS protocol.
5. **Dynamic Tester**: The component responsible for initiating the testing assessment. The module consists of two components: (a) the dynamic tester or manager and (b) the dynamic testing tool.

Moreover, the operation of the platform relies on the following databases:

- **EVEREST Database**: Holds the monitoring rules and the overall process done by EVEREST if the templates and other values important for monitor procedure to conclude.
- **Security Assurance Database**: Holds the cyber system asset model, its components, and the results of the assessments.
- **Vulnerabilities Database**: Holds the known vulnerabilities, as retrieved from the NVD database.

Finally, the Assurance tool interfaces with a set of external components, namely:

- **Message Broker (RabbitMQ[9]):** The message broker is a messaging bus that allows communication between the external components and the assurance platform using AMPQ[10] protocol. This will also act as the Trust Broker in IntellIoT; see Sect. 6.
- **OpenVAS[11]:** This is a software framework of several services and tools offering vulnerability scanning and vulnerability management. The tool is used as part of the dynamic testing offered by the Assurance Platform.

[5] https://www.elastic.co/
[6] https://www.elastic.co/beats/filebeat
[7] https://www.elastic.co/beats/metricbeat
[8] https://www.elastic.co/beats/packetbeat
[9] https://www.rabbitmq.com/
[10] https://www.rabbitmq.com/
[11] https://www.openvas.org/

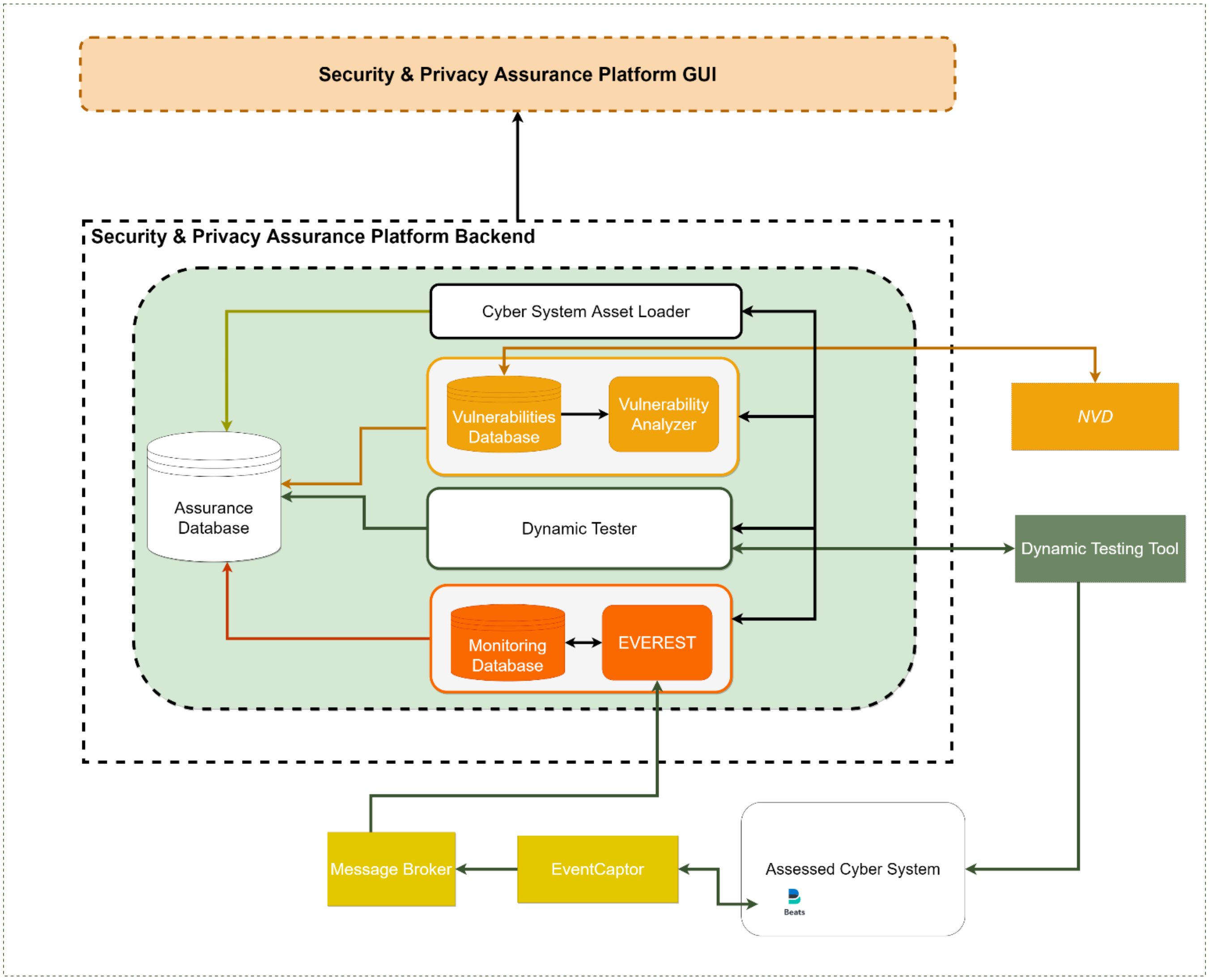


Figure 4. High-level architecture diagram of the Security Assurance Platform

2.2.1 CYBER SYSTEM ASSET LOADER

The Asset Loader module is responsible for receiving the Security Assurance Model, written in the Security Assurance Grammar, for the target organisation. The latter utilises the ANTLR4 parser generator to create the grammar and read, process, execute, or translate the structured text inside it. Lastly, the Model includes the assets of the organisation, security properties for these assets, threats that may violate these properties and the security controls that protect the assets. The internal architecture of the module is shown in Figure 5.

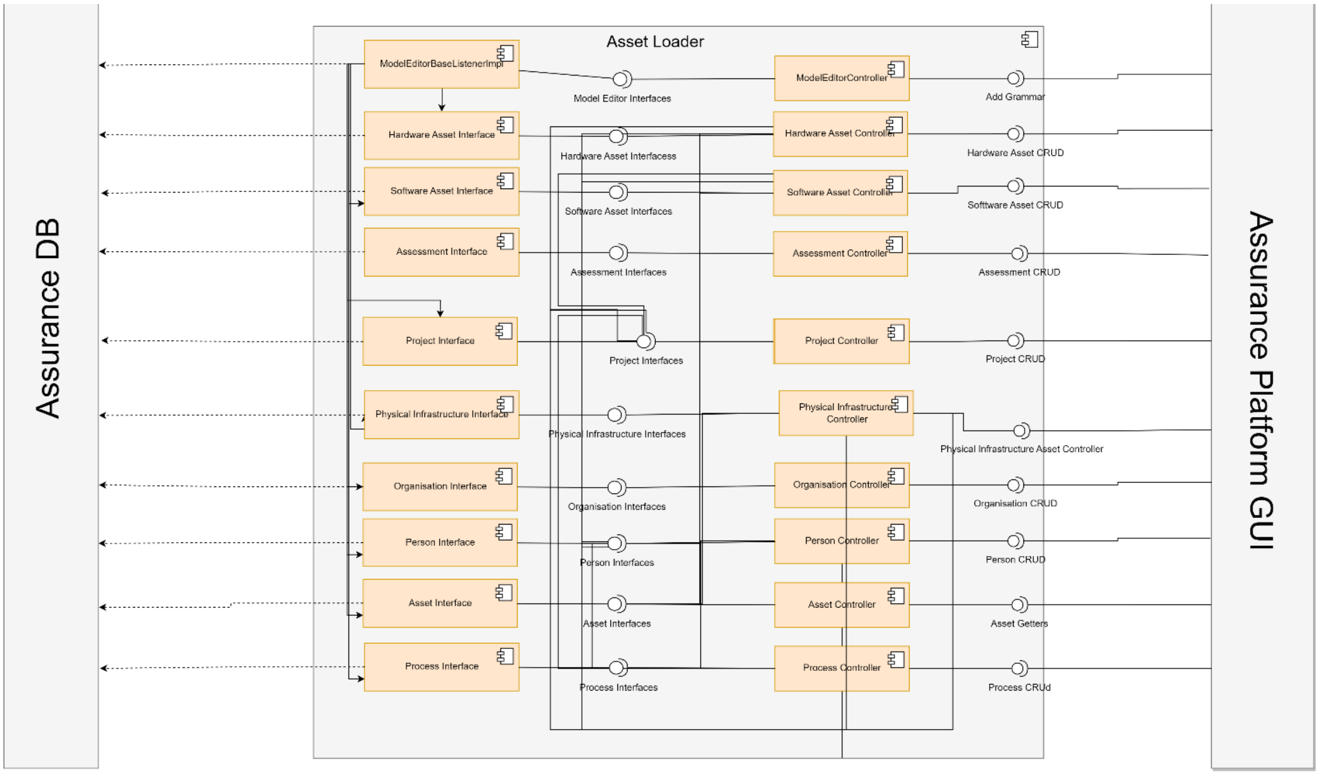


Figure 5. Internal architecture of SAP's asset loader module

2.2.2 VULNERABILITY ANALYZER

The Vulnerability Analyzer module is responsible for loading the known vulnerabilities (of the identified assets) and updating the assurance platform depending on the organisation's assets included in the assurance model. It consists of the following sub-components:

- Job Scheduler
- JSON module
- CPE constructor
- Assessment Controller
- SSE Controller

The JSON module's main functionality refers in getting-updating the CVEs as well as uploading-retrieving them from the Assurance Database. It also retrieves and sets the assessment models and the assessment criterion. The CPE constructor is responsible to construct the CPE for the assets involved in a specific assessment, whereas the Assessment Controller is responsible to initiate a new assessment and check for vulnerabilities in assets based on their CPE. Lastly, the JOB scheduler is responsible of managing the assessment results and updating the CVEs periodically. The internal architecture of the module is shown in Figure 6.

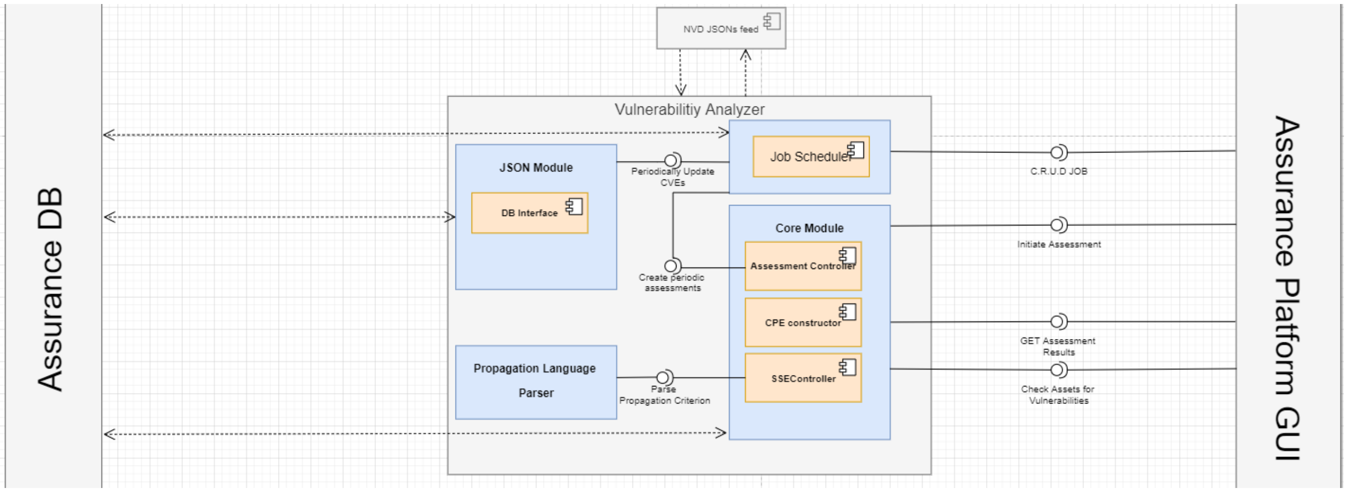


Figure 6. Internal architecture of SAP's vulnerability module

2.2.3 DYNAMIC TESTER

The Dynamic Tester module (see Figure 7) is responsible for initiating the testing and reporting the results to the assurance database. It consists of the following sub-components: **Model Loader**; **Testing Manager**; **Report Loader**; **Results Uploader** and its REST Interface.

The Model Loader is responsible for translating assessment models to parameters to be utilized by testing tools. Based on this information the Testing Manager is responsible for initiating and scheduling the testing tools to perform the security assessments.

Upon finalization, the results of the security assessments are fed into the Report Loader module which is responsible to interpret them to a format defined by assurance model. The formatted results are then uploaded to assurance database by the Results Uploader module.

Finally, the REST interface module provides the necessary REST functions that are utilized by the security assurance platform GUI to enable the aforementioned functions.

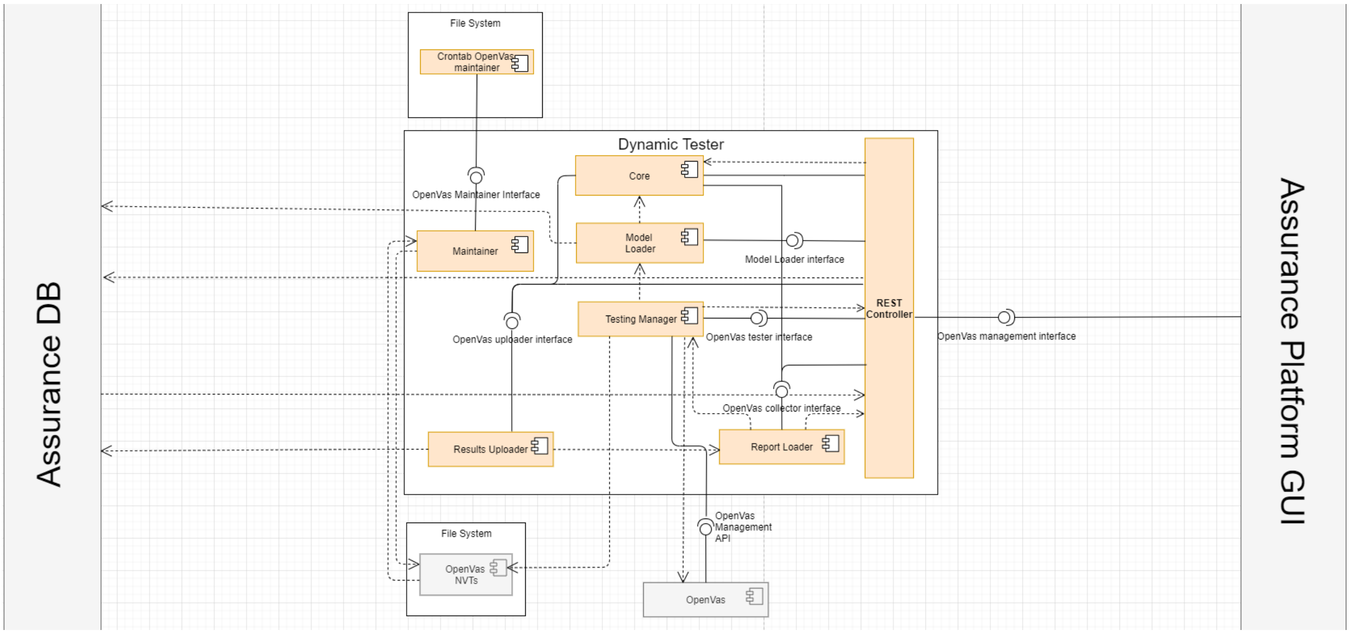


Figure 7. Internal architecture of SAP's testing module

2.2.4 EVEREST MONITORING

EVEREST is responsible for initiating, coordinating, and reporting the results of the monitoring process. This (Java-based) runtime monitoring engine is comprised of two basic submodules (a) the monitoring database and (b) the monitor. It offers an API to other SAP components to instantiate the monitoring rules to be processed. When a pattern is activated through this process, it undertakes the responsibility of checking conditions regarding the runtime operation of the components that implement the pattern. These conditions are specified within patterns by monitoring rules expressed in Event Calculus Assertion (more details on that below). EVEREST can detect violations of monitoring rules against streams of runtime events which are sent to it by different and distributed event sources through the Event Captor Module. It also able to:

- Deduce information about the state of the system being monitored using assumptions about the behaviour of a system and how runtime events may affect its state.
- Detect potential violations of the monitoring rules by estimating belief measures in the potential occurrence of such violations.
- Perform diagnostic analysis to identify whether the events causing a violation are genuine or the result of a system fault or an attack.

The internal architecture of this module is shown in Figure 8. EVEREST interacts with the REST controller that initiates and provides actions for the monitoring assessments. It is implemented in a Docker environment which provides flexibility, portability, and parallel execution capabilities. This component will be able to leverage monitoring mechanisms, such as the Intrusion Detection System (IDS) and Event Captors deployed on IntelIIoT's devices (more event captor details are provided in Sect. 7.1) to provide an evidence-based, certifiable view of the security posture of the overall system, with accountability provisions for changes that occur in said posture and the analysis of their cascading effects, supporting the runtime checking based on sets of associated claims and metrics. The methodology and procedures for the automation of the security Monitoring tool is tailored to specific security standard, service level agreements and/or legal and regulatory obligations (e.g., GDPR).

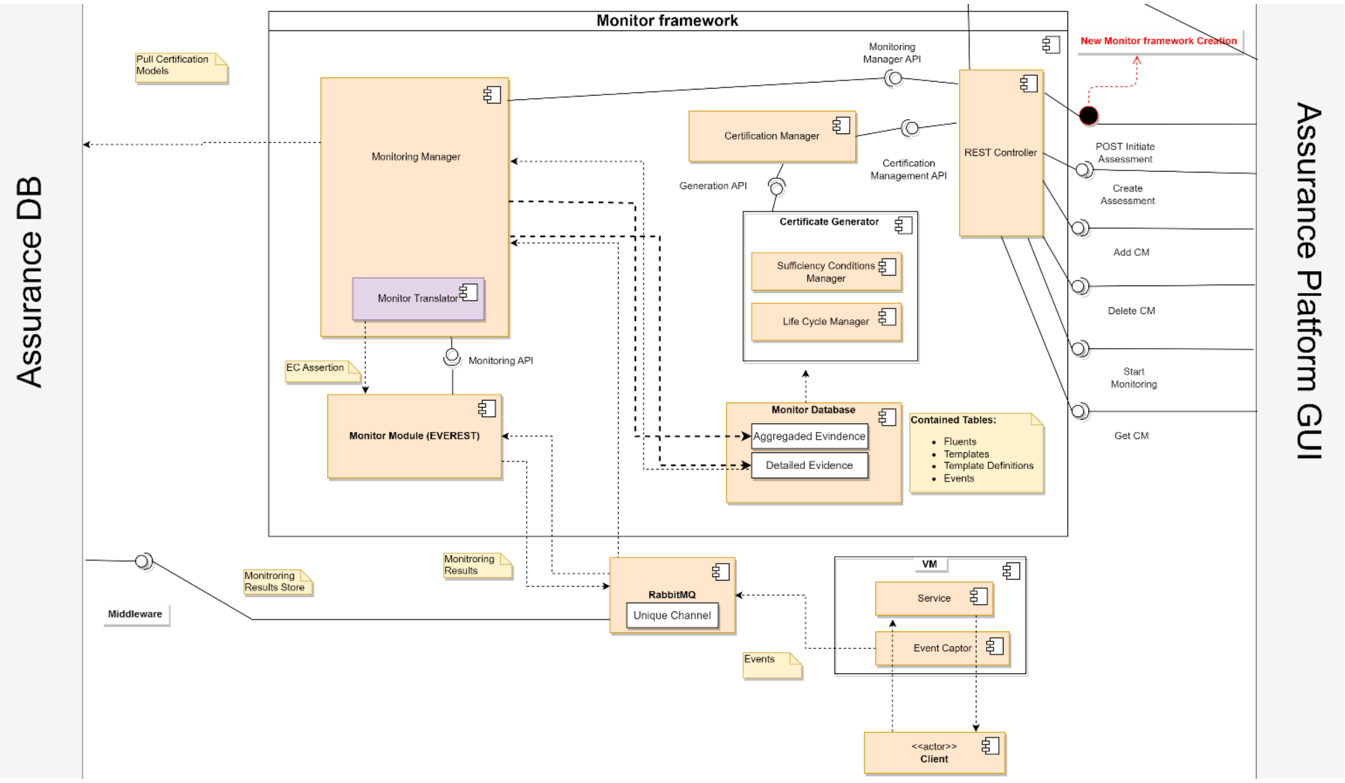


Figure 8. Internal architecture of SAP's EVEREST monitoring framework

The rules and metrics that need to be audited need to be specified within security and dependability patterns (referred to as *S&D Patterns*) using an XML based language, called EC-Assertion. Based on event calculus, EC assertion is a first-order temporal logic language primarily developed not only to represent but also to reason about actions and their effects over time. The basic elements of Event Calculus are *events* and *fluents*. An event in EC is specified as something that occurs at a specific instance of time and is of instantaneous duration. Furthermore, it may cause some change in the state of the reality that is being modelled while this state is represented by fluents. EC is implemented in Everest in the Drools[12] logical language, while some functionality is further implemented in Java. Drools is a collection of tools that allow us to separate and reason over logic and data found within business processes.

To represent the occurrence of an event, EC uses the predicate Happens which represents the occurrence of an event e that occurs at some point in time `t` within the time range `(t1, t2)` and is of instantaneous duration. The EC predicate `initiates(e, f, t)` signifies that a fluent `f` starts to hold after the event `e` occurs at time `t`. The EC predicate *`terminates(e, f, t)`* signifies that a fluent `f` ceases to hold after the event `e` occurs at time `t`. An EC formula may also use the predicates `initially(f)` and `holdsAt(f,t)` to signify that a fluent `f` holds at the start of the operation of a system and that `f` holds at time `t`, respectively.

EC-Assertion adopts the basic representation principles of EC and its axiomatic foundation and introduces special terms to represent the types of events and conditions that are needed for runtime monitoring. More specifically, given its focus on auditing the operation of software systems at runtime, events in EC-Assertion can be invocations of system operations, responses from such operations, or exchanges of messages between different system components. To represent these types of events, EC-Assertion defines a specific event structure that is syntactically represented by the event term `event(_id, _sender, _receiver, _status, _sig, _source)`.

[12] https://www.drools.org/

In this event term:

- *_id* is a unique identifier of the event;
- *_sender* is the identifier of the system component that sends the message/operation call/response;
- *_receiver* is the identifier of the system component that receives the message/operation call/response;
- *_status* is the processing status of an event (i.e., REQ if the event represents an operation invocation and RES if the event represents an operation response);
- *_sig* is the signature of the dispatched message or the operation invocation/response that is represented by the event, comprising the operation name and its arguments/result;
- *_source* is the identifier of the component where the event was captured

To provide an example of an EC monitoring rule, let us consider the case of a Monitoring Rule for Access Control, whereby the access to a webpage's (e.g., patient management web front end) administration page is monitored. Let us assume that said administration webpage is located at "`Home_page/wp-admin/admin_login.php`". Two rules are created in order to check if the admin services are only executed by admin users, and not by simple users, which could, for example, indicate that somehow a malicious user managed to perform privilege escalation and gain access to said restricted webpage. The two rules and the corresponding triggers would be as follows:

- **Rule 1** – Violation of access control by malicious user
  - **Event Type:** `event_admin_login`
  - **Event_args{}:** `{event_time,` **`John_Doe,`** `visited,` **`Home_page/wp-admin/admin_login.php`**`, 152.185.12.17,` **`simple_user`**`}`
  - **Event Trigger:** `Happens(event_admin_login, event_args{…,` **`User_role`**`}, time) ^` **`User_role=simple_user`** -> **Violation**
- **Rule 2** – Normal access of admin services
  - **Event ID:** `event_admin_login`
  - **Event_args{}:** `{event_time,` **`admin,`** `visited,` **`Home_page/wp-admin/admin_login.php`**`, 172.180.10.15,` **`administrator`**`}`
  - **Event Trigger:** `Happens(event_admin_login, event_args{…,` **`User_role`**`}, time) ^` **`User_role=administrator`** -> **Compliance**

Similar rules can be defined for different monitoring events across the layers of protected infrastructure, from the hardware to the network and to the process (application, operating system, etc.) level.

Finally, in terms of deployment, EVEREST can be operated on a containerized environment, while It can support Kubernetes clustered based architecture for scalable and distributed event recognition for the core part, combining it with cloud deployment compliancy (crucial for introducing it as a microservice, when needed).

2.3 The IntellIoT Assurance Model

Being model-driven, at the core of the operation of the Security Assurance Platform is the specification of the associated Assurance Model. Thus, the IntellIoT Assurance Model must be defined, and should holistically cover IntellIoT and its Use Case deployments, in this case.

In more detail, the assurance model should specify all assets of the target cyber system to be protected, known threats that may affect the physical or software components of the system; assumptions regarding the external environment of the cyber system and the behaviour of agents (human- or system-agents) related to it that may affect it (i.e., prevent or introduce threats); and security controls used to mitigate the risks arising from the threats.

The assurance model also specifies assessment procedures, to identify vulnerabilities, assess the proper function of security controls, and to determine how to detect and respond to cyber-attacks. To support this feature, it can also specify any assessment tools that should be employed for the aforementioned assessments prior the deployment of the system (i.e., static analysis and testing tools) or during its operation (i.e., monitoring and dynamic testing tools). Moreover, it specifies parameters determining how the attacks may manifest, how the security controls may respond to them (e.g., the attack manifestation events captured and detection time, the undertaken response actions) and the outputs that the deployed assessment tools will generate for the situation.

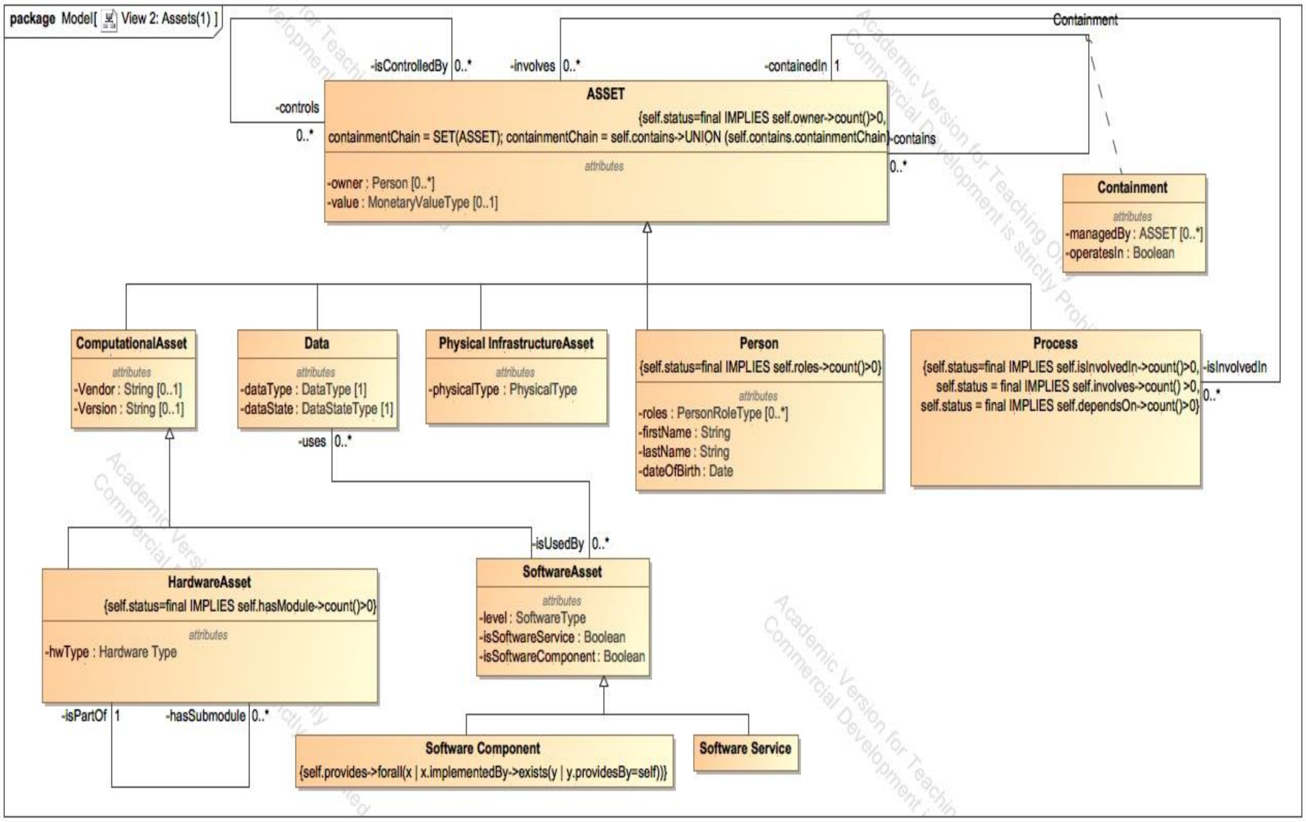

package Model[View 2: Assets(1)]
Containment
-isControlledBy 0..*
-involves 0..*
-containedIn 1
-controls
0..*
ASSET
{self.status=final IMPLIES self.owner->count()>0,
containmentChain = SET(ASSET); containmentChain = self.contains->UNION (self.contains.containmentChain}
-contains
0..*
attributes
-owner : Person [0..*]
-value : MonetaryValueType [0..1]
Containment
attributes
-managedBy : ASSET [0..*]
-operatesIn : Boolean
ComputationalAsset
attributes
-Vendor : String [0..1]
-Version : String [0..1]
Data
attributes
-dataType : DataType [1]
-dataState : DataStateType [1]
-uses 0..*
Physical InfrastructureAsset
attributes
-physicalType : PhysicalType
Person
{self.status=final IMPLIES self.roles->count()>0}
attributes
-roles : PersonRoleType [0..*]
-firstName : String
-lastName : String
-dateOfBirth : Date
Process
{self.status=final IMPLIES self.isInvolvedIn->count()>0,
self.status = final IMPLIES self.involves->count() >0,
self.status = final IMPLIES self.dependsOn->count()>0}
-isInvolvedIn
0..*
-isUsedBy 0..*
HardwareAsset
{self.status=final IMPLIES self.hasModule->count()>0}
attributes
-hwType : Hardware Type
-isPartOf 1
-hasSubmodule 0..*
SoftwareAsset
attributes
-level : SoftwareType
-isSoftwareService : Boolean
-isSoftwareComponent : Boolean
Software Component
{self.provides->forall(x | x.implementedBy->exists(y | y.providesBy=self))}
Software Service

Figure 9. Part of the Assurance Model, showing a view of the Asset sub-model

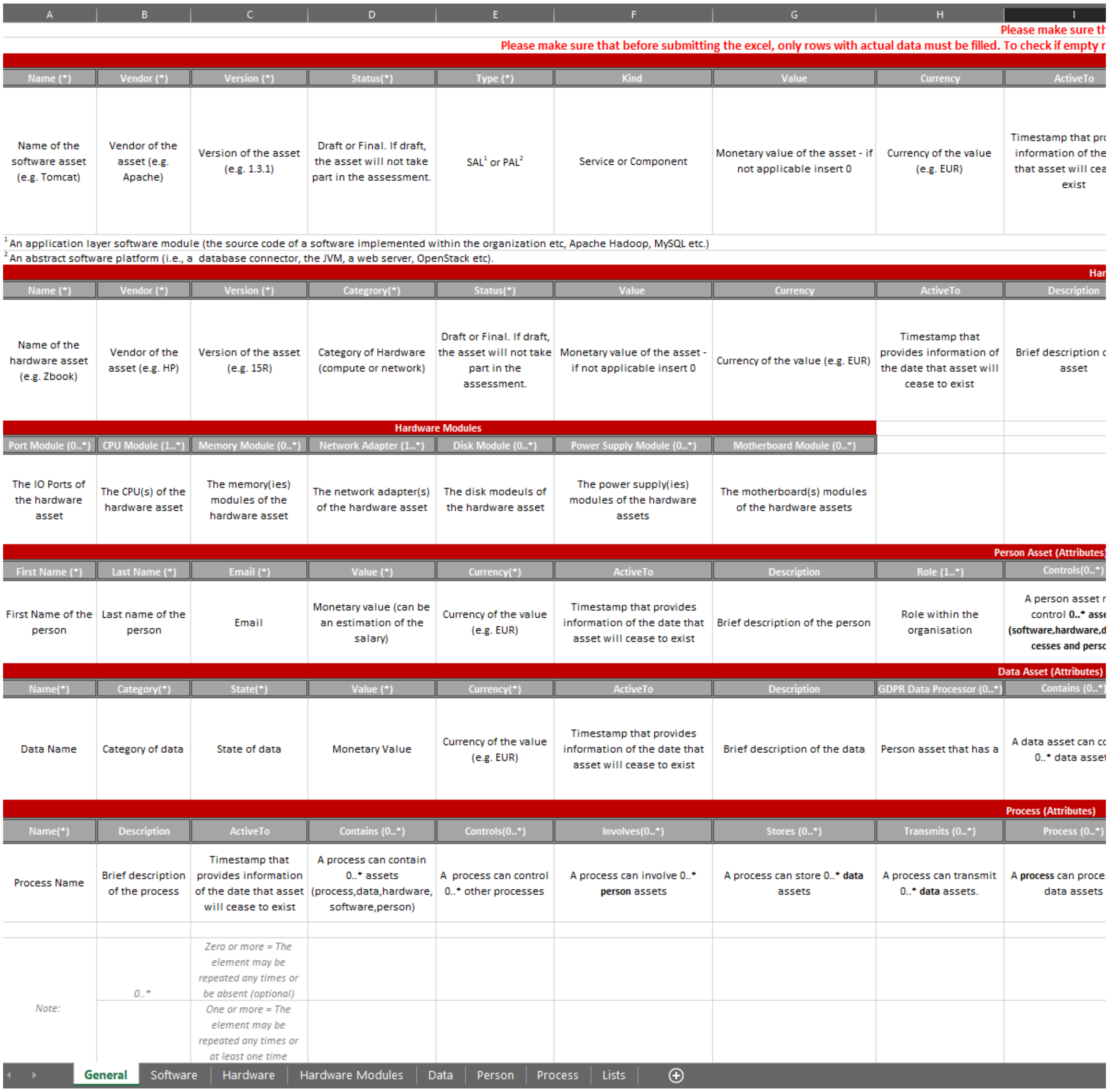
Since it encompasses all the above, the final model is quite complex - for the sake of brevity, only a high-level description is provided herein. More specifically, the Assurance model consists of the following:

- **Security Assurance Model Element:** The core element of the model, inherited by every other class within the model. Its specification includes the name of the element, the timestamp of the insertion of the element in the assurance platform, the timestamp of the deletion of the element from the assurance platform, a brief description of the element that states its purpose, and the user that inserted this element in the platform.
- **Asset sub-model:** Describes the different assets of the cyber system (i.e., all IntellIoT assets). In addition to the attributes inherited from the Security Assurance Model Element, it also includes the owner (person that owns the asset), its value (in monetary terms) and a number of associations, such as if it is protected by one or more security control(s), if it is contained within another asset and/or if it contains and/or controls other asset(s), and its exposed interfaces. Moreover, the Asset sub-model includes a number of sub-models for different types of assets; namely: *Physical Infrastructure Asset sub-model, Hardware Asset sub-model,*

Software Asset sub-model, Data Asset sub-model, Person Asset sub-model, Process Asset sub-model and Security Control Asset sub-model.

A partial view of the Assurance Model, covering the different types of assets in the Asset sub-model and their relationships, is provided in Figure 9.

To create an accurate instance of the IntellIoT assurance model, a specific process is established whereby all partners (i.e., asset owners) are involved. In more details, all Asset sub-model fields needed for assets' specification have been mapped onto tabs and tables of an Excel-based form (see Figure 10 and Annex A – IntellIoT Asset Model specification form). Said file was created to allow all partners to define the needed fields for their assets (IntellIoT components, as involved in each of the three use cases) without having to interact with the Assurance Tool itself.



A	B	C	D	E	F	G	H	I
								Please make sure th
				Please make sure that before submitting the excel, only rows with actual data must be filled. To check if empty r				
Name (*)	Vendor (*)	Version (*)	Status(*)	Type (*)	Kind	Value	Currency	ActiveTo
Name of the software asset (e.g. Tomcat)	Vendor of the asset (e.g. Apache)	Version of the asset (e.g. 1.3.1)	Draft or Final. If draft, the asset will not take part in the assessment.	SAL[1] or PAL[2]	Service or Component	Monetary value of the asset - if not applicable insert 0	Currency of the value (e.g. EUR)	Timestamp that pr information of the that asset will cea exist
[1] An application layer software module (the source code of a software implemented within the organization etc, Apache Hadoop, MySQL etc.)								
[2] An abstract software platform (i.e., a database connector, the JVM, a web server, OpenStack etc).								
								Har
Name (*)	Vendor (*)	Version (*)	Categrory(*)	Status(*)	Value	Currency	ActiveTo	Description
Name of the hardware asset (e.g. Zbook)	Vendor of the asset (e.g. HP)	Version of the asset (e.g. 15R)	Category of Hardware (compute or network)	Draft or Final. If draft, the asset will not take part in the assessment.	Monetary value of the asset - if not applicable insert 0	Currency of the value (e.g. EUR)	Timestamp that provides information of the date that asset will cease to exist	Brief description c asset
				Hardware Modules				
Port Module (0..*)	CPU Module (1..*)	Memory Module (0..*)	Network Adapter (1..*)	Disk Module (0..*)	Power Supply Module (0..*)	Motherboard Module (0..*)		
The IO Ports of the hardware asset	The CPU(s) of the hardware asset	The memory(ies) modules of the hardware asset	The network adapter(s) of the hardware asset	The disk modeuls of the hardware asset	The power supply(ies) modules of the hardware assets	The motherboard(s) modules of the hardware assets		
								Person Asset (Attributes)
First Name (*)	Last Name (*)	Email (*)	Value (*)	Currency(*)	ActiveTo	Description	Role (1..*)	Controls(0..*)
First Name of the person	Last name of the person	Email	Monetary value (can be an estimation of the salary)	Currency of the value (e.g. EUR)	Timestamp that provides information of the date that asset will cease to exist	Brief description of the person	Role within the organisation	A person asset r control **0..* asse (software,hardware,d cesses and persc**
								Data Asset (Attributes)
Name(*)	Category(*)	State(*)	Value (*)	Currency(*)	ActiveTo	Description	GDPR Data Processor (0..*)	Contains (0..*)
Data Name	Category of data	State of data	Monetary Value	Currency of the value (e.g. EUR)	Timestamp that provides information of the date that asset will cease to exist	Brief description of the data	Person asset that has a	A data asset can cc 0..* data asset
								Process (Attributes)
Name(*)	Description	ActiveTo	Contains (0..*)	Controls(0..*)	Involves(0..*)	Stores (0..*)	Transmits (0..*)	Process (0..*)
Process Name	Brief description of the process	Timestamp that provides information of the date that asset will cease to exist	A process can contain 0..* assets (process,data,hardware, software,person)	A process can control 0..* other processes	A process can involve 0..* **person** assets	A process can store 0..* **data** assets	A process can transmit 0..* **data** assets.	A **process** can proce data assets
Note:	*0..**	*Zero or more = The element may be repeated any times or be absent (optional)*						
		One or more = The element may be repeated any times or at least one time						

Figure 10. Partial view of the IntellIoT Asset Model specification form (cover page with instructions) – full view in Annex A – IntellIoT Asset Model specification form

In addition to the Excel-based form mentioned above, the asset model can be populated through the SAP front-end (a "wizard" guides the user through the steps), though this is a more time-consuming process, not intended for bulk specification of assets.

A third approach is using the Asset Model Grammar that is aligned with the structure of the underlying asset model. This method enables the bulk specification of assets within the SAP, where using the Excel form is considered inefficient (e.g., large number of assets). An example of an asset definition (in this case an instance of the Ubuntu Operating System) using the Grammar is provided below:

```
SoftwareAsset(vendor("Ubuntu"),version("18.04
LTS"),name("Ubuntu"),kind(Service),type(PAL),project("IntellIoT"),organisation("Sph
ynx Analytics Ltd."),description("Server OS"))
```

Additional samples of asset definitions through the Grammar are provided in Annex B – Asset Model Grammar.

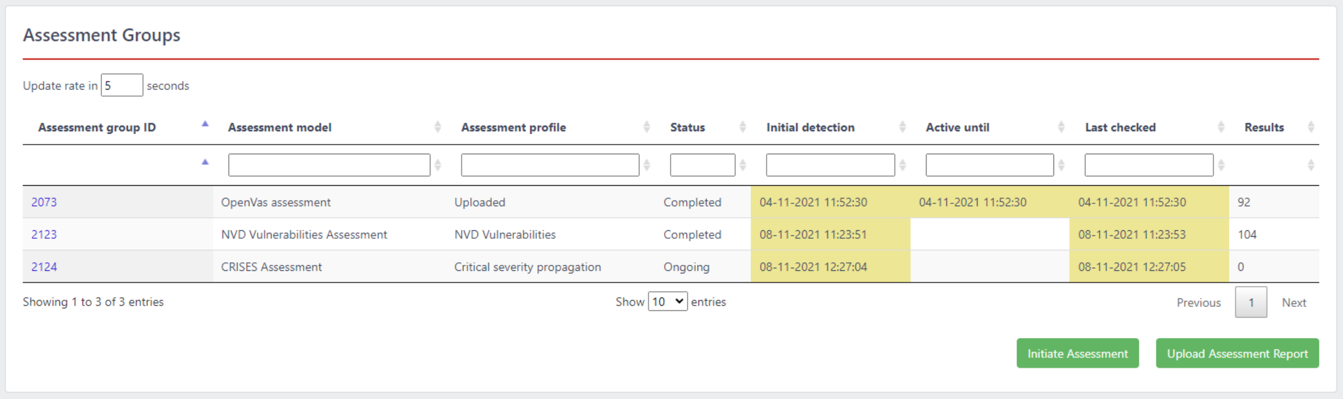
Once the process is completed, three instances of the IntellIoT Assurance Model will be derived, one for each use case deployment, covering the specific assets involved in said deployment. These will, of course, first reflect the Cycle 1 release and demonstrators of IntellIoT, while a second version of the models will be specified before the Cycle 2 demonstration. The latter will cover both the new/updated components involved in Cycle 2, but also the extended Use Case environments that will be used for the final validation.

2.4 Model-driven Assessments

The Assurance Tool, based on the IntellIoT Assurance Model described in the previous section, performs various types of security assessments based on the corresponding assessment models. More specifically, it supports:

(i) Monitoring Assessments;
(ii) Vulnerability Analysis Assessments;
(iii) Dynamic Testing Assessments;
(iv) Hybrid Assessments, combing (A)-(C) above.

Figure 11 presents the Assurance Tool Assessment page that allows the operator at the SAP (i.e., SAP user) to: (a) initiate a new assessment, (b) upload an existing assessment report and (c) view the existing assessments. Each existing assessment holds a number of general information such as: (a) the assessment model that was utilised (e.g., NVD Vulnerability Assessment), (b) the assessment profile that was used (e.g., focusing on Confidentiality), (c) the status of the assessment (e.g., ongoing), (d) the assessment's initial detection date, (e) how long the assessment is valid (this is mostly used by the monitoring assessment), (f) when the assessment was last checked and (g) the number of current assessment findings.



Assessment Groups

Update rate in 5 seconds

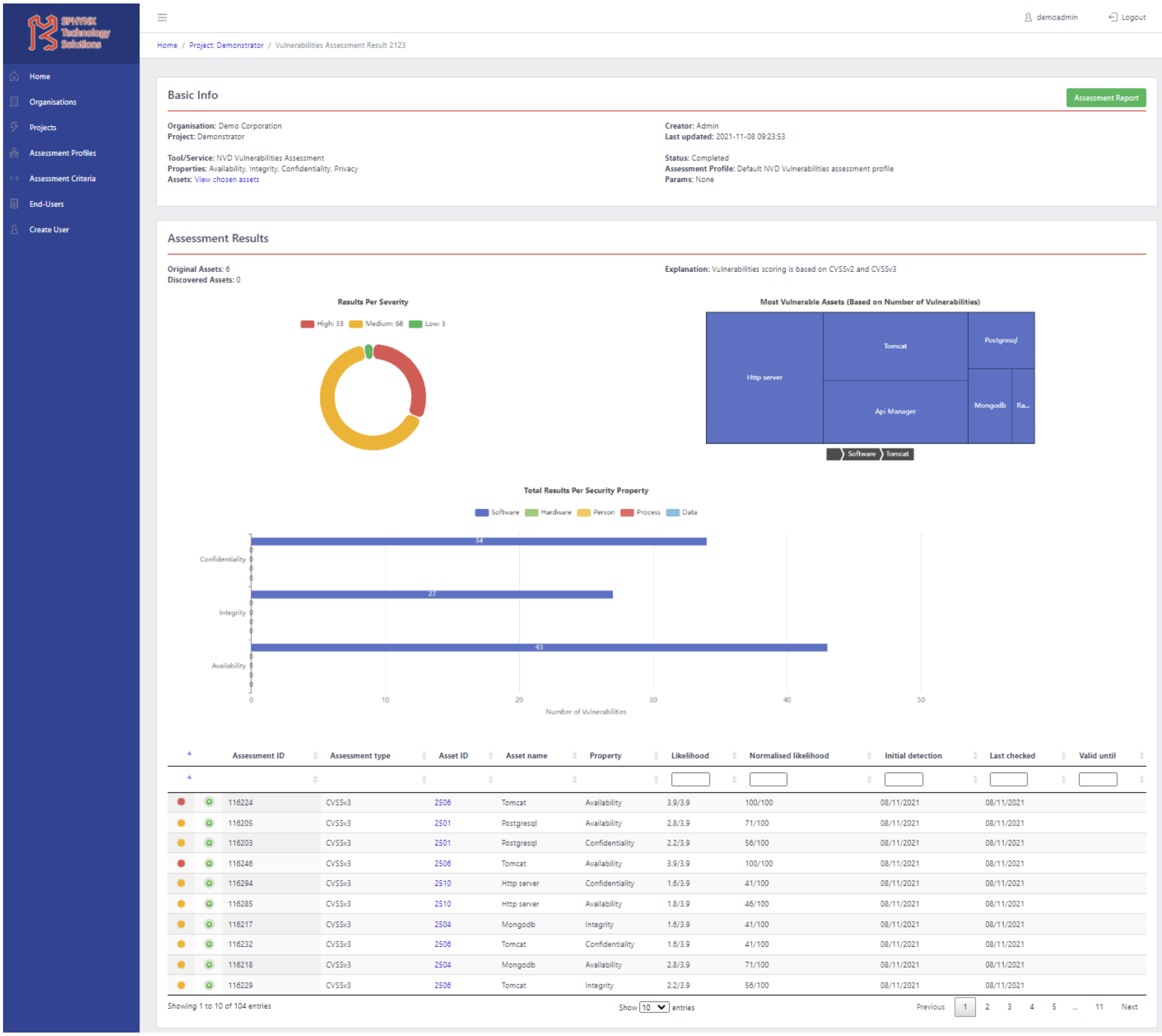
Assessment group ID	Assessment model	Assessment profile	Status	Initial detection	Active until	Last checked	Results
2073	OpenVas assessment	Uploaded	Completed	04-11-2021 11:52:30	04-11-2021 11:52:30	04-11-2021 11:52:30	92
2123	NVD Vulnerabilities Assessment	NVD Vulnerabilities	Completed	08-11-2021 11:23:51		08-11-2021 11:23:53	104
2124	CRISES Assessment	Critical severity propagation	Ongoing	08-11-2021 12:27:04		08-11-2021 12:27:05	0

Showing 1 to 3 of 3 entries

Show 10 entries

Figure 11. Listing of executed types of Security Assessments on SAP front-end

A user can examine the results of an assessment and some basic information about it by clicking on the "Assessment Group ID" column. As shown in Figure 12, the user is being presented with the basic information of the assessment such as a brief description, the project it belongs to, its creator, the date it was last updated, the tool/service that is being used, the security properties it checks, its status, the involved assets, and a brief description of the assessment profile. Some key statistics and other information are provided to the user in the form of charts and graphs (e.g., distribution of findings by severity, most vulnerable assets). Further below, the user can see individual assessment results, with some general parameters such as the assessment type, the asset it involves, the security property, the tool likelihood and a universal normalized likelihood, an initial detection timestamp (if applicable), the time it was last checked and the time it ceased to exist (if applicable).



Basic Info

Organisation: Demo Corporation
Project: Demonstrator

Tool/Service: NVD Vulnerabilities Assessment
Properties: Availability, Integrity, Confidentiality, Privacy
Assets: View chosen assets

Creator: Admin
Last updated: 2021-11-08 09:23:53

Status: Completed
Assessment Profile: Default NVD Vulnerabilities assessment profile
Params: None

Assessment Results

Original Assets: 6
Discovered Assets: 0

Explanation: Vulnerabilities scoring is based on CVSSv2 and CVSSv3

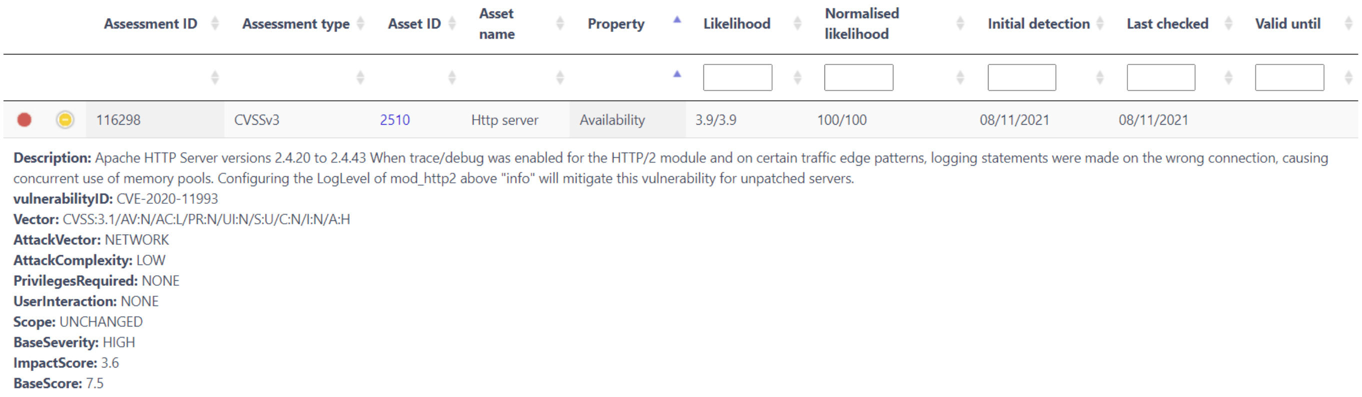
		Assessment ID	Assessment type	Asset ID	Asset name	Property	Likelihood	Normalised likelihood	Initial detection	Last checked	Valid until
🔴	⊕	116224	CVSSv3	2506	Tomcat	Availability	3.9/3.9	100/100	08/11/2021	08/11/2021	
🟠	⊕	116205	CVSSv3	2501	Postgresql	Availability	2.8/3.9	71/100	08/11/2021	08/11/2021	
🟠	⊕	116203	CVSSv3	2501	Postgresql	Confidentiality	2.2/3.9	56/100	08/11/2021	08/11/2021	
🔴	⊕	116246	CVSSv3	2506	Tomcat	Availability	3.9/3.9	100/100	08/11/2021	08/11/2021	
🟠	⊕	116294	CVSSv3	2510	Http server	Confidentiality	1.6/3.9	41/100	08/11/2021	08/11/2021	
🟠	⊕	116285	CVSSv3	2510	Http server	Availability	1.8/3.9	46/100	08/11/2021	08/11/2021	
🟠	⊕	116217	CVSSv3	2504	Mongodb	Integrity	1.6/3.9	41/100	08/11/2021	08/11/2021	
🟠	⊕	116232	CVSSv3	2506	Tomcat	Confidentiality	1.6/3.9	41/100	08/11/2021	08/11/2021	
🟠	⊕	116218	CVSSv3	2504	Mongodb	Availability	2.8/3.9	71/100	08/11/2021	08/11/2021	
🟠	⊕	116229	CVSSv3	2506	Tomcat	Integrity	2.2/3.9	56/100	08/11/2021	08/11/2021	

Showing 1 to 10 of 104 entries

Figure 12. An example of an assessment results screen in the SAP front end.

More specific information is provided in the screens of the different assessment types (i)-(iv), customised to better present the different types of assessment results. For instance, a specific result from a Vulnerability Assessment (i.e., using the Vulnerability Module – see Sect. 2.2.2) is shown in Figure 13, whereby CVE-2020-11993, pertaining to certain versions of the Apache HTTP server is found in the modelled assets. In this case, the presented information follows the latest version (V3.1) of the Common Vulnerability Scoring System (CVSS[13]), that provides a standardised way to capture the principal characteristics of a vulnerability and produce a numerical score reflecting its severity.

[13] https://www.first.org/cvss/v3.1/specification-document

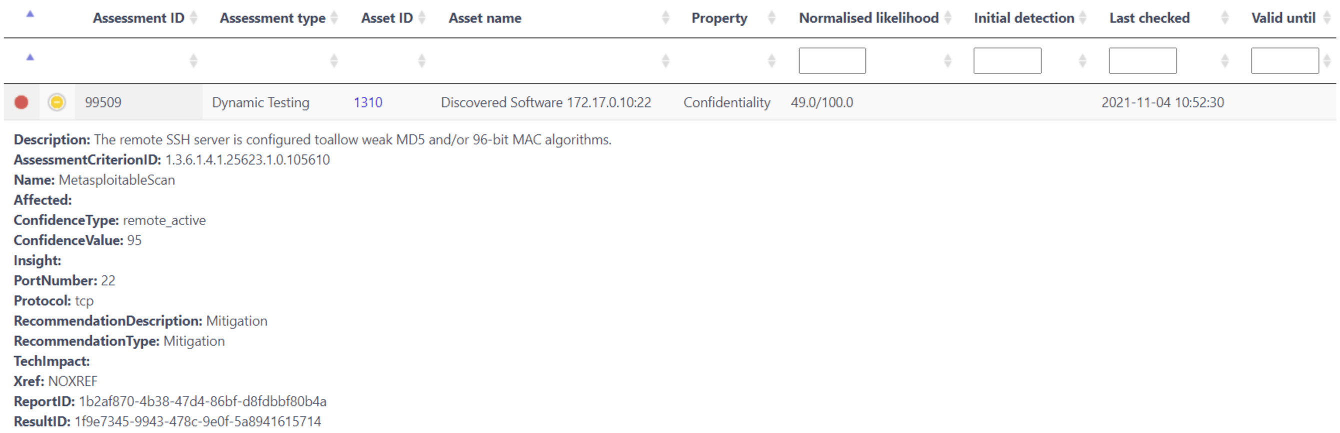


	Assessment ID	Assessment type	Asset ID	Asset name	Property	Likelihood	Normalised likelihood	Initial detection	Last checked	Valid until
● ⊖	116298	CVSSv3	2510	Http server	Availability	3.9/3.9	100/100	08/11/2021	08/11/2021	

Description: Apache HTTP Server versions 2.4.20 to 2.4.43 When trace/debug was enabled for the HTTP/2 module and on certain traffic edge patterns, logging statements were made on the wrong connection, causing concurrent use of memory pools. Configuring the LogLevel of mod_http2 above "info" will mitigate this vulnerability for unpatched servers.
vulnerabilityID: CVE-2020-11993
Vector: CVSS:3.1/AV:N/AC:L/PR:N/UI:N/S:U/C:N/I:N/A:H
AttackVector: NETWORK
AttackComplexity: LOW
PrivilegesRequired: NONE
UserInteraction: NONE
Scope: UNCHANGED
BaseSeverity: HIGH
ImpactScore: 3.6
BaseScore: 7.5

Figure 13. Viewing details of a specific finding of a Vulnerability Assessment

Another example, this time expanding on a specific finding of a Dynamic Testing Assessment carried out using the OpenVAS tool (i.e., using the Testing Module – see Sect. 2.2.3) is shown in Figure 14. In this case, a finding is presented that pertains to the SSH server found during the testing, and the tool identifies a specific vulnerability that stems from a misconfiguration of said server (revealed by directly interacting with the server). Here additional fields are provided, such as how the tool discovered the vulnerability, the confidence in the result (from 0-100, with 100 being that the vulnerability is certainly exploitable), and recommendations to mitigate the finding.

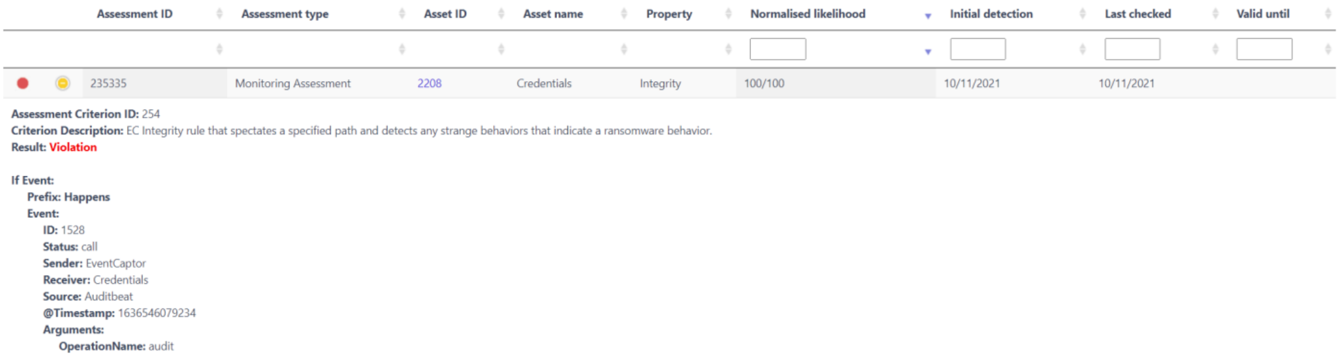


	Assessment ID	Assessment type	Asset ID	Asset name	Property	Normalised likelihood	Initial detection	Last checked	Valid until
● ⊖	99509	Dynamic Testing	1310	Discovered Software 172.17.0.10:22	Confidentiality	49.0/100.0		2021-11-04 10:52:30	

Description: The remote SSH server is configured toallow weak MD5 and/or 96-bit MAC algorithms.
AssessmentCriterionID: 1.3.6.1.4.1.25623.1.0.105610
Name: MetasploitableScan
Affected:
ConfidenceType: remote_active
ConfidenceValue: 95
Insight:
PortNumber: 22
Protocol: tcp
RecommendationDescription: Mitigation
RecommendationType: Mitigation
TechImpact:
Xref: NOXREF
ReportID: 1b2af870-4b38-47d4-86bf-d8fdbbf80b4a
ResultID: 1f9e7345-9943-478c-9e0f-5a8941615714

Figure 14. Viewing details of a specific finding of a Dynamic Testing Assessment

Finally, Figure 15 presents details on a finding from a Monitoring Assessment (i.e., using the EVEREST Monitoring Module, as detailed in Sect. 2.2.4). Here the finding is created through the "Violation" of a monitoring rule that was defined to observe for a specific pattern that may indicate ransomware activity. The result provides details on which Event Captor triggered the rule (i.e., where the violation was observed), the exact source and receiver, the time stamp, and other details that allow to uniquely identify the event (and, consequently, the suspicious behaviour), allowing triggering of appropriate mitigation actions, if needed (e.g., through the MTDs), and providing the necessary evidence required for audit purposes.



		Assessment ID	Assessment type	Asset ID	Asset name	Property	Normalised likelihood	Initial detection	Last checked	Valid until
●	●	235335	Monitoring Assessment	2208	Credentials	Integrity	100/100	10/11/2021	10/11/2021	

Assessment Criterion ID: 254
Criterion Description: EC Integrity rule that spectates a specified path and detects any strange behaviors that indicate a ransomware behavior.
Result: Violation

```
If Event:
    Prefix: Happens
    Event:
        ID: 1528
        Status: call
        Sender: EventCaptor
        Receiver: Credentials
        Source: Auditbeat
        @Timestamp: 1636546079234
        Arguments:
            OperationName: audit
```

Figure 15. Viewing details of a specific finding of a Monitoring Assessment

Finally, in terms of Hybrid Assessments (i.e., the most complex assessment type), a purpose-defined language is developed – CRISES - to support such Hybrid Assessments that will combine the results from other Assessments (as the ones shown above) based on criteria defined by the user.

In more detail, CRISES is a pipelined, query-type language that allows for the definition of arbitrary risk models for the propagation of assessments produced by SAP assessments. CRISES also allows the execution of a hybrid analysis, i.e., an analysis that combines two or more of SAP's assessments.

CRISES can be as simple as:

```
FETCH y1:Assessment_Model_Execution, y2:Assessment_Model_Execution, y3:Assessment_Model_Execution,
x:Asset, z:Asset, ar1:Monitoring_Assessment_Result, ar2: CTI_Assessment_Result,
ar3:Monitoring_Assessment_Result

SUCH THAT (y1.INVOLVES=x AND y2.INVOLVES=x AND y1.PRODUCES=ar1 AND y2.PRODUCES=ar2 AND y3.INVOLVES=z
AND y3.PRODUCES=ar3)

FILTER (x.ASSET_TYPE=DATA AND z.ASSET_TYPE=PROCESS, ar1.timestamp IN (CURRENT_TIMESTAMP -
365,CURRENT_TIMESTAMP) AND x.CATEGORY=authentication/authorization AND z.DEPENDS=x)

GENERATE

ASSESSMENT_RESULT nar.assessment_Result

ASSET nar.asset IN (z)

SECURITY_PROPERTY (nar.Security_Property = ar3.Security_Property)

LIKELIHOOD (nar.likelihood = MAX((ARO(ar2)),(COUNT(ar1.likelihood=1)/COUNT(ar1))))

VALUE (nar.value = FORMULA(ar3.variable(downtime)*z.value))
```

As you may observe, in CRISES each line of the query is a transformation of the previous line's result.

Further, CRISES is designed considering the following principles:

- Pipelined: A CRISES query is a linean pipeline of transformations.
- Extensible: CRISES is based on SPHYNX's Assurance Model. As the model evolves, CRISES will be extended to support the definition/utilisation of the newly introduced components (e.g. new assets or assessments).
- Analytical: CRISES queries are analytical, as they emphasize data transformations, and speed.

Therefore, through the SPA front-end, CRISES (hybrid) assessments will be able to be defined and executed.

2.5 Orchestration, Automation & Incident Response

A novel tool showcased in Cycle 2 of IntellIoT is the Incident Response tool, being considered part of SAP’s toolset, that allows the orchestration & automation of the framework’s various Trust enablers to respond to various incidents detected.

This enabler is based on the Sphynx Incident Response (IR) platform, which is a system that enables the manual or automated execution of “Collaborative Automated Course of Action Operations” (CACAO [10]) security playbooks. CACAO is an OASIS specification that provides a playbook schema and a taxonomy that standardizes the way one can create, document, and share defenders’ cybersecurity operations processes and procedure.

The platform can be set up either as a standalone system or as a module integrated with the SAP. As a standalone solution, the IR platform can import, export, and execute CACAO security playbooks triggered by a variety of third-party tools utilizing each playbook's REST API. As a module of the SAP, the IR platform can be used to execute security playbooks triggered by the SAP’s components, such as EVEREST and CRISIS and utilize information obtained by the Asset Model. Also, the IR platform can be used to orchestrate the SAP’s components, in addition to IntellIoT’s other trust enablers.

Overall, this tool offers a graphical drag-n-drop interface for creating and editing CACAO security playbooks, that can later be executed or exported as CACAO JSON files following the CACAO specification. Figure 16 shows how a playbook (in this case a preventative playbook related to the FuzzyPanda malware) can be defined within the tool’s GUI.

Finally, the IR platform also offers an interactive dashboard that provides real-time views of the system's status and the execution of security playbooks along with high- and low-level logs, KPIs, user notification and other information.

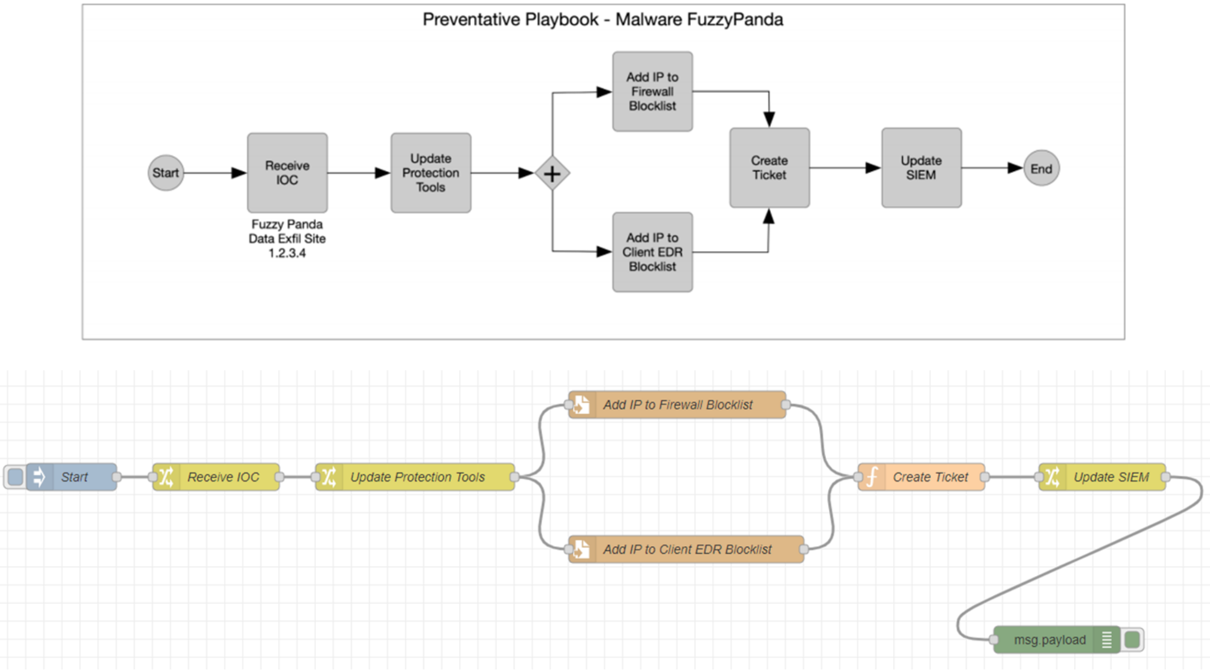

Preventative Playbook - Malware FuzzyPanda
Start
Receive IOC
Fuzzy Panda Data Exfil Site 1.2.3.4
Update Protection Tools
Add IP to Firewall Blocklist
Add IP to Client EDR Blocklist
Create Ticket
Update SIEM
End
Start
Receive IOC
Update Protection Tools
Add IP to Firewall Blocklist
Add IP to Client EDR Blocklist
Create Ticket
Update SIEM
msg.payload

Figure 16. Sample IR playbook (top) defined within the IRM editor (bottom)

2.5.1 IR TOOL ARCHITECTURE

The Incident Response platform is composed of five main components as presented in Figure 17. The various components can be co-located on a single host or distributed across multiple hosts. Each component is isolated in its dedicated Docker container while native deployment is also available but not recommended. Also, the components should preferably be deployed on a secured and monitored infrastructure, outside of the target organization to ensure their uninterrupted and tamper-proof execution.

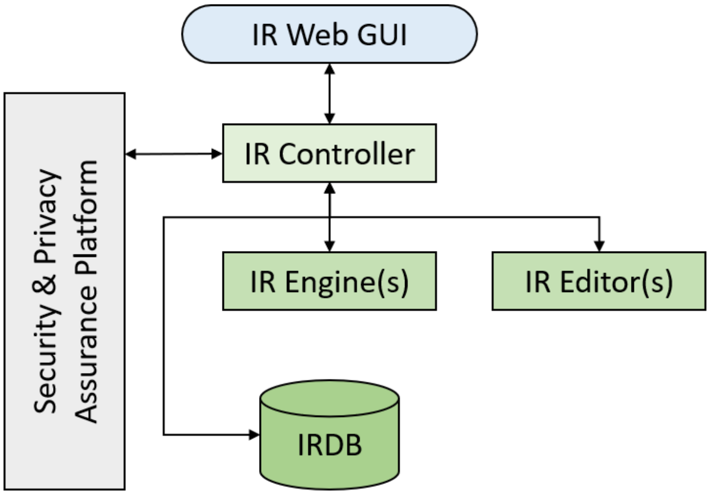


Figure 17. IR Platform architecture overview.

More details on each component are provided below:

- **IR Web GUI:** The Web-based front-end through which the end users and administrators can interact with and control the IR platform. The GUI is implemented using the Angular[14] framework and provides dedicated views for browsing the available playbooks and allows users to enable or disable a playbook's availability for execution. Also, the GUI offers real-time views of enabled playbooks through which the platform's operators can monitor, start, stop, or restart a playbook's execution. The monitoring view includes an interactive, real-time graph presenting each playbook's step status as the playbook is executing, high- and low-level logs, the event that triggered the execution and various statistics, such as execution metrics. Also, administrators can manage the available playbook execution engines, create, or delete engine instances and assign playbooks to the available engines. Finally, the GUI provides a graphical drag-and-drop editor where playbooks can be edited or created by modifying their execution graph, exported as CACAO JSON files, or imported via a valid CACAO JSON file.
- **IR Controller:** The Java/Spring Boot-based[15] REST controller that orchestrates the GUI, the Engine(s), the Editor(s) and the IRDB. The controller provides separate APIs for managing (i) the available IR engines, (ii) the Editors used by each user, (iii) playbook modifications, (iv) logging capabilities, (v) playbook availability and execution status, (vi) metrics and KPIs. The IR Controller can be executed on a dedicated host, isolated from the rest of the platform's components.

[14] https://angular.io/
[15] https://spring.io/

- **IR Engine:** A sand-boxed Node-RED[16] instance that hosts the CACAO security playbook engine module that serves as the platform's playbook execution engine. The instance's native Web GUI is disabled, and no playbook modifications are allowed for playbooks running in this instance. The engine module is developed using NodeJS, HTML, CSS, and Jolt Specs[17]. An IR platform instance can utilize more than one engine for redundancy, isolation, testing or scalability. Engine instances can be managed through the IR Web GUI or directly through the respective Engine REST API.
- **IR Editor:** A sand-boxed Node-RED instance that hosts the CACAO security playbook engine module that serves as the modification space for new or existing playbooks. Playbooks in this instance can only be modified and cannot be executed through this instance. IR editor instances are unique per user. Each Editor instance is created on request and is discarded after use. The engine module found in these instances also contains the translate node that responsible for transforming CACAO playbooks to Node-RED flows. Editor instances can be managed through the IR Web GUI or directly through the respective Editor REST API.
- **Irdb:** A PostgreSQL[18] database that stores all the required information for playbook execution and storage. This database is detached from the rest of the SPAP's databases. The database is maintained under the IRDB directory.

2.5.2 PLAYBOOK DETAILS

2.5.2.1 PLAYBOOK STEPS' OVERVIEW

The IR platform enables the design and execution of CACAO security playbooks following the v1.1 CACAO specification. Such playbooks can be composed of the following seven steps: (i) *start*, (ii) *end*, (iii) *single*, (iv) *parallel*, (v) *if*, (vi) *switch* and (vii) *while* step.

The *start* and *end* steps indicate the starting and ending point of each playbook and thus are always required. The *single* steps are responsible for executing the actions indicated at each execution point. These actions can be shell commands, execution of REST API calls or requests to be executed manually by a human operator. The *parallel* steps indicate the execution of a set of steps in parallel while the *if* and *switch* commands designate branching based on a condition. Finally, the *while* steps indicate looping based on a condition. The steps are linked together, starting from the *start* step and ending at the *end* step, thus composing the playbook's logic as a graph with each step being a node.

The IR platform also provides an extra step, dedicated to translating CACAO playbooks to IR Engine executable playbook flows in real-time, named *translate*. In the Engine, each step is available as a graph node, that can be dragged and dropped on the canvas in order to design or edit a playbook. The list of available steps is presented in Figure 18.

[16] https://nodered.org
[17] https://github.com/bazaarvoice/jolt
[18] https://www.postgresql.org

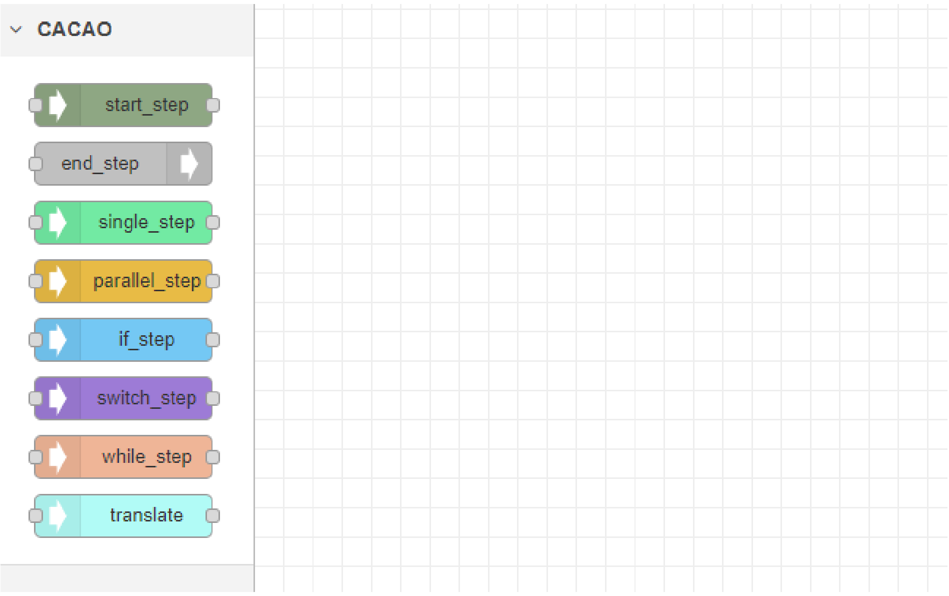


Figure 18. CACAO playbook steps as drag-and-drop enabled graph nodes.

2.5.2.2 PLAYBOOK DESIGN

Designing a playbook is performed in a drag-and-drop fashion, starting with placing a *start* and an *end* step on the canvas. Then, the playbook's logic is created by placing, *single* and conditional steps on the canvas and linking them together with edges connecting the various steps. The execution follows the edges from the *start* step to the *end* step and branches according to the specified conditional steps and the evaluation of each condition.

An example of a playbook containing three *single* steps that will be executed in sequence is presented in Figure 19. The execution starts from the leftmost node (the *start* step) and follows the edge towards the first *single* step, named "Receive white list". This step is responsible for performing the appropriate action(s) and command(s) that will retrieve the specified IP whitelist in this example. Steps can use variables to write and read data and these variables are passed to the following steps while they are executed. Once this step is finished, the execution follows the edge towards the next *single* step named "Update Firewall". This step is now responsible to update the firewall with the previously retrieved white list, utilizing the variables set by the previous step. Then, the playbook executes the "Notify Admin" *single* step, responsible to notify the network administrator about the operations performed by the playbook. The execution terminates upon reaching the end step.

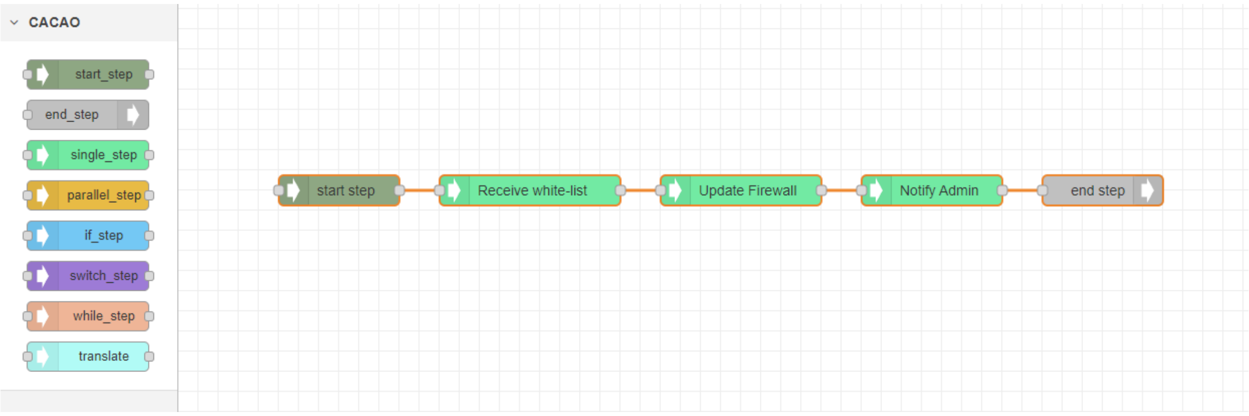


Figure 19. A simple CACAO playbook performing three operations.

This simple playbook can be executed by the Engine or exported as a CACAO JSON file to be shared across other parties. While the playbook's parameters might require tuning based on the target system, the playbook's logic is preserved when sharing the playbook. For example, this playbook handles the logical operation of retrieving an IP white-list, updating the firewall with the white-list, and then notifying the administrator. However, the commands that have to be executed to perform these actions might need to be modified depending on the target system. For example, the playbook might need to retrieve the white list from a different location, update a different type of firewall system and notify a different administrator when it is utilized by another organization.

2.5.3 INTELLIOT USE CASE -SPECIFIC PLAYBOOKS

In this section we present the playbooks designed to be utilized within each of IntellIoT's use cases, for the Cycle 2 (& final) demonstration of the project. These follow the enhanced use case scenario descriptions that have been documented and planned for Cycle 2, as detailed in deliverable D2.4 – "Use Case specification & Open Call definition (final version)". It is expected that updates will take place once the playbooks are actually tested in the final IntellIoT integrated framework, but any such updates will be documented in the relevant WP5 deliverables.

2.5.3.1 USE CASE 1

In this use case, the playbook presented in Figure 20 is used to notify the administrators about mitigation plans performed by the MTD. Once there is a status change event, the playbook is triggered an its first operation is to receive information about the current MTD status. Then, the playbook evaluates the current status to the previous and if a change is observed, it notifies the administrators via e-mail. No action is performed if the event that triggered the playbook does not involve changes to MTD's status.

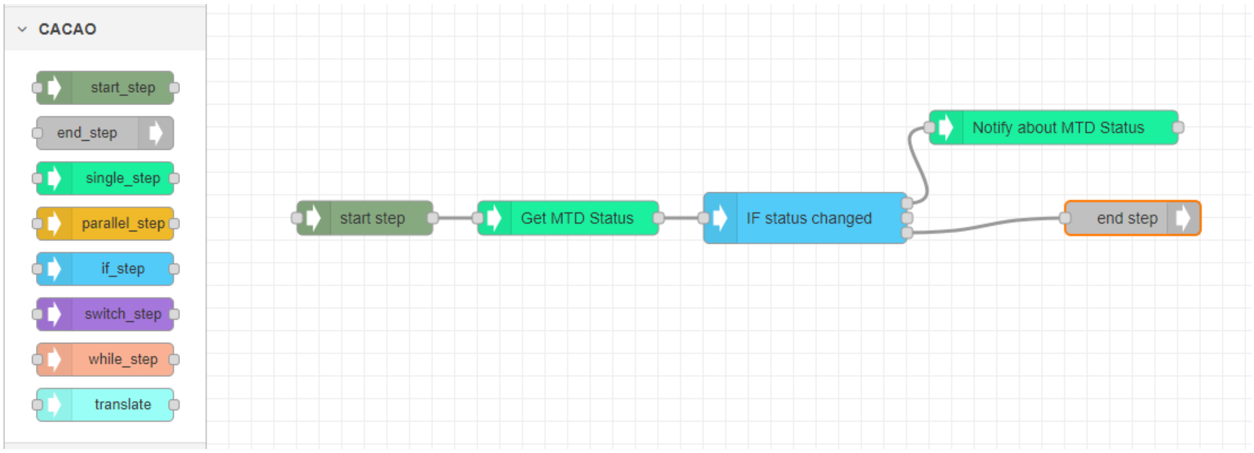


Figure 20. Indicative Use Case 1 playbook.

2.5.3.2 USE CASE 2

In this use case, two separate playbooks are utilized, as presented in Figure 21. The first playbook is triggered to mitigate a ransomware attack while the second is triggered to mitigate a botnet malware infection. Both playbooks start by isolating the host from the network to prevent further malware contamination in the system and request a CRISES assessment. Then, the ransomware-specific playbook notifies the administrators that a ransomware mitigation is taking place and proceeds with removing the malicious executable. Once the system is disinfected, the playbook restores possibly encrypted files from the designated backup. Then, it restores the host's connection and terminates.

The botnet-specific playbook generates a different notification message and proceeds with removing all botnet-related files and executables. Finally, when the attack is mitigated, it restores the host's network connection and terminates.

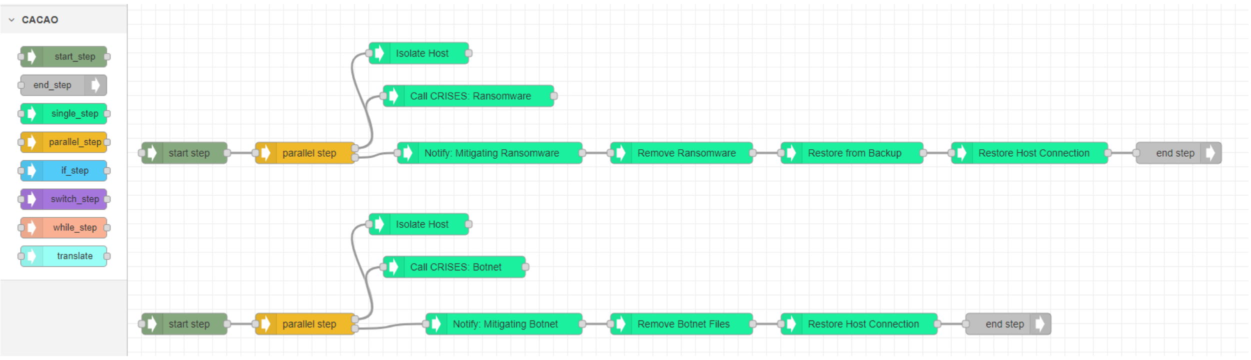


Figure 21. Indicative Use Case 2 playbook.

2.5.3.3 USE CASE 3

In this use case, the playbook is set to listen for events indicating suspicious robot activity. Once such an event is captured, the playbook notifies the administrator about the suspicious event and requests a confirmation of whether to proceed with the mitigation. If the administrator responds positively, the playbook logs the event and the administrator's response and the triggers the MTD. Otherwise, only the event and the negative administrator response are logged. The playbook is presented in Figure 22.

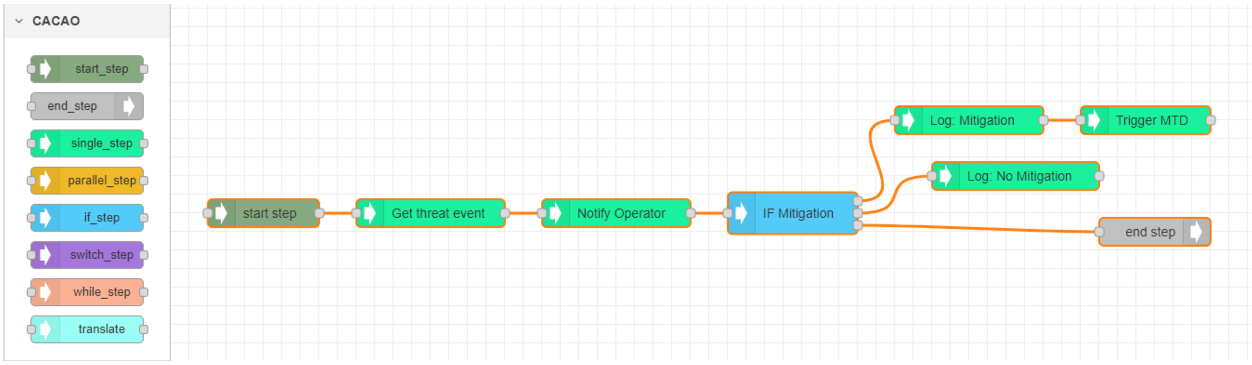


Figure 22. Indicative Use Case 3 playbook.

3 AUTHENTICATION, AUTHORISATION AND ACCOUNTING

Authentication, Authorization, and Accounting (AAA) in IntellIoT is provided through a framework that allows legitimate users or applications to gain access to protected resources, thus ensuring network security. It can enforce policies (e.g., define multiple permission levels) and audit usage.

The solution selected for IntellIoT is Keycloak[19]. Keycloak is an open-source Identity and Access Management tool for modern applications and services. It uses industry-standard protocols like OpenID Connect[20] for authentication and OAuth 2.0[21] [1] for authorization (OpenID Connect is an extension to OAuth 2.0). This allows for easy integration and well-regarded security.

Keycloak includes a dedicated server that centrally controls user access. This decouples local security configuration considerations and allows for better scalability and less administrative tasks. For example, if a user is added in Keycloak and configured to have access on some servers within the network, no additional configuration to those servers is needed. The same applies for either adding or revoking user permissions or adding a new resource that some users need to have access to. Furthermore, the servers available on the network are not tasked with storing user credentials locally, which is a preferable approach from both a security and an administrative perspective.

Authorization is the process of evaluating to what extent a user can access a resource. With OAuth 2.0, the following four roles are defined:

- **Resource Owner** (i.e., any entity that owns protected resources, such as files)
- **Resource Server** (e.g., the actual server that keeps the files)
- **Client** (e.g., an application that requests access to a resource from the server is a client)
- **Authorization Server** (the Keycloak server itself in this case)

When a Client wants to access a resource on behalf of an Owner in the Server, it first contacts the Authorization Server. The Authorization Server issues a JSON Web Token (JWT) [3] that grants limited access to the resources, which can then be used to access the Resource Server. JWT tokens are also a standard format based on JSON, supported by libraries for various programming languages[22]. An example id token from authorization is:

```
{
  "exp": 1637007044,
  "iat": 1637006744,
  "auth_time": 1637006744,
  "jti": "fc16ab93-321f-4546-82a7-49f3ecf2b5bf",
  "iss": "http://localhost:8080/auth/realms/myrealm",
  "aud": "myclient",
  "sub": "8007e9f0-db9e-412b-aff8-7775c4088d92",
  "typ": "ID",
  "azp": "myclient",
```

[19] https://www.keycloak.org/
[20] https://openid.net/connect/
[21] https://oauth.net/2/
[22] https://jwt.io/

```
  "nonce": "35aa914f-a761-47d6-814e-be1119b9baec",
  "session_state": "716beddd-14e0-49ca-9081-a6f2a76e881d",
  "at_hash": "9VSilBvnLGVgqtyMYhkHUg",
  "acr": "1",
  "sid": "716beddd-14e0-49ca-9081-a6f2a76e881d",
  "email_verified": true,
  "preferred_username": "myuser"
}
```

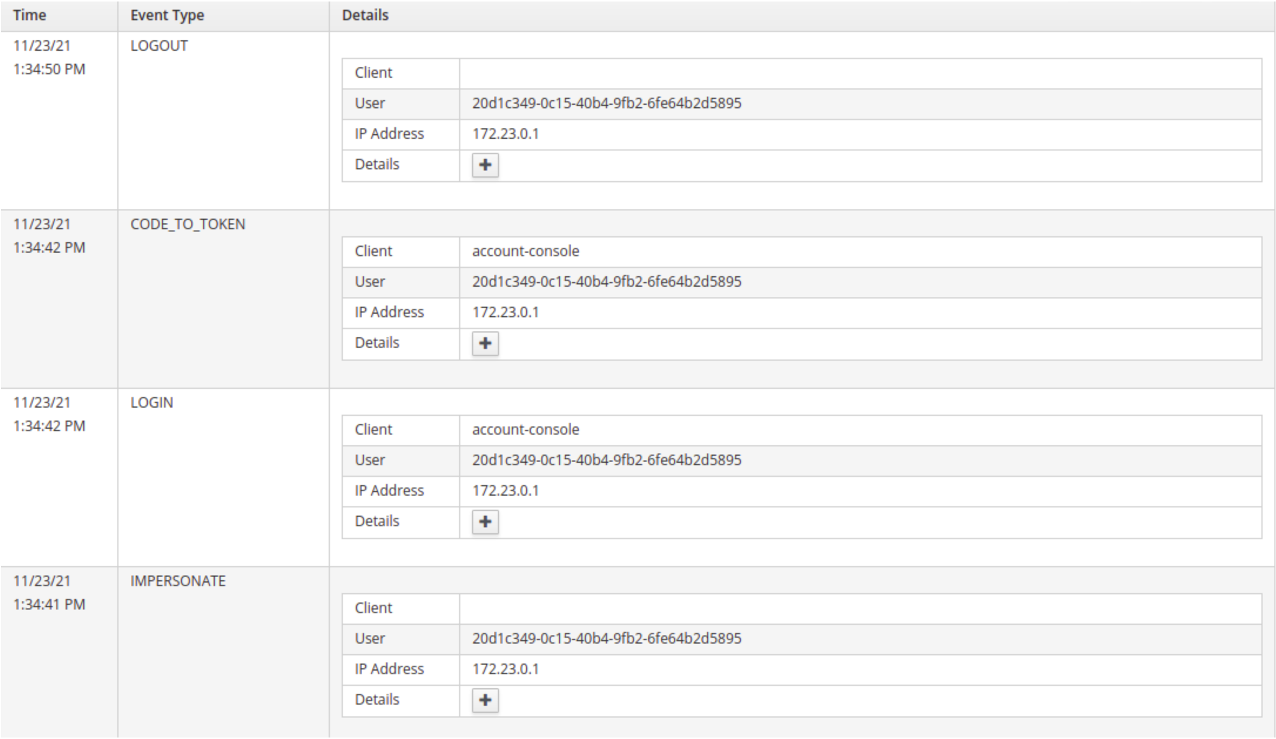
Authentication is the process of identifying a user. OpenID Connect defines three roles:

- **End User** (i.e., entity that needs to be authenticated)
- **Relying Party** (the application/server that asks for a user to authenticate himself/herself before accessing it)
- **OpenID Provider** (the server providing the actual authentication, i.e., Keycloak in this case)

Similarly, to the authorization case, a JWT token is used, that contains additional information to signify the authentication process. An example access token from authentication is:

```
{
  "exp": 1637007044,
  "iat": 1637006744,
  "auth_time": 1637006744,
  "jti": "a7b83fea-c54e-4af1-83e9-3ed4e5a2b0c2",
  "iss": "http://localhost:8080/auth/realms/myrealm",
  "aud": "account",
  "sub": "8007e9f0-db9e-412b-aff8-7775c4088d92",
  "typ": "Bearer",
  "azp": "myclient",
  "nonce": "35aa914f-a761-47d6-814e-be1119b9baec",
  "session_state": "716beddd-14e0-49ca-9081-a6f2a76e881d",
  "acr": "1",
  "allowed-origins": [
    "http://localhost:8000"
  ],
  "realm_access": {
    "roles": [
      "default-roles-myrealm",
      "offline_access",
      "uma_authorization",
      "myrole"
    ]
  },
  "resource_access": {
    "account": {
      "roles": [
        "manage-account",
        "manage-account-links",
        "view-profile"
      ]
    }
  },
  "scope": "openid email profile",
  "sid": "716beddd-14e0-49ca-9081-a6f2a76e881d",
  "email_verified": true,
  "preferred_username": "myuser"
}
```

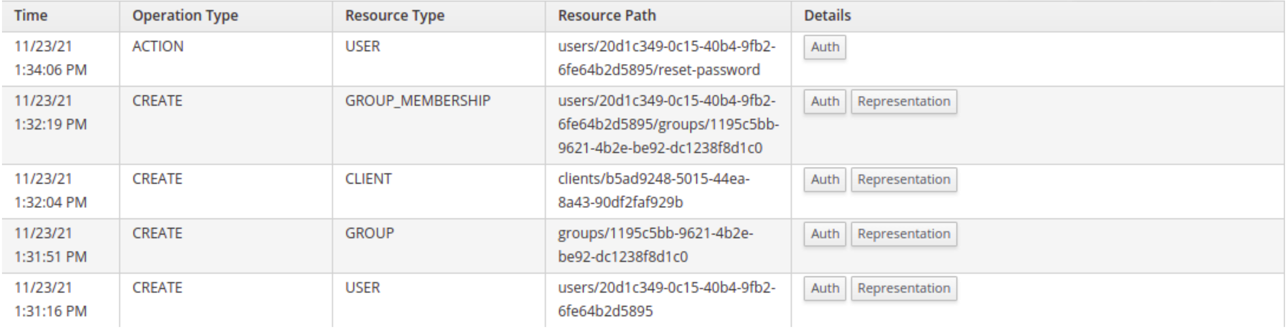
Accounting is the last functionality provided which is about monitoring authentication and authorization events for auditing. These are clustered in two categories: the login events and the admin events. Login events are generated during normal operation and cover all authentication and authorization aspects. Some basic examples are 'Login', 'Login Error', 'Register' and 'Logout', as shown in Figure 23.



Time	Event Type	Details
11/23/21 1:34:50 PM	LOGOUT	Client: User: 20d1c349-0c15-40b4-9fb2-6fe64b2d5895 IP Address: 172.23.0.1 Details: +
11/23/21 1:34:42 PM	CODE_TO_TOKEN	Client: account-console User: 20d1c349-0c15-40b4-9fb2-6fe64b2d5895 IP Address: 172.23.0.1 Details: +
11/23/21 1:34:42 PM	LOGIN	Client: account-console User: 20d1c349-0c15-40b4-9fb2-6fe64b2d5895 IP Address: 172.23.0.1 Details: +
11/23/21 1:34:41 PM	IMPERSONATE	Client: User: 20d1c349-0c15-40b4-9fb2-6fe64b2d5895 IP Address: 172.23.0.1 Details: +

Figure 23. Login events in the Accounting subsystem of Keycloak

Admin events are generated during Keycloak administration and cover any action that can be performed from within the administration web UI. Example of such events are 'Create/User', 'Create/Group' and 'Action/User' (see Figure 24).



Time	Operation Type	Resource Type	Resource Path	Details
11/23/21 1:34:06 PM	ACTION	USER	users/20d1c349-0c15-40b4-9fb2-6fe64b2d5895/reset-password	Auth
11/23/21 1:32:19 PM	CREATE	GROUP_MEMBERSHIP	users/20d1c349-0c15-40b4-9fb2-6fe64b2d5895/groups/1195c5bb-9621-4b2e-be92-dc1238f8d1c0	Auth Representation
11/23/21 1:32:04 PM	CREATE	CLIENT	clients/b5ad9248-5015-44ea-8a43-90df2faf929b	Auth Representation
11/23/21 1:31:51 PM	CREATE	GROUP	groups/1195c5bb-9621-4b2e-be92-dc1238f8d1c0	Auth Representation
11/23/21 1:31:16 PM	CREATE	USER	users/20d1c349-0c15-40b4-9fb2-6fe64b2d5895	Auth Representation

Figure 24. Admin events (e.g., user creation) as recorded in the Accounting subsystem of Keycloak

Every action can be recorded and stored in the Keycloak database as well as the system log. For example, a system log for a 'Login' event is shown below:

```
Nov 12 11:33:16 mathousalix oauth2-aaa[2010]: 09:33:16,343 DEBUG
[org.keycloak.events] (default task-7) type=LOGIN, realmId=master,
clientId=security-admin-console, userId=8a28a08b-c8f2-4fb2-a34d-2867033b5230,
ipAddress=172.20.0.1, auth_method=openid-connect, auth_type=code,
response_type=code, redirect_uri=http://localhost:8080/auth/admin/master/console/,
consent=no_consent_required, code_id=ac84a4c0-0e3f-4490-80ec-8d3e0bf9d504,
username=admin, response_mode=fragment, authSessionParentId=ac84a4c0-0e3f-4490-
80ec-8d3e0bf9d504, authSessionTabId=t6PT86TqkU4
```

In the following two subsections, two approaches in the deployment of Keycloak in IntellIoT are presented. The first one is a containerised direct deployment of Keycloak, while the second one uses an intermediate reverse proxy node between a web application and a service that requires authentication and authorization.

3.1 Direct deployment

To facilitate integration with the IntellIoT deployments in the different use cases, Keycloak will be used as a Docker[23] container, allowing to be easily spawned in different use case environments.

An example authentication for an application[24] is showcased in Figure 25. A newly created instance of Keycloak contains only an administrator account and a default Master realm. A realm is a self-contained configuration, isolated from other realms. It aggregates all the relevant information such as the users, groups, roles that comprises a secure environment.

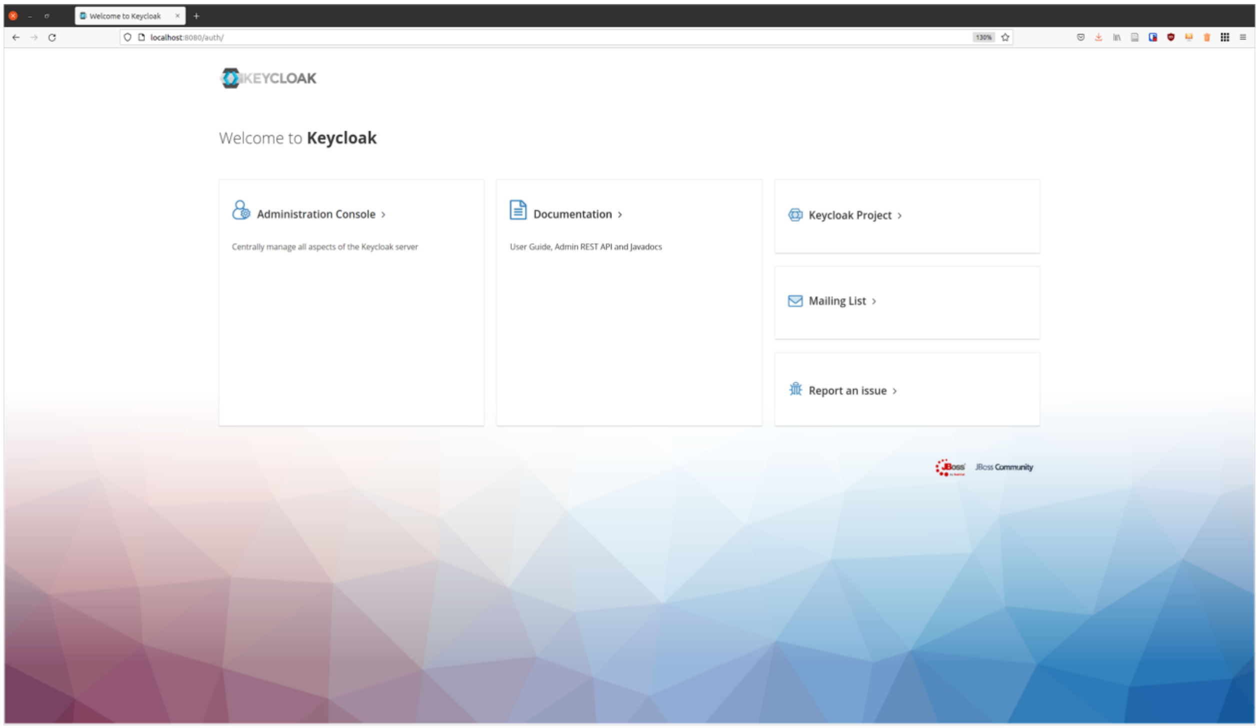
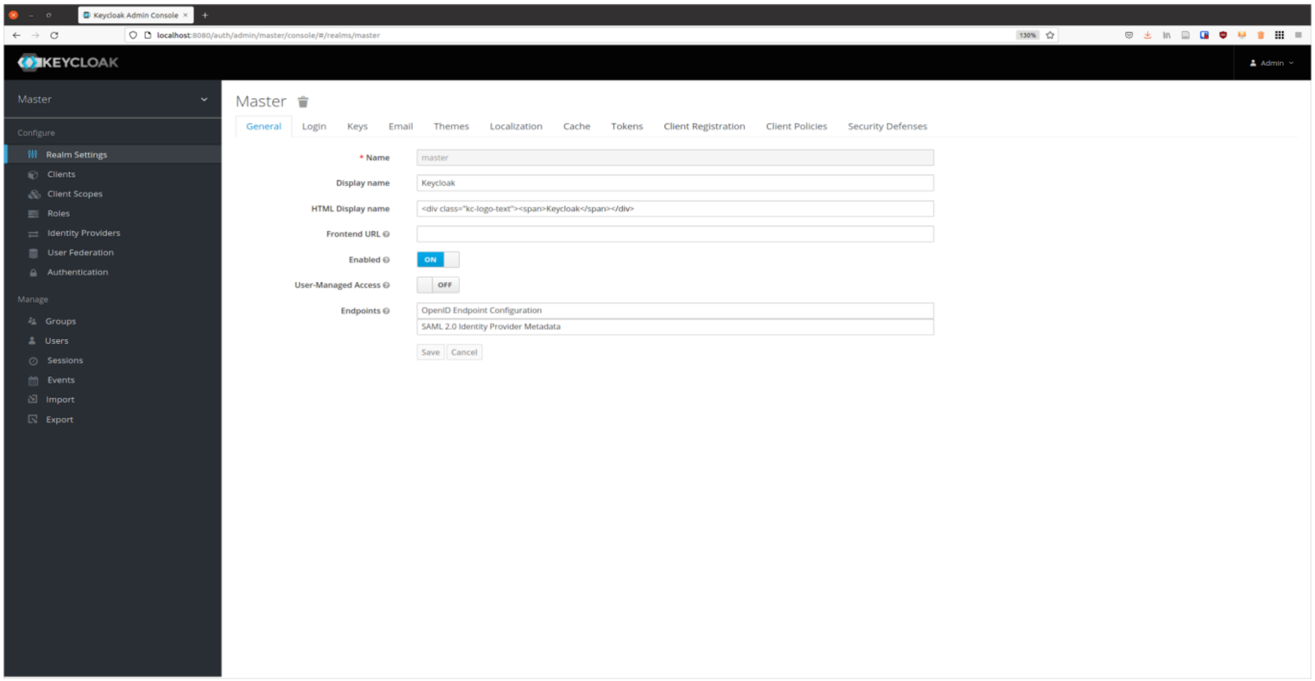


Figure 25. Keycloak homepage

As shown in Figure 26 and Figure 27, a new realm, can be created to support the IntellIoT use cases (a realm per use case deployment). We can afterwards start adding all the details that make up the realm. For this example, we have added a group (*iot_group*), a user (*iot_user*), a client (*iot_client*) and a role (*iot_role*). The user is mapped to the group, client, and role. This mapping defines what the user can do.

[23] https://www.docker.com/
[24] https://github.com/PacktPublishing/Keycloak-Identity-and-Access-Management-for-Modern-Applications



* Name: master

Display name: Keycloak

HTML Display name: <div class="kc-logo-text"><span>Keycloak</span></div>

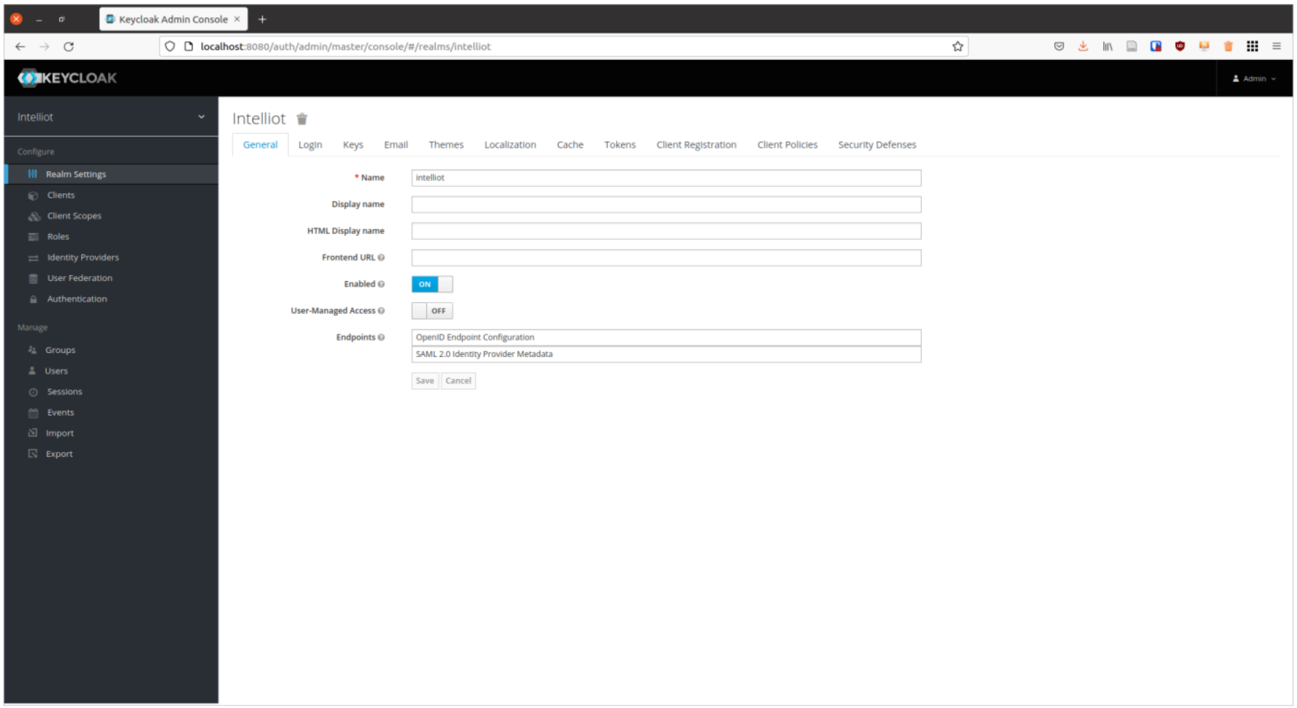
Frontend URL:

Enabled: ON

User-Managed Access: OFF

Endpoints: OpenID Endpoint Configuration
SAML 2.0 Identity Provider Metadata

Figure 26. First administrator login to Master realm



* Name: intelliot

Display name:

HTML Display name:

Frontend URL:

Enabled: ON

User-Managed Access: OFF

Endpoints: OpenID Endpoint Configuration
SAML 2.0 Identity Provider Metadata

Figure 27. Newly created IntellIoT realm

A sample application is created to test and showcase Keycloak's capabilities (see Figure 28). When the Login button is clicked, a redirect happens to the Keycloak Authentication Server for the user to login (see Figure 29). The application must know where the Keycloak Server is and the realm it needs to get access to.

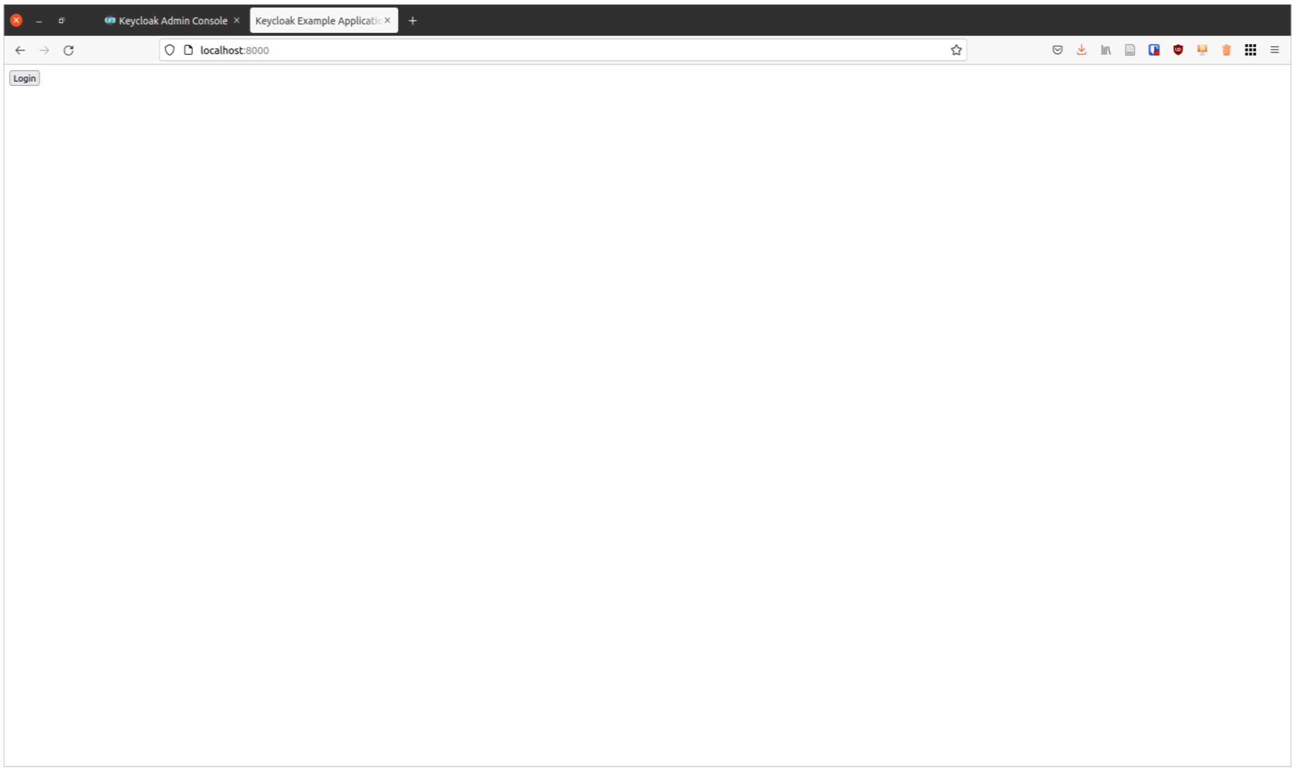
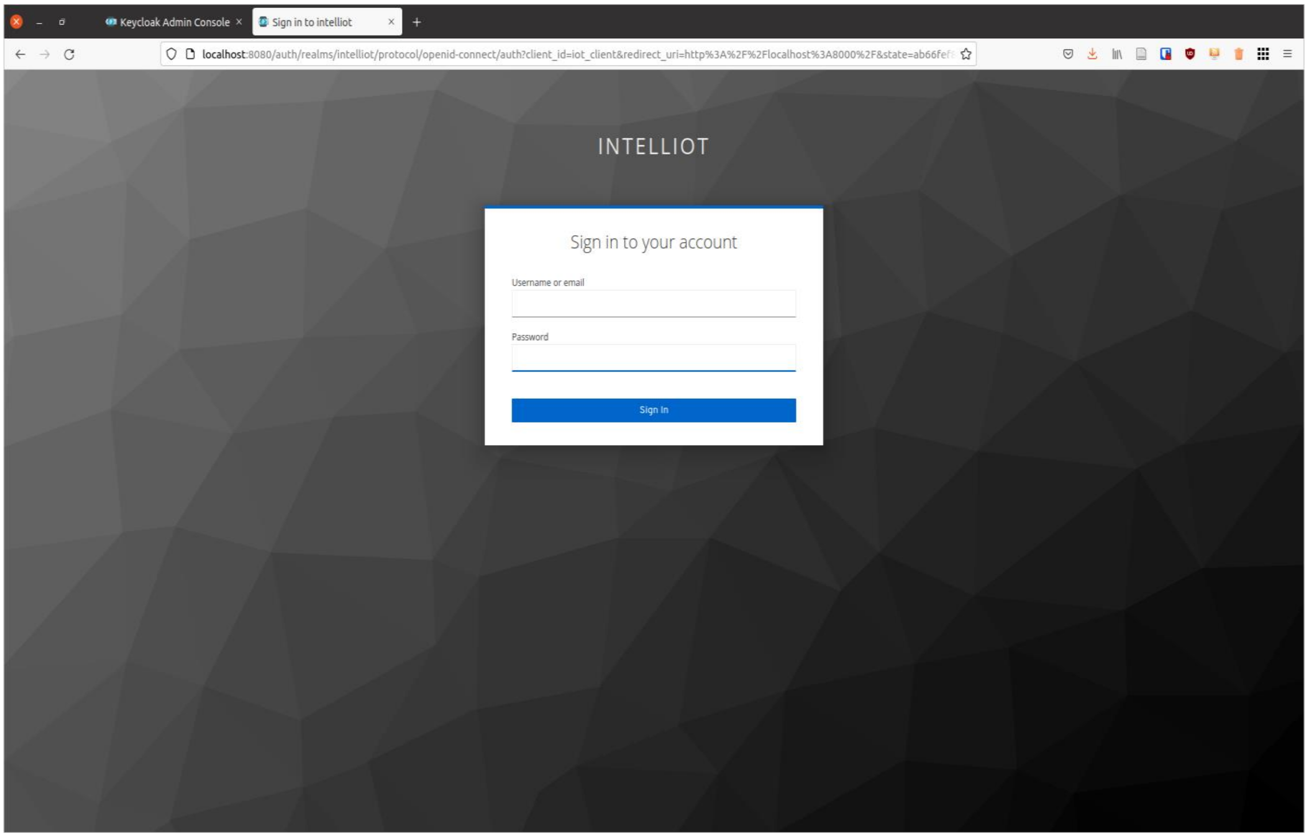


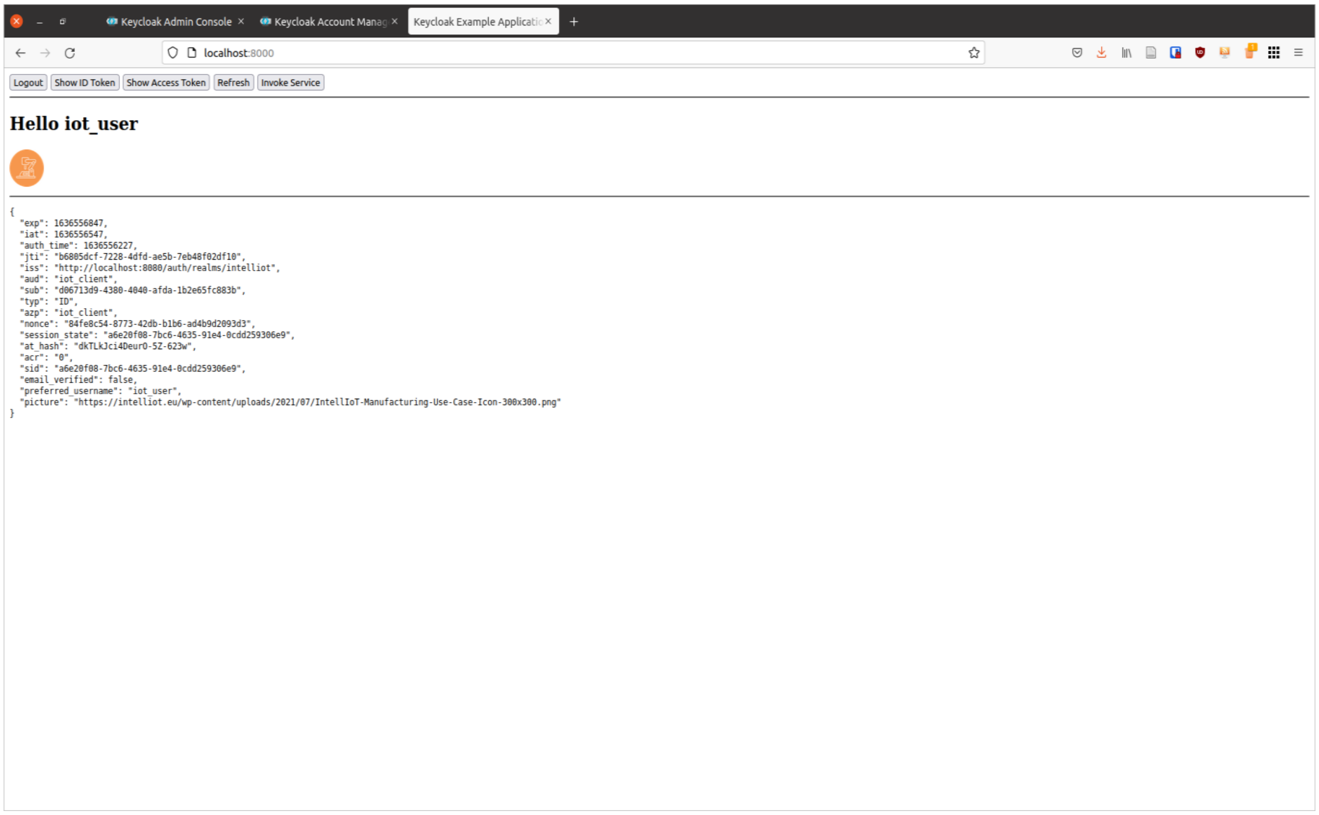
Figure 28. Simple application with login protected by Keycloak



localhost:8080/auth/realms/intelliot/protocol/openid-connect/auth?client_id=iot_client&redirect_uri=http%3A%2F%2Flocalhost%3A8000%2F&state=ab66fef

Figure 29. Redirect to Keycloak for authentication

After entering the credentials and Keycloak verifies that the user exists and can use the application, we are redirected back to the application (Figure 30).



Hello iot_user

```
{
  "exp": 1636556847,
  "iat": 1636556547,
  "auth_time": 1636556227,
  "jti": "b6805dcf-7228-4dfd-ae5b-7eb48f02df10",
  "iss": "http://localhost:8080/auth/realms/intelliot",
  "aud": "iot_client",
  "sub": "d06713d9-4380-4040-afda-1b2e65fc883b",
  "typ": "ID",
  "azp": "iot_client",
  "nonce": "84fe8c54-8773-42db-b1b6-ad4b9d2093d3",
  "session_state": "a6e20f08-7bc6-4635-91e4-0cdd259306e9",
  "at_hash": "dkTLkJci4Deur0-5Z-623w",
  "acr": "0",
  "sid": "a6e20f08-7bc6-4635-91e4-0cdd259306e9",
  "email_verified": false,
  "preferred_username": "iot_user",
  "picture": "https://intelliot.eu/wp-content/uploads/2021/07/IntellIoT-Manufacturing-Use-Case-Icon-300x300.png"
}
```

Figure 30. User logged in successfully to test application, via Keycloak

3.2 Deployment through Reverse Proxy

In the example showcased in the previous subsection, the application uses Node.js[25] libraries to properly integrate with Keycloak. This is not always needed or feasible, for example when an application needs to authenticate itself. An alternative scenario is to use a reverse proxy, e.g., Nginx[26], to be integrated with Keycloak.

Having a reverse proxy as an intermediate for web applications that do not have OAuth 2.0/OpenID Connect support can provide authentication and authorization capabilities for them and even simplify the whole architecture of a system.

Overall, integrating Keycloak with Nginx as a reverse proxy provides a secure and scalable solution for managing identity and access for web applications and services. Reverse proxy acts as a gatekeeper, protecting the application from unauthorized access, while Keycloak provides centralized authentication and authorization services. Different users may have different access rights to the applications and with the integration of Keycloak this can be controlled.

A role is a set of permissions that can be assigned to users or groups to control their access to the resource. A role can be created in Keycloak by navigating to the "Roles" tab of the client configuration and clicking the "Add Role" button.

Figure 31 demonstrates this architecture, where a reverse proxy acts as a middleman between the application and the web service that requires authentication/authorization.

[25] https://nodejs.org/en/
[26] https://nginx.org/en/

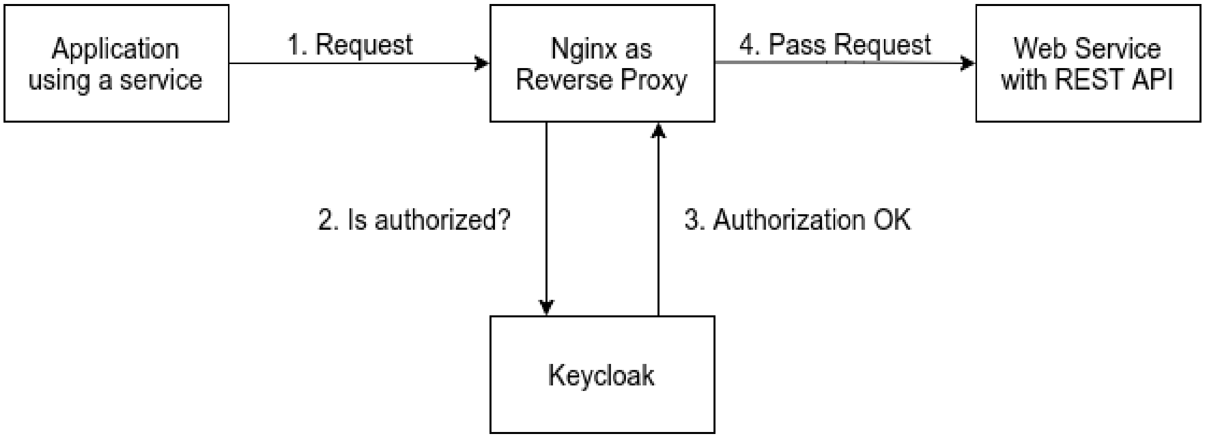


Figure 31. Deployment of Keycloak with a reverse proxy (Nginx).

3.3 Deployment and Functional Testing

During the first cycle of the project, the development of the component had been completed and initial testing was performed in a lab environment that TSI had setup in its premises. During cycle 2, AAA has been integrated both within IntellIoT use cases and with external partners (Open Call 1 winners). As such, the AAA solution has been through operational testing in multiple environments. This has led to several bug fixes as well as functionality improvements, leading to well-matured and fully functional component, ready to be deployed in any real-world scenario. It should be noted that this component has been selected by all Open Call 2 winners and it is currently integrated in all deployment scenarios beyond the project's use cases.

4 TRUST-BASED INTRUSION DETECTION SYSTEM (IDS)

A Trust-based Intrusion Detection System (IDS) is designed, developed, and integrated into IntellIoT in the form of a software component to be executed on each network node (e.g., drone, tractor, wearable device, robotic arm). More specifically, each instance of the Trust IDS sniffs network traffic and analyses its characteristics to assign a trust value for every network node it has communicated with. This system is used to characterise the trustworthiness of nodes in the network according to certain criteria and assist isolating those that are considered as untrustworthy.

In more detail, when it is first executed, each instance assigns a neutral trust value to all other encountered nodes. After collecting enough data inside a configurable window of time, it computes new trust values based on several filters (trust criteria). Examples of such filters include packet rate and throughput. These filters have configurable thresholds that when exceeded result in a decrease in trust for each associated network node. When thresholds are not exceeded, the trust value of the corresponding node is increased. At the end of every time window, trust values are updated and communicated to the rest of the security components. It is then upon the other security components to take appropriate actions based on the IDS analysis.

The Trust-based IDS deployed in IntellIoT is a custom tool developed in the Go[27] programming language and makes use of only one external library, gopacket[28], which provides packet processing capabilities. The tool runs on top of Linux OS as a userland application that requires only access to the network interface. A containerised version of the tool is also available.

Figure 32 demonstrates the basic architecture of the IDS system. The IDS tool supports two configurable filters aiming to detect and prevent (by notifying other security components in the IntellIoT Security stack) rogue nodes that overwhelm the network with unacceptable amounts of network traffic. This also applies to denial-of-service (DoS) attacks that behave in a similar fashion; however, in this case, the excessive traffic is not caused by intermittent events or malfunctions but it is instrumented by a malicious actor. The architecture of the tool allows for future integration of additional filters, each of which may have its own independent parameters.

[27] https://golang.org/

[28] https://github.com/google/gopacket

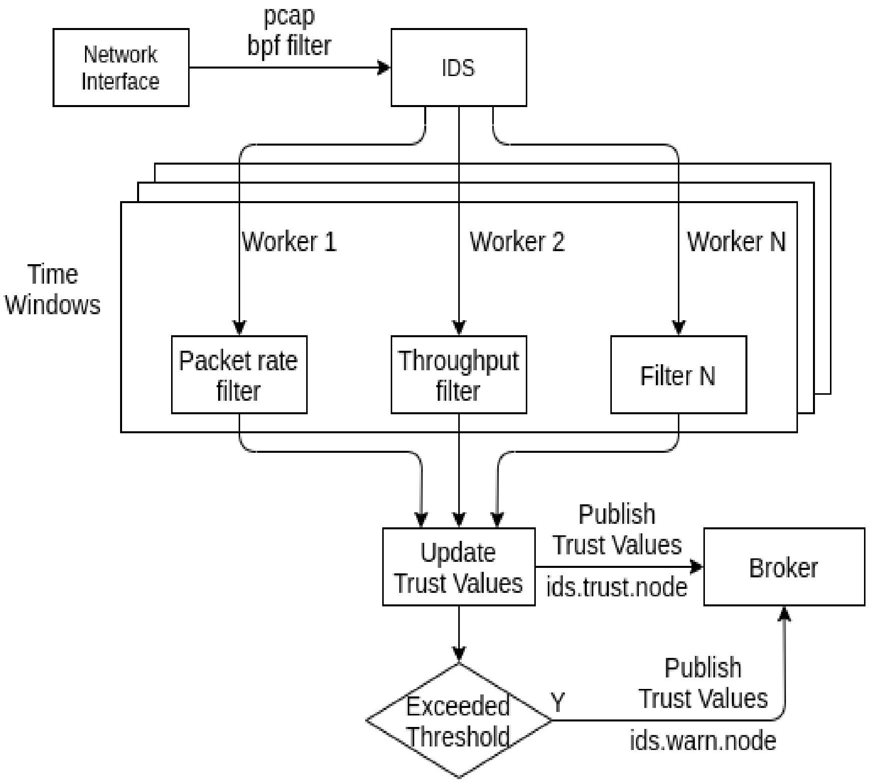


Figure 32. Architecture of the Trust-based IDS tool.

At each time interval, the IDS collects all data recorded for each node and computes a pass/fail value depending on the configuration of the filters (one value for each node). A pass value indicates that the communication with a node is within the acceptable limits set as the filter parameters. Respectively, a fail value indicates that the corresponding node has operated outside of acceptable limits.

The vector of all those values is passed to the Trust Compute component of the tool. For every node on the network, the Trust Compute component starts with a neutral trust value that as mentioned above is raised or decreased according to the behaviour of the node. The computation of trust favours the early and fast detection of malfunctioning / malicious nodes by assigning heavier weights to the fail values received by the filters than the pass ones. Similar to [7], the failure values have a 4:1 larger impact than the pass values. This means that the Trust Value of each network node will decrease four times faster than the rate it increases and therefore an erroneous behaviour will be captured rapidly, and the node will need several time windows of proper functioning to reinstate its trust.

The Trust Component will consider a network node as untrustworthy once its computed trust value falls below a certain threshold. In this case, it will trigger a warning message to external security modules (such as the MTD server and SAP) indicating that priority action should be taken. Otherwise, the computed trust values are periodically transmitted to the external security modules.

Two important remarks need to be made. First, the process of declaring a node as untrustworthy masks random events that may be attributed to a momentarily out-of-expected behaviour - a single event cannot render a node as untrustworthy. This is accomplished by using a configurable threshold below the neutral trust value to declare a node as untrustworthy. Second, this threshold value is part of the user configuration of the tool, and it is set using a manual process or some prespecified heuristic.

The Trust-based IDS instances are executed on each network node we need to analyse its network traffic. As mentioned above, there exists a common secure channel, which is an Advanced Message Queueing Protocol (AMQP) broker, that is used to send the trust values and warning messages to the other security components (the MTD module, detailed in Sect. 5, and the SAP, detailed in Sect. 2). AMQP is an application layer messaging protocol that allows for various routing topologies, such as point-to-point and publish-subscribe, with TLS support to provide secure communication. This communication scheme is depicted in Figure 33. More details on the AMQP Trust Broker are provided in Sect. 6.

The integration between the Trust IDS and the rest of the Trust Enablers is shown in Figure 33. More details on the integration approach are also provided in Sect. 6.

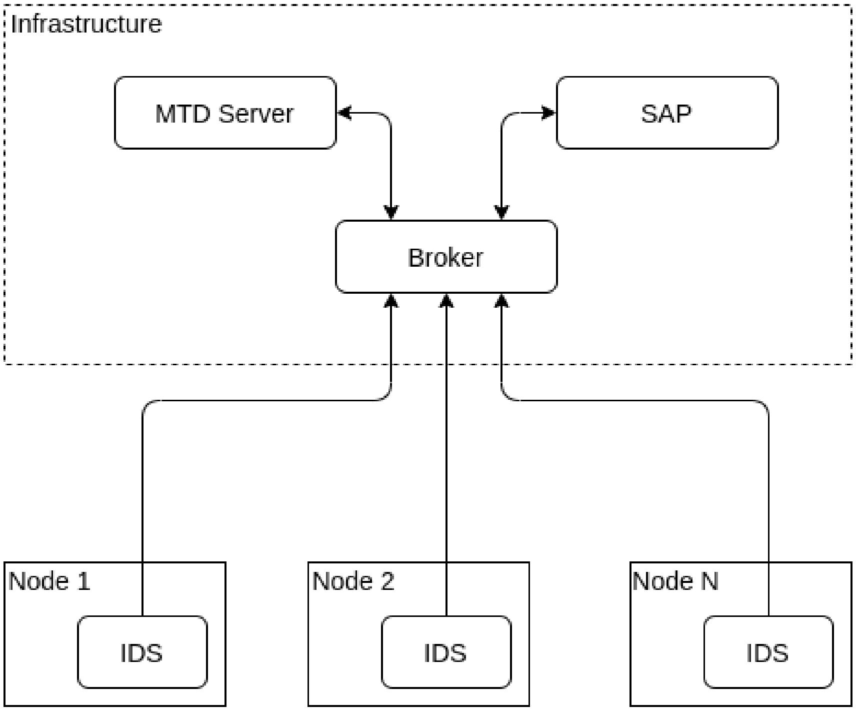


Figure 33. Communication between IDS components and the MTD and SAP modules

During the first cycle, Trust-IDS employed user configurable thresholds to reward or penalize the network behavior of communicating nodes. For the second cycle, we have added support for describing expected traffic from known nodes and evaluating the captured traffic using cross-correlation. For example, sensor nodes can be described as devices that are expected to generate sporadic network traffic, that is periods of inactivity followed by periods of small spikes in packet transmissions due to sensor readings. Every time the captured traffic exhibits a strong correlation with the expected traffic a reward is made. In the same manner, a weak correlation results in a penalty.

5 MOVING TARGET DEFENCES (MTD)

Currently, network infrastructures have adopted mostly static configurations, and rely on traffic monitoring and perimeter defence techniques (for example, Firewalls and Intrusion Detection Systems) to identify and mitigate attacks. But given enough time and resources, these defences can be breached.

A new approach is Moving Target Defence (MTD), which is based on the notion that if the defending infrastructure has a dynamic and constantly shifting configuration, attacking it and exploiting vulnerabilities becomes much harder. The attacker now has to 'chase' a constantly moving target, uncover possible vulnerabilities and exploit them before they are rendered invalid by an upcoming configuration change. To make the situation even worse for the attacker, the configuration change is not random, but guided by traditional defences like an Intrusion Detection System, which means that over time, the system becomes more secure against an incoming attack. While in traditional systems with static configurations the difficulty of an attack goes down with time, with MTD it goes up.

MTD can be applied in several different ways, such as changing operating systems, address space, network configuration etc. In IntellIoT, we focus on managing the network configuration and dynamically changing it to fit the needs of the infrastructure. Examples of our strategies include the periodic shuffle of IP addresses and communication ports, as well as the encryption of network traffic while changing in different time intervals (or as a response to certain events) of the encryption keys and the encryption algorithms used to counter sniffing and Man-In-The-Middle attacks.

The basic principles of our MTD architecture have been described in deliverable D2.6. In what follows, we re-elaborate those main concepts for reasons of completeness and then proceed with details about the actual implementation of the final MTD infrastructure.

The IntellIoT MTD system is a client-server set of software components that manages the configuration of the edge network. The MTD server is responsible for managing all the clients, handling events like warnings from the IDS or actions from the HIL service and generating new configurations. The MTD clients are responsible for applying the configuration sent by the server, and based on that configuration, encrypt the traffic, and transmit it through secure tunnels (PPTP [4] with IPSec [5]) to avoid packet sniffing and Man-In-The-Middle attacks. In that context, the MTD server handles all complexity and performs all computations, while the MTD clients simply have to perform configuration changes. As such, MTD client components are very lightweight processes that can be installed even in the simplest of devices, making them appropriate for any kind of IoT deployment.

The server and clients communicate by exchanging the network configuration. Some parts of the network configuration are the same for all clients, and while others are specific to each client. The configuration has the following format:

```
type VPNConfig struct {

    //TUN

    CIDR string

    IsSet bool

    //UDP

    Port   int

    Protoc string

    IsSet bool

    //Cipher

    CipherKey  string

    CipherType cipher.CipherType
    //router
    ExtIP       string
    IntIP       string
    RoutesToAdd[]router.Route
    RoutesToRemove []string
}
```

The CIDR, ExtIP and LocIP are specific to each client, while everything else is common for all clients.

The way our MTD works is that in each client we provide a new network interface (*mtd0*) with its own IP address, named internal IP (*IntIP*). That means that each client has a pair of IP addresses, the IP address with which it communicates to the network, named external IP (*ExtIP*) and the internal IP. Such a pair is considered a route. When an application uses the mtd0 interface, the packets that are generated have the internal IPs as source and destination, and when trying to send the packet to another client, we first search the destination to find the corresponding external IP. If the route is found, we then encrypt the packet and encapsulate it in a UDP packet with the external IPs as source and destination.

5.1 MTD Server

The MTD server *proactively* generates a new configuration at fixed time intervals to shift the attack surface. When a warning is received from another security component (such as the Trust IDS or the SAP), it *reactively* generates a mitigation configuration based on predefined strategies to mitigate the possible attack. It is also possible for the HIL to send actions (e.g., *isolate node X*) through the Security Assurance Platform. Configuration changes focus on network layer 3 and above, and do not interfere with the TSN controller and the resource reservations it maintains.

The MTD server is mainly comprised of four different modules (that we call *handlers*) and a client database; see Figure 34. Based on a static configuration provided at start up, the MTD server connects to the message broker (see Sect. 6).

The first main handler is the registration/deregistration handler. This handler manages registration requests from new clients (nodes of the IoT infrastructure) and deregistration warnings from existing clients. More specifically:

- When a new client requests to register, it provides its current IP address and a client name. The client's name is automatically generated by the MTD client, it is later used to connect to the message broker and must follow a specific format that will be presentedin the client section. Both the IP address and the client name are checked and if they conflict with an existing client the registration is rejected. If there are no conflicts, a client handler is created, and the client is added to the internal client database.
- When an existing client deregisters, the client handler is removed from the database and stopped. After any changes to the database, a new configuration is generated and sent to all remaining clients. The new configuration has an IP pair assigned to the new client in the case of a registration and includes a new routing table that either includes the newly registered client or excludes the deregistered one. All other parts of the configuration remain the same.

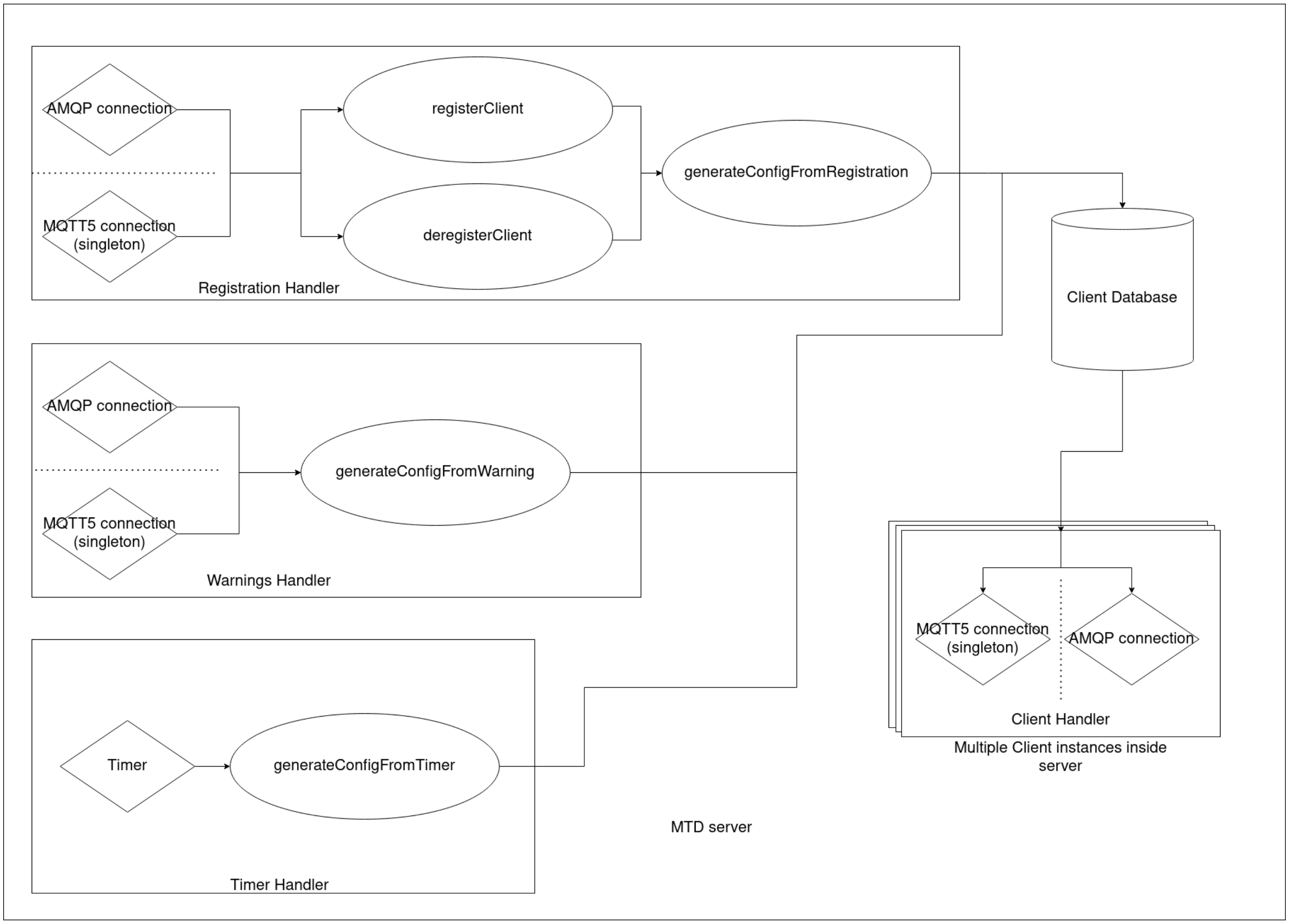


Figure 34. MTD server Architecture

The second main handler is the warnings handler. Every message that comes from an external source (e.g., HIL, SAP, IDS etc) is handled as a warning. Warnings have the following format:

```
type warning struct {
    Type   string
    Action string
    Body   string
    Time   *timestamppb.Timestamp
}
```

The available types are "`info`", "`warning`" and "`error`". The available actions are "`drop`" to drop an active client and "`allow`" to restore connectivity to a dropped client. Also, the Body variable contains information relevant to the type and action of the warning. Finally, a timestamp is included for logging purposes.

Currently, the only supported type-action pairs are *error-block* to block a client and *error-allow* to restore one. When we receive an error-block message, we read the body for identification about the client to be blocked and search the database. If we find the client, we set it as dropped and regenerate a configuration with that client removed from the routing table. Similarly, when we receive an error-allow message, we search for the client, unset the dropped flag and regenerate a configuration with that client added to the routing table.

Future work is to add strategies for known attacks and based on the warnings we receive, generate configurations that do not necessarily drop a client, but mitigate attacks in other ways as well.

The third main handler is the timer handler. This handler generates a new configuration at fixed intervals to shift the attack surface. Currently, when the internal timer sends a tick, one of three possible changes is performed:

- Update the UDP (external) connection configuration
- Update the TUN (internal) connection configuration
- Update the encryption

When updating the UDP connection, we change the external IP address of each node, and the port that all nodes use to exchange encrypted traffic. The outcome of this change is that all clients are shifted, and an external attacker that might have found a vulnerability in a specific client would have to start searching for that client again, and a Man-In-The-Middle attack would have to scan the network again to find the new port.

When updating the TUN connection, we change the internal IP address of each node. The rationale is that by changing the routing table we make it harder for attackers to gather information about the topology of the system, even if they gain access to one of the clients.

MTD supports switching between unencrypted and encrypted traffic. The system supports unencrypted traffic, unencrypted traffic with snappy compression and AES CBC encryption [8][9]. For the latter, different key sizes (128, 192 and 256 bits) are supported, and the system may perform changes to both key value and key size. A random key generator is employed. At the current stage of development, we are also working on supporting switching between different modes of the AES encryption standard, namely AES CBC encryption with snappy compression, AES CBC encryption with HMAC for validation and AES CBC encryption with HMAC for validation and snappy compression.

It should be mentioned that AES encryption does come with a performance penalty for clients that are based on very simple compute devices and that is the reason why we have also chosen to support unencrypted traffic when there is no indication of threats. As a middle ground solution, in the future we plan to investigate encryption schemes specifically tailored for resource constrained devices.

The final type of handler is the client handler, one of which is spawned for each registered client. The client handler has the state of each client as assigned by the server, as well as a keep-alive connection. At fixed intervals, each client handler sends a keep-alive request to the client, and the client has to respond within a specific time interval, or it is considered disconnected and removed from the client database.

Finally, a connection to the TSN controller has been added, in order to send isolation requests or see the topology graph from the MTD server. The API has been implemented and it remains to be tested during IntellIoT framework integration activities.

5.2 MTD Client

The MTD clients (see Figure 35) are responsible for managing the network configuration, maintaining an encrypted connection between each other using the routing table sent by the MTD server and applying any changes the server sends.

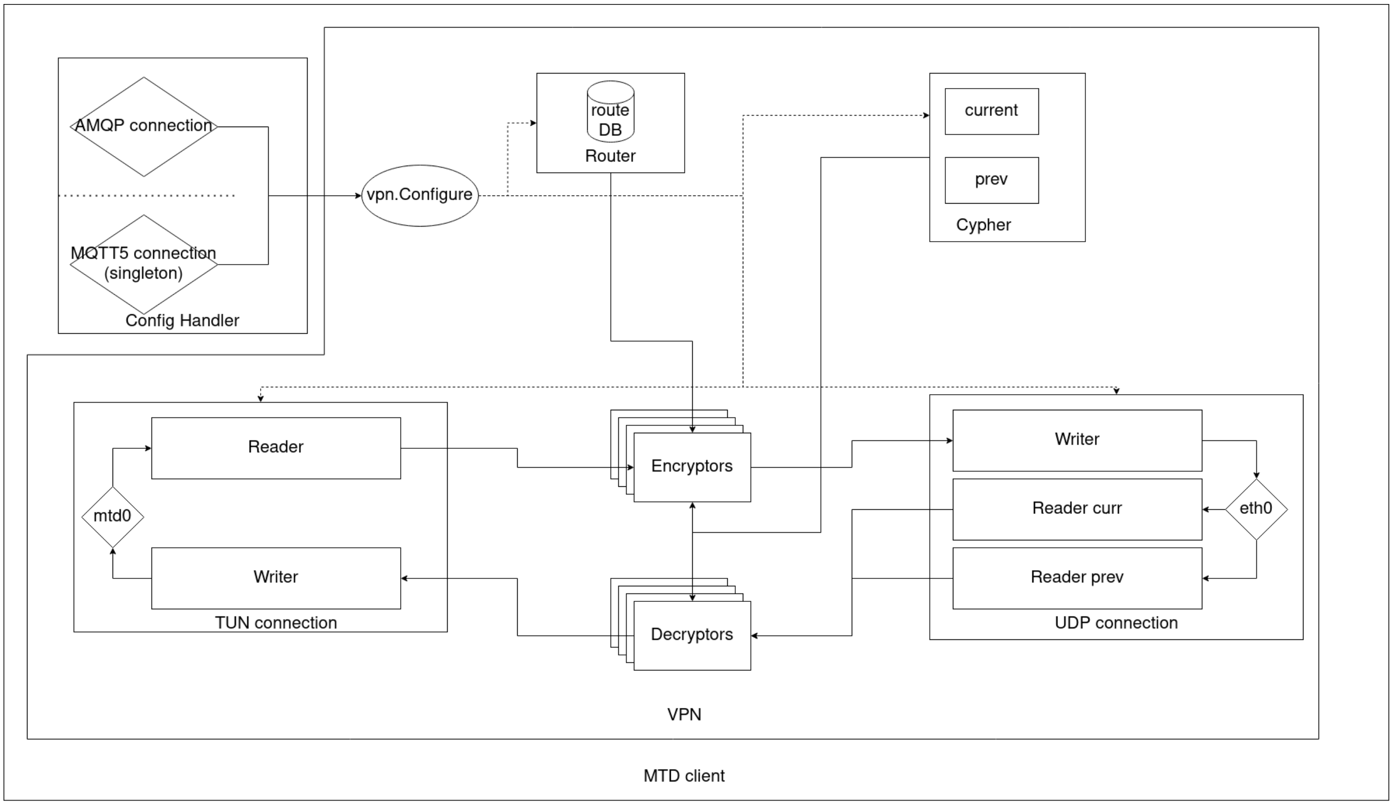


Figure 35. MTD client Architecture

The MTD client contains a config handler, and a VPN module. The VPN module is comprised of:

- A TUN connection and a virtual ethernet interface
- A Router with an internal routing table
- A cipher
- Several Encryptor and Decryptor workers
- A UDP connection using the active network connection of the device

The config handler is responsible for receiving the configuration from the server and sending it to the VPN module. The VPN module then breaks the config into parts and sends each part to the corresponding submodule.

The TUN connection receives unencrypted packets from the application layer to encrypt and send to other clients, and packets from other clients after they have been decrypted to send to the application layer. At initialization a virtual network interface is created (mtd0) and after registering with the server, an internal IP address is assigned to it. A writer and a reader are opened on the interface that are responsible for transferring packets to and from it.

The Router is responsible for keeping the routing table up to date based on the configuration sent by the server and searching the routing table to resolve routes when requested by the encryptors.

The cipher is responsible for keeping the active algorithm and key in sync with the server. At any point there are two states of the cipher, the current and the previous state. The current state is used when encrypting packets and the default state when decrypting packets. If the decryption with the current state fails, we fall back to the previous state. That is expected behaviour when an update to the cipher occurs, since in-flight packets encrypted with the previous key and/or algorithm might reach the client after the update. The previous state is kept active for a limited period of time after each update.

The encryptor workers receive unencrypted packets from the TUN connection, request a route from the routing table and if a route is found, use the cipher to encrypt the packet and send it along with the route to the UDP connection. Multiple encryptor workers can be spawned based on the static configuration of the client, the needs and the available resources of the device, to leverage parallelism to reduce the latency incurred by the encryption.

The decryptor workers receive encrypted packets from the UDP connection and use the cipher to decrypt them and send them to the TUN connection. Similarly, to the encryptor workers, multiple decryptor workers can be spawned.

The UDP connection is the opposite of the TUN connection. It receives encrypted packets from other clients to decrypt and send to the application layer and sends packets from the application layer to other clients after they have been encrypted. After registering with the server, every time an encrypted packet is sent from an encryptor along with the route, that packet is encapsulated in a UDP packet and sent to the destination using the port specified by the server. Similarly, every time a packet is received from the port specified by the server, that packet is sent to the decryptors. The UDP connection keeps two readers active, one for the current configuration and one for the previous. The reason is the same as for the cipher, to be able to receive packets that were in flight when the update occurred.

At start up, each client must register with the server by sending a registration request containing the client's name and IP address through the broker. The registration process goes through the following steps:

1. Authentication: The server first verifies the identity of the client by checking their credentials. This involves checking the client database to ensure that the client is authorized to register within the network. If the client's credentials are valid, the server will proceed to the next step.
2. Acknowledgment: Once the client's identity is confirmed, the server sends an acknowledgement (ack) message back to the client, letting them know that their registration request was received and accepted.
3. Registration: The server then adds the client's information to its client database, which registers the client as an authorized member of the network. This allows the client to access the resources and services provided by the network.
4. Configuration update: Finally, the server triggers a configuration update to ensure that all other nodes in the network are aware of the newly registered client. This update may include distributing updated routing tables, updating External and Internal IPs table.

The client's name is a combination of the username of the user that owns this device and the device's client ID in the format *<username>_<clientID>* (e.g. ,TSI_sensor1, TSI_sensor2, SANL_tractor etc).

Finally, each client opens a keep-alive connection to the server and waits for keep-alive requests from the server. When a request is received, the client responds with a status OK message. If the server does not send a request after a fixed amount of time, the connection to the server is considered to be lost. After that the client will be deregistered following the same process as the register.

More details on the integration of MTDs with the rest of the trust components through the dedicated broker is provided in Sect. 6.

6 TRUST MESSAGE BROKER & TRUST COMPONENTS' INTEGRATION

A key characteristic that maximises the efficacy of IntellIoT's Trust Enablers is their tight integration and continuous communication through the dedicated Trust Broker, based on RabbitMQ[29] and using the AMPQ[30] binary protocol. More details on the different components and their role in this integration, along with their key interactions with other components are provided below.

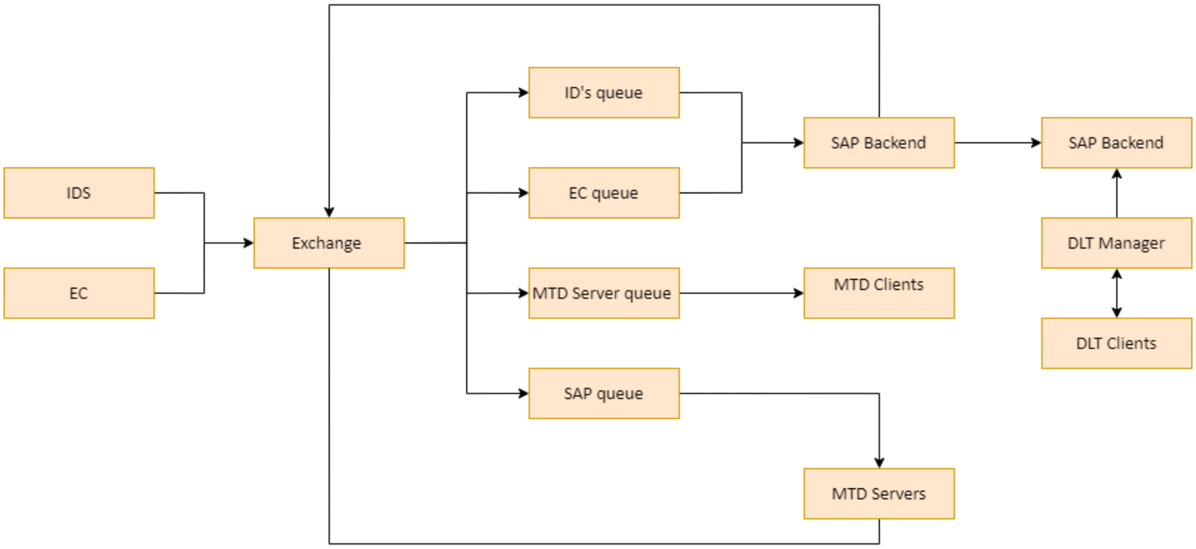
6.1 Trust Enablers' Integration Overview

The Trust IDS (see Sect. 4) continuously records events such as network traffic and analyses it for anomalies. They are responsible for aggregating pertinent evidence from multiple sources related to the operation of individual components, IDS computes a local trust value for each other node that it communicates with. When the trust value for a node drops below a threshold, it generates a warning. These warnings are left to be processed by the rest of the system in order to determine if an action is needed to be taken against offending nodes.

Similar to the IDS, the Event Captors (ECs; see Sect. 7.1) are software modules responsible for aggregating pertinent evidence from multiple sources related to the operation of individual components, as well as the overarching processes where these components are involved in, thus enabling the real-time, continuous assessment of the security posture of the IntellIoT system. ECs can be deployed across all layers of the IntellIoT architecture, from the robot arm (e.g., to monitor telemetry that may indicate abnormal activities) to device operating systems (e.g., to monitor running processes) and backend storage databases (e.g., to parse access logs or calculate uptime), transmitting their monitoring evidence to the Security Assurance Platform (SAP).

The SAP (see Sect. 2) is central to the trustworthiness components and has its own queue in the message broker pipeline. SAP digest messages respectively from the IDS queue and EC queue while in the same time through appropriate REST APIs it can communicate with the Distributed Ledger Trustworthiness (DLT) manager.

Finally, the MTDs (see Sect. 5) are responsible for mitigation actions once the SAP receives an Intrusion Warning from the IDS. MTDs are divided into two distinct components (the server MTD, and the client MTD) with the first having its own queue (MTD server queue) while MTD clients consumes messages from the latter queue.



[29] https://www.rabbitmq.com/
[30] https://www.rabbitmq.com/

Figure 36. Overview of Trust Enablers' integration via the shared Trust Broker

Each of the above-mentioned components are considered as producers and/or publishers to the Trust Broker, declaring its own exchange queue (Figure 36). There are in total 4 queues bounded to the topic exchange with 4 routing key patterns (#ids, #mtd, #sap, #ec, for Trust IDS, MTD, SAP and EC -related messages, respectively), while in the topic exchange the Queues are linked using the routing key patterns instead of a simple routing key.

The flow of a messages in Topic Exchange follows the typical publish/subscribe scheme. More specifically:

- A message Queue binds to an Exchange with a routing key pattern (P).
- A publisher sends a message with a routing key (K) to the Topic Exchange.
- The message is passed to the Queue if P matches with K. The routing key matching is decided as discussed below.
- The consumer subscribing to the Queue receives the message.

In terms of Topic Exchange requirements, the specific routing patterns are followed:

- A routing key in Topic Exchange must consist of Zero or more words delimited by dots
- A routing pattern is similar to a regular expression with only *, . and # allowed. The symbol star (*) means exactly one word allowed. Similarly, the symbol hash (#) means zero or more number of words allowed. The symbol dot (.) means – word delimiter.
- Multiple key terms are separated by the dot delimiter.
- If a routing pattern is ids.*, it means any message sent with the routing key “ids” as the first word will reach the queue. For example, ids.event will reach this Queue, but event.ids will not work.

6.2 IDS integration details

IDS exposes two topics, in JSON format, to the broker for the rest of the security components to consume and take appropriate actions. The first one is the trust topic `‘ids.trust.[node id]’`, where each IDS instance publishes its trust values for the nodes it has communicated with. An example payload is:

```
{
  “10.0.0.1”: 0.0,
  “10.0.0.2”: 1.0,
              ...
}
```

The second topic is the `‘ids.warn.[node id]’`, where each IDS instance publishes a list of nodes that are considered untrustworthy. An example payload is:

```
{
  “nodes”: [
    “10.0.0.1”
  ]
}
```

6.3 MTD integration details

Apart from waiting input from the IDS topics described above, the following topics are used:

- *mtd.registration*
- *mtd.config.<client name>*
- *mtd.keepaliveReq.<client name>*
- *mtd.keepaliveResp.<client name>*

Details on each of the four topics are provided in the subsections that follow.

6.3.1 MTD REGISTRATION TOPIC

MTD clients have write access to this topic and the server has read access. This is the topic where clients publish registration/deregistration requests.

The format is as follows:

```
type registrationCfg struct {
    Action   string
    NodeName string
    NodeIP   string
}
```

An example payload is provided below:

```
{
  "Action": "register",
  "NodeName": "TSI_sensor1",
  "NodeIp": "192.168.1.10"
}

{
  "Action": "deregister",
  "NodeName": "TSI_sensor1",
  "NodeIp": ""
}
```

6.3.2 MTD CONFIG TOPIC

A new subtopic is created for each registered client and each client has read access only to its own subtopic. The server has write access to all subtopics and sends personalised configurations to each client, possibly skipping clients that are deemed compromised.

The format is as follows:

```
type VPNConfig struct {
    //TUN
    CIDR string
    //UDP
    Port   int
    Protoc string
    //Cipher
    CipherKey  string
    CipherType cipher.CipherType
    //router
    ExtIP      string
    LocIP      string
    RoutesToAddmap[string]string
    RoutesToRemove []string
}
```

An example payload is provided below:

```
{
  "CIDR": "10.0.0.2/24",
  “IsSet": “true",
  "Port": 30000,
  "Protoc": "udp4",
  “IsSet": ”true",  "CipherKey": "3863766a4c4f553166502d716a324b69",
  "CipherType": 3,
  "ExtIP": "192.168.176.5",
  "LocIP": "10.0.0.2",
  "RoutesToAdd": {
“client_device1” "10.0.0.1"  "192.168.176.4",
“client_device2” "10.0.0.2"  "192.168.176.5",
  },
  "RoutesToRemove": [
"10.0.0.3"
  ]
}
```

6.3.3 MTD KEEP-ALIVE REQUEST AND KEEP-ALIVE RESPONSE TOPICS

Similarl to the configuration topic, a new subtopic is created for each registered client and each client has read access only to its own request subtopic and write access to its own response subtopic. The server has write access to all request subtopics and read access to all response subtopics. The server sends requests to which the clients must answer within a specific amount of time before being treated as disconnected. The payload is a randomly generated string that the client has to send back along with its status using its own response topic.

6.3.4 MTD AND SAP

The MTD client and server applications communicate over a secure channel provided by the Trust Message Broker. More specifically, the MTD Server consumes messages generated from IDS and takes mitigation actions when this is needed. When such an action is taken, the server needs to notify the Security Assurance Platform, as it is the component providing a holistic view of the current security and privacy posture of the system to the operators. This happens through the *'mtd.alert'* topic.

The reverse case is also needed. The Security Assurance Platform, through the event captors, can also identify attacks and trigger a mitigation action using the *'mtd.trigger'* topic.

Both of these follow the same payload logic as the *'ids.warn' topic:*

```
{
  “nodes”: [
    “10.0.0.1”
  ]
}
```

6.4 Integration & interplay of Security Assurance Platform with the DLTs

Distributed ledger technologies (DLTs) are positioned as a key enabler for trusted and reliable distributed monitoring systems since these support immutable and transparent information sharing among involved untrusted parties. In DLTs, the authentication process relies on consensus among multiple DLT managers in the network. While the terms DLT and Blockchain will be used interchangeably, Blockchains are a type of DLT, where chains of blocks are made up of digital pieces of information called transactions and every node maintains a copy of the ledger. Therefore, in a DLT-enabled network, transactions contain, for example, monitoring control messages, and these are recorded and synchronized in a distributed manner in all the participants of the system. These participants are called miners or peers, and, in some specific DLTs, users are charged a transaction fee to perform (crypto) transactions. In addition, DLTs allow the storage of all transactions into immutable records and every record distributed across many participants. Thus, security in DLTs comes from the distributed characteristic, but also the use of strong public-key cryptography and strong cryptographic hashes.

The benefits of the integration of DLTs into IoT monitoring systems include:

i) guarantee of immutability and transparency for report data;
ii) removal of the need for third parties;
iii) development of a transparent system for heterogeneous secured monitoring networks to prevent tampering and injection of fake data from the stakeholders

While DLTs are a key trust enabler in the project, the bulk of the efforts on the development of the resource-aware DLT components developed within IntelIIoT take place within Task 3.4 ("Decentralized trust via secure interaction & contracts"), and for Cycle 1 are documented in the corresponding deliverable, i.e., D3.4 – "Decentralized trust via secure interaction and contracts (first version)". For the sake of brevity, these details will not be repeated here.

Nevertheless, details on the integration of the DLT with the SAP will be provided below. This integration facilitates the trust-by-design approach of IntellIoT, as it allows the recording of security and privacy -pertinent evidence from the SAP in the Ledger, in a tamper-proof manner. This provides an additional layer of trust for said evidence aggregated at the SAP, which may include:

1) Evidence generated internally at the SAP (e.g., vulnerability or dynamic testing assessment results);
2) Evidence the SAP collects from monitoring and interacting with other Trust Enablers (e.g., Trust IDS alerts, or triggered MTD strategies)
3) Monitoring Evidence from monitoring the Event Captors deployed across the various layers of IntellIoT and the protected deployment.

Through interaction between the SAP and the DLT Manager, the above types of Evidence are recorded in the Ledger in an automated manner, and the entries (more specifically, transaction and block IDs) are returned to the SAP, to be provided to the SAP operator for verification (e.g., in the case of any audit).

More details on how each of the above three cases are relayed from the SAP to the DLT Manager are provided in the following subsections.

6.4.1 SAP TO DLT RECORD OF INTERNALLY GENERATED EVIDENCE

Messages of this type (e.g., assessment results) can be sent to the DLT for recording using a JSON format having the following structure:

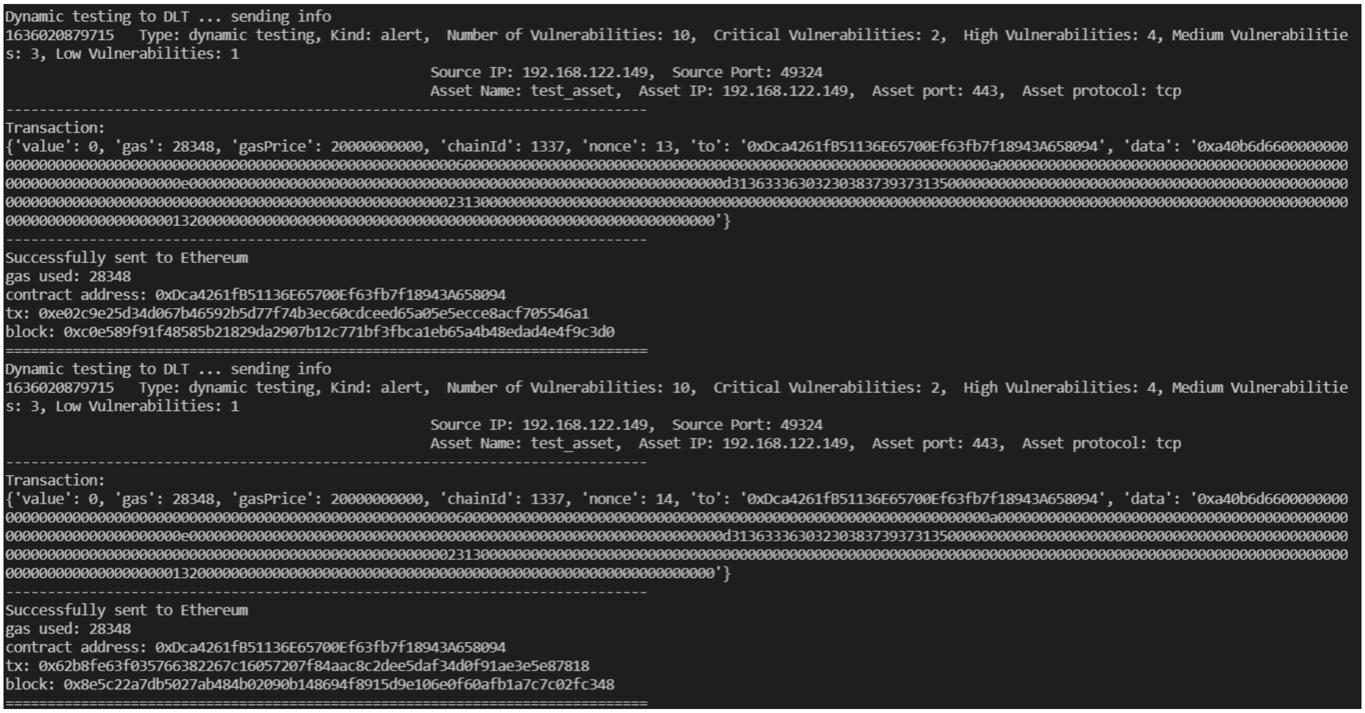
```
"@timestamp": <timestamp>,
"event": {
"kind": <kind of event>,
"category": <category of event>,
"type": <type of event>,
"number_of_vulnerabilities": <the number of vulnerabilities>,
"critical_vulnerabilities": <the number of critical vulnerabilities>,
"high_vulnerabilities": <the number of high vulnerabilities>,
"medium_vulnerabilities": <the number of medium vulnerabilities>,
"low_vulnerabilities": <the number of low vulnerabilities>,

},
"src_ip": <dynamic tester ip>,
"src_port": <dynamic tester port>,
"assets":[  #< assets that were tested>
    "asset_1":{
    "asset_ip":<asset ip>,
    "asset_name":<asset name>,
    "asset_port":<asset port>,
    "port_protocol":<asset protocol>},
    ...
    "asset_N":{
    "asset_ip":<asset ip>,
    "asset_name":<asset name>,
    "asset_port":<asset port>,
    "port_protocol":<asset protocol>},
]
}
}
```

An example based on the above template is provided below:

```
{
"@timestamp": 2017-04-07T22:24:37.251547+0100,
"event": {
"kind": “alert",
"category": “dynamic_testing”,
"type": “dynamic_testing_report”,
"number_of_vulnerabilities": "{{X}}"
"critical_vulnerabilities": "{{Y}}"
"high_vulnerabilities": "{{Z}}"
"medium_vulnerabilities": "{{W}}"
"low_vulnerabilities": "{{V}}"
},
"src_ip": "192.168.122.149",
"src_port": 49324,
"assets":[
    "asset_1":{
    "asset_ip":"192.168.1.1"
    "asset_name":"test_asset"
    "asset_port":"443",
    "port_protocol":tcp},
    "asset_2":{
    "asset_ip":"192.168.1.2"
    "asset_name":"test_asset2"
    "asset_port":"443",
    "port_protocol":tcp},
]
}
```

Furthermore, a screenshot of such a message exchange between the SAP and the DLT Manager, from the early integration testing taking place between the two components, is shown in Figure 37.



```
Dynamic testing to DLT ... sending info
1636020879715   Type: dynamic testing, Kind: alert,  Number of Vulnerabilities: 10,  Critical Vulnerabilities: 2,  High Vulnerabilities: 4, Medium Vulnerabilitie
s: 3, Low Vulnerabilities: 1
                                                   Source IP: 192.168.122.149,  Source Port: 49324
                                                   Asset Name: test_asset,  Asset IP: 192.168.122.149,  Asset port: 443,  Asset protocol: tcp
-----------------------------------------------------------------------------
Transaction:
{'value': 0, 'gas': 28348, 'gasPrice': 20000000000, 'chainId': 1337, 'nonce': 13, 'to': '0xDca4261fB51136E65700Ef63fb7f18943A658094', 'data': '0xa40b6d6600000000
0000000000000000000000000000000000000000000000000000006000000000000000000000000000000000000000000000000000000000000000a000000000000000000000000000000000000000000
000000000000000000000e0000000000000000000000000000000000000000000000000000000000000000d31363336303230383739373135000000000000000000000000000000000000000000000000
00000000000000000000000000000000000000000000000000000231300000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
0000000000000000000013200000000000000000000000000000000000000000000000000000000000000'}
-----------------------------------------------------------------------------
Successfully sent to Ethereum
gas used: 28348
contract address: 0xDca4261fB51136E65700Ef63fb7f18943A658094
tx: 0xe02c9e25d34d067b46592b5d77f74b3ec60cdceed65a05e5ecce8acf705546a1
block: 0xc0e589f91f48585b21829da2907b12c771bf3fbca1eb65a4b48edad4e4f9c3d0
=============================================================================
Dynamic testing to DLT ... sending info
1636020879715   Type: dynamic testing, Kind: alert,  Number of Vulnerabilities: 10,  Critical Vulnerabilities: 2,  High Vulnerabilities: 4, Medium Vulnerabilitie
s: 3, Low Vulnerabilities: 1
                                                   Source IP: 192.168.122.149,  Source Port: 49324
                                                   Asset Name: test_asset,  Asset IP: 192.168.122.149,  Asset port: 443,  Asset protocol: tcp
-----------------------------------------------------------------------------
Transaction:
{'value': 0, 'gas': 28348, 'gasPrice': 20000000000, 'chainId': 1337, 'nonce': 14, 'to': '0xDca4261fB51136E65700Ef63fb7f18943A658094', 'data': '0xa40b6d6600000000
0000000000000000000000000000000000000000000000000000006000000000000000000000000000000000000000000000000000000000000000a000000000000000000000000000000000000000000
000000000000000000000e0000000000000000000000000000000000000000000000000000000000000000d31363336303230383739373135000000000000000000000000000000000000000000000000
00000000000000000000000000000000000000000000000000000231300000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
0000000000000000000013200000000000000000000000000000000000000000000000000000000000000'}
-----------------------------------------------------------------------------
Successfully sent to Ethereum
gas used: 28348
contract address: 0xDca4261fB51136E65700Ef63fb7f18943A658094
tx: 0x62b8fe63f035766382267c16057207f84aac8c2dee5daf34d0f91ae3e5e87818
block: 0x8e5c22a7db5027ab484b02090b148694f8915d9e106e0f60afb1a7c7c02fc348
=============================================================================
```

Figure 37. Recording of SAP Assessment Results in the Ledger, via interaction with DLT Manager (request & response).

6.4.2 SAP TO DLT RECORD OF TRUST ENABLER EVIDENCE

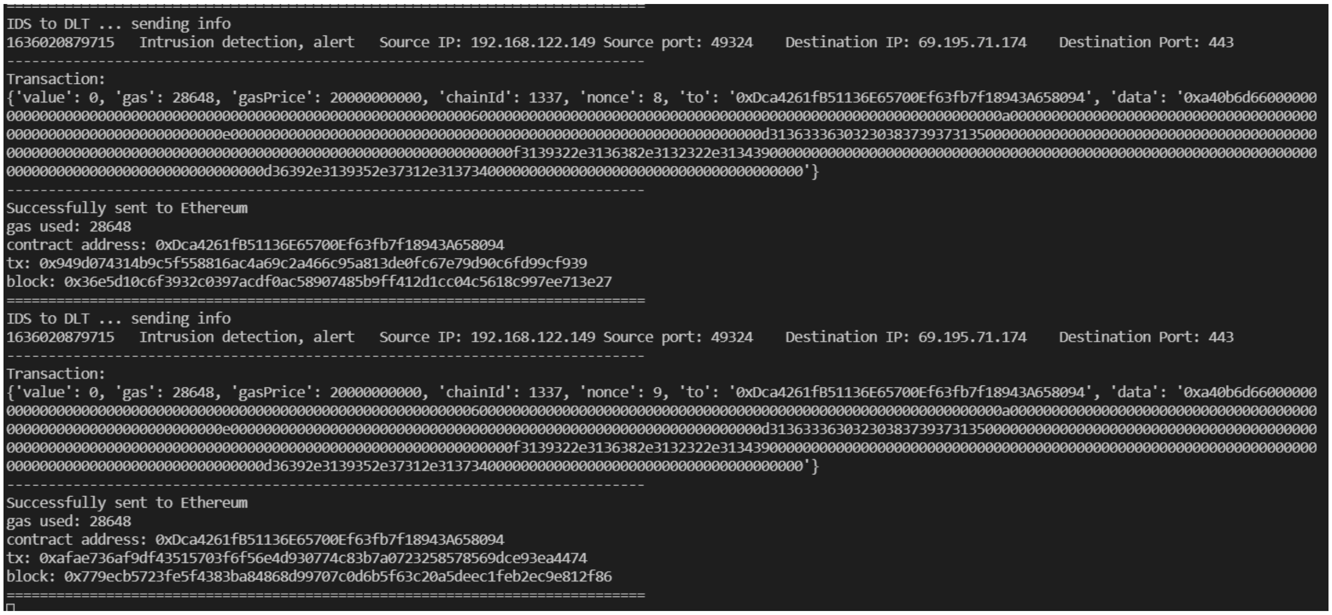
Messages of this type (e.g., alerts from the Trust IDS) can be sent to the DLT for recording using a JSON format having the following structure:

```
{
"@timestamp": <timestamp>,
"event": {
"kind": <kind of event>,
"category": <category of event>,
"type": <type of event>,
},
"src_ip": <source ip>,
"src_port": <source destination>,
"dest_ip": <destination ip>,
"dest_port": <destination port>,
"proto": <protocol>,
"app_proto": <protocol specs>,
}
```

An example based on the above template is provided below:

```
{
"@timestamp": 2017-04-07T22:24:37.251547+0100,
"event": {
"kind": “alert",
"category": “intrusion_detection”,
"type": “anomaly”,
},
"src_ip": "192.168.122.149",
"src_port": 49324,
"dest_ip": "69.195.71.174",
"dest_port": 443,
"proto": "TCP",
"app_proto": "tls",
}
```

A screenshot of such a message exchange between the SAP and the DLT Manager, whereby Trust IDS events aggregated by the former are related to the latter, is shown in Figure 38.



```
=============================================================================
IDS to DLT ... sending info
1636020879715   Intrusion detection, alert   Source IP: 192.168.122.149 Source port: 49324    Destination IP: 69.195.71.174    Destination Port: 443
-----------------------------------------------------------------------------
Transaction:
{'value': 0, 'gas': 28648, 'gasPrice': 20000000000, 'chainId': 1337, 'nonce': 8, 'to': '0xDca4261fB51136E65700Ef63fb7f18943A658094', 'data': '0xa40b6d66000000
0000000000000000000000000000000000000000000000000000000060000000000000000000000000000000000000000000000000000000000000000a0000000000000000000000000000000000000
00000000000000000000000000e000000000000000000000000000000000000000000000000000000000000000d313633363032303837393731350000000000000000000000000000000000000000
000000000000000000000000000000000000000000000000000000000000f3139322e3136382e3132322e313439000000000000000000000000000000000000000000000000000000000000000000
0000000000000000000000000000000d36392e3139352e37312e31373400000000000000000000000000000000000000'}
-----------------------------------------------------------------------------
Successfully sent to Ethereum
gas used: 28648
contract address: 0xDca4261fB51136E65700Ef63fb7f18943A658094
tx: 0x949d074314b9c5f558816ac4a69c2a466c95a813de0fc67e79d90c6fd99cf939
block: 0x36e5d10c6f3932c0397acdf0ac58907485b9ff412d1cc04c5618c997ee713e27
=============================================================================
IDS to DLT ... sending info
1636020879715   Intrusion detection, alert   Source IP: 192.168.122.149 Source port: 49324    Destination IP: 69.195.71.174    Destination Port: 443
-----------------------------------------------------------------------------
Transaction:
{'value': 0, 'gas': 28648, 'gasPrice': 20000000000, 'chainId': 1337, 'nonce': 9, 'to': '0xDca4261fB51136E65700Ef63fb7f18943A658094', 'data': '0xa40b6d66000000
0000000000000000000000000000000000000000000000000000000060000000000000000000000000000000000000000000000000000000000000000a0000000000000000000000000000000000000
00000000000000000000000000e000000000000000000000000000000000000000000000000000000000000000d313633363032303837393731350000000000000000000000000000000000000000
000000000000000000000000000000000000000000000000000000000000f3139322e3136382e3132322e313439000000000000000000000000000000000000000000000000000000000000000000
0000000000000000000000000000000d36392e3139352e37312e31373400000000000000000000000000000000000000'}
-----------------------------------------------------------------------------
Successfully sent to Ethereum
gas used: 28648
contract address: 0xDca4261fB51136E65700Ef63fb7f18943A658094
tx: 0xafae736af9df43515703f6f56e4d930774c83b7a0723258578569dce93ea4474
block: 0x779ecb5723fe5f4383ba84868d99707c0d6b5f63c20a5deec1feb2ec9e812f86
=============================================================================
```

Figure 38. Recording of Trust IDS events in the Ledger, via interaction between SAP and DLT Manager (request & response)

6.4.3 SAP TO DLT RECORD OF MONITORING EVIDENCE

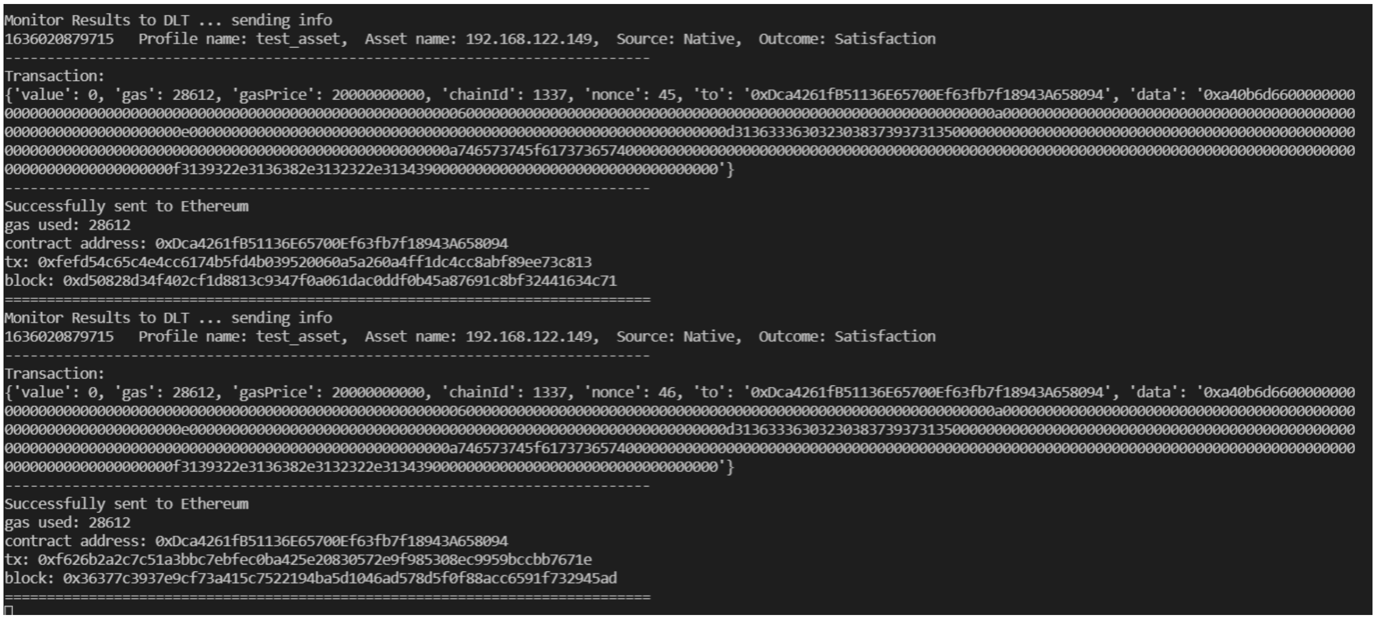
Messages of this type (e.g., Monitoring Rule triggers via Event Captor inputs) can be sent to the DLT for recording using a JSON format having the following structure:

```
{
"@timestamp": <timestamp>,
"event": {
"Profile": <the Assessment Profile name>,
"Asset Name": <The name of the Asset>,
"Source": <the source of the event, e.g. Filebeat, Auditbeat, Native>,
},
"Outcome": <The monitor result, Satisfaction/Violation>
}
```

An example based on the above template is provided below:

```
{
"@timestamp": 2017-04-07T22:24:37.251547+0100,
"event": {
"Profile": Availability,
"Asset Name": testasset,
"Source":  Native,
},
"Outcome": Satisfaction
}
```

A screenshot from such a message exchange, whereby a Monitoring Rule trigger is recorded from the SAP in the Ledger, is shown in Figure 39.



```
Monitor Results to DLT ... sending info
1636020879715   Profile name: test_asset,  Asset name: 192.168.122.149,  Source: Native,  Outcome: Satisfaction
-----------------------------------------------------------------------------
Transaction:
{'value': 0, 'gas': 28612, 'gasPrice': 20000000000, 'chainId': 1337, 'nonce': 45, 'to': '0xDca4261fB51136E65700Ef63fb7f18943A658094', 'data': '0xa40b6d6600000000
00000000000000000000000000000000000000000000000000000060000000000000000000000000000000000000000000000000000000000000000a000000000000000000000000000000000000000000
000000000000000000000e00000000000000000000000000000000000000000000000000000000000000000d3136333630323038373937313500000000000000000000000000000000000000000000000
00000000000000000000000000000000000000000000000000000a74657374 5f61737365740000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
00000000000000000000f3139322e3136382e3132322e3134390000000000000000000000000000000000'}
-----------------------------------------------------------------------------
Successfully sent to Ethereum
gas used: 28612
contract address: 0xDca4261fB51136E65700Ef63fb7f18943A658094
tx: 0xfefd54c65c4e4cc6174b5fd4b039520060a5a260a4ff1dc4cc8abf89ee73c813
block: 0xd50828d34f402cf1d8813c9347f0a061dac0ddf0b45a87691c8bf32441634c71
=============================================================================
Monitor Results to DLT ... sending info
1636020879715   Profile name: test_asset,  Asset name: 192.168.122.149,  Source: Native,  Outcome: Satisfaction
-----------------------------------------------------------------------------
Transaction:
{'value': 0, 'gas': 28612, 'gasPrice': 20000000000, 'chainId': 1337, 'nonce': 46, 'to': '0xDca4261fB51136E65700Ef63fb7f18943A658094', 'data': '0xa40b6d6600000000
00000000000000000000000000000000000000000000000000000060000000000000000000000000000000000000000000000000000000000000000a000000000000000000000000000000000000000000
000000000000000000000e00000000000000000000000000000000000000000000000000000000000000000d3136333630323038373937313500000000000000000000000000000000000000000000000
00000000000000000000000000000000000000000000000000000a746573745f61737365740000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
00000000000000000000f3139322e3136382e3132322e3134390000000000000000000000000000000000'}
-----------------------------------------------------------------------------
Successfully sent to Ethereum
gas used: 28612
contract address: 0xDca4261fB51136E65700Ef63fb7f18943A658094
tx: 0xf626b2a2c7c51a3bbc7ebfec0ba425e20830572e9f985308ec9959bccbb7671e
block: 0x36377c3937e9cf73a415c7522194ba5d1046ad578d5f0f88acc6591f732945ad
=============================================================================
```

Figure 39. Recording of Monitoring Rule trigger evidence in the Ledger, via interaction between SAP and DLT Manager (request & response).

7 ADDITIONAL SECURITY, PRIVACY, AND TRUST PRIMITIVES

In addition to the various trust enablers defined above, IntellIoT also integrates a number of additional design choices and enablers that facilitate its trust-by-design approach. These are detailed in the subsections that follow.

7.1 Multi-layer Monitoring

Multi-layer monitoring is an important part of the trust-by-design in IntellIoT, as it provides the means to collect the necessary evidence needed to monitor and ensure that the related mechanisms work properly and safeguard the system and the users. This monitoring encompasses:

- the security posture of the IoT environment where IntellIoT is deployed, including the application assets and the IntellIoT components;
- the operation of all the other security, privacy, and trust primitives, as defined herein.

Evidence from the above sources leveraged in real-time to provide an up-to-date view of the security and privacy posture of the protected infrastructure and the IntellIoT framework, via the SAP component (see Sect. 2). More details in terms of the implementation are provided in the subsections that follow.

7.1.1 EVENT CAPTORS

The event captors are responsible for aggregating required evidence from multiple sources related to the operation of individual components, as well as the overarching processes where these components are involved in, enabling the real time, continuous assessment of the security posture of the IntellIoT system. Data and events are mostly collected through ElasticSearch based on lightweight shippers (referred to as "Beats", such as FileBeat[31], MetricBeat[32], and PacketBeat[33]), that forward and centralize log data. Data can also be collected through Logstash, an open server-side data processing pipeline that ingests data from a multitude of sources, transforms it, and then sends it to ElasticSearch.

The Elastic Common Schema (ECS) will be used as an open-source specification for defining a common set of fields among with the data model that will be used when storing event data in Elasticsearch. Furthermore, ECS will be used to specify the field names and datatypes to be stored while supporting uniform data modelling, enabling to analyse data from diverse sources.

7.1.2 EVENTS COMMON SCHEMA SPECIFICATION

At a high level, ECS provides fields to classify events and data in two different ways: "Where is the data is coming from?" and "What data is it?". ECS defines four categorization fields for this purpose[34]:

- *Event.kind:* Highest level in the ECS category hierarchy, providing high-level information about what type of information the event contains, without being specific to the contents of the event. Possible values include:
  - *alert*
  - *event*
  - *metric*
  - *state*
  - *pipeline_error - signal*

[31] https://www.elastic.co/beats/filebeat
[32] https://www.elastic.co/beats/metricbeat
[33] https://www.elastic.co/beats/packetbeat
[34] https://www.elastic.co/guide/en/ecs/current/ecs-event.html

- *Event.category:* Second level in the ECS category hierarchy, representing "big buckets" of ECS categories. Possible values include:
    - *authentication*
    - *configuration*
    - *database*
    - *driver*
    - *file*
    - *host*
    - *iam*
    - *intrusion_detection*
    - *malware*
    - *network*
    - *package*
    - *process*
    - *registry*
    - *session*
    - *web*
- *Event.type:* Third level in the ECS category hierarchy, representing a "sub-bucket" categorisation. When used along with "Event.category", it enables filtering events to a level appropriate for single visualization. Possible values include:
    - *access*
    - *admin*
    - *allowed*
    - *change*
    - *connection*
    - *creation*
    - *deletion*
    - *denied*
    - *end*
    - *error*
    - *group*
    - *info*
    - *installation*
    - *protocol*
    - *start*
    - *user*
- *Event.outcome:* Fourth level in the ECS category hierarchy. Denotes whether the event represents a success or a failure from the perspective of the entity that produced the event. Possible values include:
    - *failure*
    - *success*
    - *unknown*

Finally, the payload specification is as follows:

```
{
        "@timestamp": "<the time stamp>",
        "event": {
                "kind": "<>",
                "category": "<>",
                "type": "<>",
                "outcome": "<>",
        },
        "<payload>" : "all possible recorded from Elasticsearch (ECS fields) except
"event" gategories"
}
```

7.2 5G Security Considerations

In the following section, the 5G security architecture will be briefly described. A longer description is provided in the 3GPP TS 33.501 document.

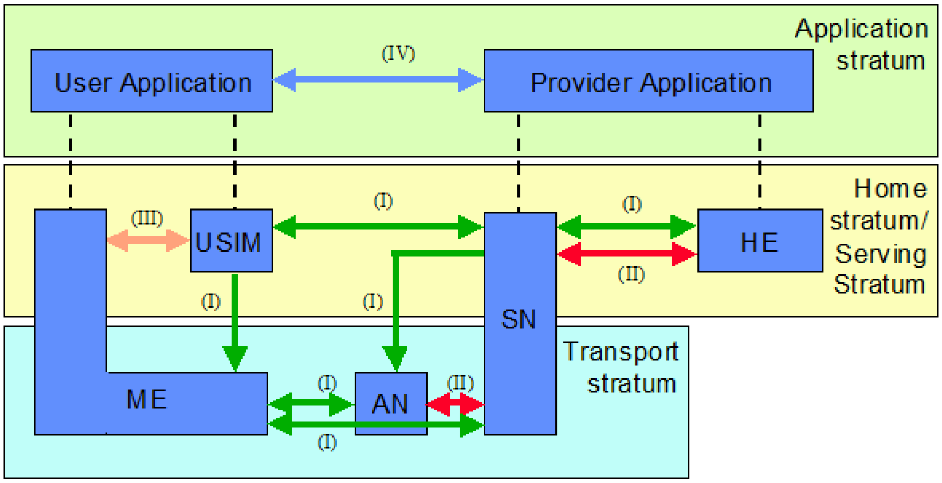


Figure 40. Generic 5G Security Architecture (source: 3GPP)

The generic 5G security architecture is depicted in Figure 40, which describes several 5G security domains:

- **Network access security (I):** the set of security features that enable a UE to authenticate and access services via the network securely, including the 3GPP access and non-3GPP access, and in particularly, to protect against attacks on the (radio) interfaces. In addition, it includes the security context delivery from the Serving Network (SN) to the Access Network (AN) for the access security.
- **Network domain security (II):** the set of security features that enable network nodes to securely exchange signalling data and user plane data.
- **User domain security (III):** the set of security features that secure the user access to mobile equipment.
- **Application domain security (IV):** the set of security features that enable applications in the user domain and in the provider domain to exchange messages securely. Application domain security is out of scope of the present document.
- **Service-based Architecture (SBA) domain security (V):** the set of security features that enables network functions of the SBA architecture to securely communicate within the serving network (SN) domain and with other network domains. Such features include network function registration, discovery, and authorization security aspects, as well as the protection for the service-based interfaces. SBA domain security is a new security feature compared to the 4G security architecture as described in 3GPP TS 33.401.

- **Visibility and configurability of security (VI):** the set of features that enable the user to be informed whether a security feature is in operation or not.

7.2.1 OVERVIEW OF COMMON 4G/5G SECURITY

The generic 3GPP security functions may be split in two categories:

- **Access-layer security –** this aims at securing the wireless link between the mobile terminal and the base station (4G eNB or 5G gNB) again security attacks. This is primarily done through mutual authentication between the UE and the gNB (gNB authenticating to the UE as well as the UE authenticating to the gNB) using cryptographic mechanisms stored in the USIM. Although the mechanisms have been generalized to support additional IETF-based security mechanisms, the Access-layer security between 4G or 5G network did not evolve significantly.
- **Network-domain security –** this aims at securing the various back-end entities in a 4G or 5G network. As depicted on Figure 41, these security mechanisms have been primarily designed in the case of roaming or virtual networks, as it remains largely assumed that network-domain entities operate in a monolithic and secured environment (i.e., owned by the same operator at the operator's premise). Accordingly, a 4G eNB or a 5G gNB should mutually authenticate with the visited PLMN (Public Land Mobile Network). Similarly, the visited PLMN must mutually authenticate to the Home HSS (the home database containing the access rights of the user).

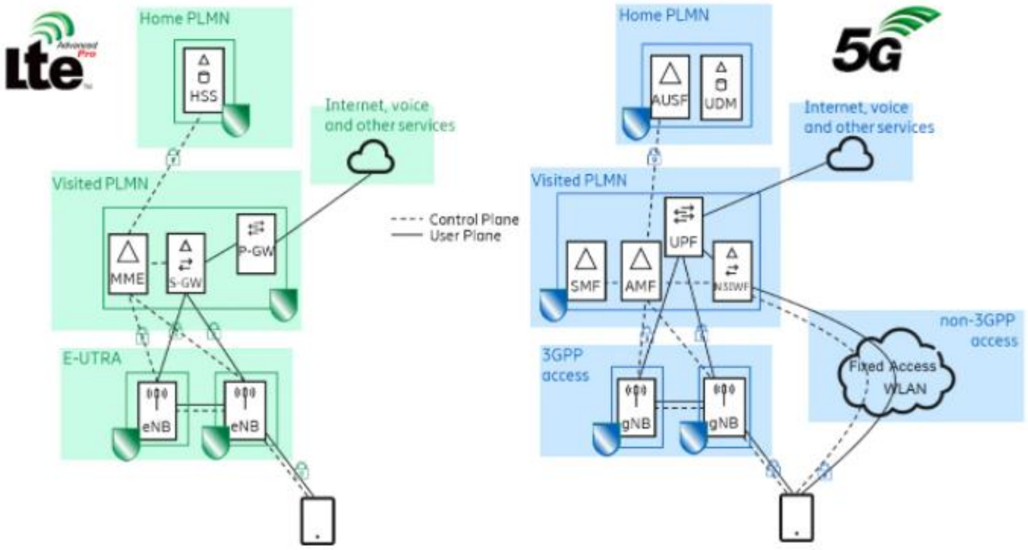


Figure 41. Network-domain security mechanisms (Source: Ericsson)

7.2.2 NEW 5G-SPECIFIC INNOVATIONS

If the 5G security architecture inherits many functions from previous generations (LTE or UMTS), it has a few major new security functions primarily adapted to handle three key 5G innovations: 5G end-to-end security, service-based architecture (i.e., slicing) and security on the user plane.

7.2.2.1 NEW AUTHENTICATION FRAMEWORK

The main authentication framework is known as the primary authentication and consists of the exchange of session keys between the UE and the eNB/gNB during the device registration phase. One limitation is that the security mechanisms are specific to 3GPP and cannot be extended beyond cellular operators, e.g., on a data network or a public internet. The new authentication framework enhances the primary authentication by supporting additional security and authentication algorithms as defined by the IETF under the name Extensible Authentication Protocols (EAP). EAP enables to use additional security credentials than those stored on the USIM card and would enable end-to-end security beyond the scope of cellular operators.

7.2.2.2 ENHANCED SUBSCRIBER PRIVACY

One major flaw in subscriber privacy in cellular networks is known as 'fake base stations', which can be applied through mechanisms known as IMSI catchers. Since 3G, a dual authentication has been enforced where the base station has to authenticate to the user in the same way as the user needs to authenticate to the base station. Yet, side information, such as device capabilities or correlation between protocol messages could still reveal much of the identity of a subscriber. 5G aims at mitigating such risk by proactively limiting the number of messages sent in cleartext even at an early stage of protocol negotiation.

7.2.2.3 SERVICE BASED ARCHITECTURE AND INTERCONNECT SECURITY

Service-based architectures (SBA) is a major paradigm shift introduced in 5G networks. It relates to extend of traditional point-to-point interfaces between network functions to new service-based interfaces, where the overall network architecture is designed as a dynamic, on-demand exposed service set to network entities (e.g., a MEC service might or might not be exposed to a core network or a user-plane function (UPF). SBA additionally increases the level of security protocols from a purely L3 level (IPSec) to L4 TLS mechanisms to protect the integrity at transport level or even OAuth 2.0 protocols to secure the integrity at the application level.

7.2.2.4 INTEGRITY PROTECTION OF THE USER PLANE

If various mechanisms have been designed in 3G and 4G to protect the control plane, the user plane has always been a weak link of a cellular network. For example, if a mutual authentication has been introduced as early as 3G in order to guarantee that both a UE and a eNB/gNB are legitimate and allowed to use a particular service, data transmitted on 3G and 4G networks were still cleartext, unless covered by an additional end-2-end security level between a provider and consumer beyond the cellular infrastructure. 5G improves this by enforcing the *availability* of encryption and integrity protection mechanisms on the user plane between a UE and a gNB. By 'availability', it means that 5G operators must have such functions available if the devices require them, but they do not need to use it by default. Cryptographic mechanisms are indeed resource demanding and not all classes of mobile entities (ME) can support them.

7.3 Other best practices, processes, and technologies

In addition to all the above provisions towards a trustworthy-by-design framework, IntellIoT also adopts best practices and industry-established standards in all types of interactions that involve the processing, storage and transmission of data. Some key examples are provided below, while additional details will be provided in the deliverables documenting the setup of the demonstrator environments (i.e., D5.2 and D5.5), as some of these aspects are merely configuration provisions and not the development of novel technologies or specific building blocks.

Concerning web and other user interactions foreseen in IntellIoT (e.g., to define end user goals, or to access the SAP web front end) applications will use the Transport Layer Security (TLS) protocol (at v1.3 since August 2018 [6]). A successor to the Secure Sockets Layer (SSL) protocol, TLS uses a combination of symmetric and public-key encryption to achieve its goal. Both parties create a secure communication channel at the beginning using public-key cryptography. During this period, they can exchange all the parameters for their communication as well as agree on a symmetric key for the rest of the communication which is a less resource intensive type of communication.

Another important consideration in this regard is the protection of the Trust Broker that all Trust Enablers use to integrate and interact with each other (see Sect. 6). As mentioned above, this is based on the AMQP protocol. This protocol guarantees the immutability of the messages exchanged using hashes. On top of that the AMQPS variant is going to be used, which is AMQP over TLS so no third party can have access to the information exchanged between the secure components.

Furthermore, for data at rest, meaning any data store (e.g., files or databases, such as the patient databased in Use Case 2) that exists in a node and needs to be accessed only by specific users/applications, appropriate encryption mechanisms will be used, appropriate to the sensitivity and criticality of the data to be protected. The encryption mechanisms will be combined with the authentication and authorization provided by the AAA component (see Sect. 3).

Finally, during the setup of the testing environment and, secure-by-default and fail-secure device configuration will be adopted for all key components (e.g., from network controllers and switches to sensor nodes and edge devices – tractor, robotic arm, etc.), to ensure that devices are secure out of the box (integrating all security-related bootstrapping procedures as needed) and, in the case of any failure, either by a fault or a malicious action, they will revert to a safe state.

8 CONCLUSIONS

This deliverable is the final output of Task 4.4 ("Trustworthy infrastructure by design") and, as such, documented the design and development of the final version of the security, privacy and trust enablers comprising the "Trust pillar" of IntellIoT, as defined within the corresponding final version of the framework's Architecture (as documented in D2.6).

As with all IntellIoT building block implementation tasks in WP3 and WP4, the components' specifications and associated interactions and requirements defined within D2.3 (& later D2.6), drove the design and development of the trust enablers presented herein. These covered all three pillars comprising the trust-by-design approach of IntellIoT, including continuous assurance, security, privacy and trust primitives, as well as the multi-layer monitoring of relevant operational parameters.

In terms of next steps, the building blocks defined herein will be provided as input to Task 5.1, towards the delivery of the final (Cycle 2) integrated version of IntellIoT, to be documented in D5.4 – "Integrated IntellIoT framework & use case implementations (final version)". These will be followed by the associated demonstration activities in Task 5.2 ("Deployment, testing & demonstration") – to be documented in D5.5 – "Deployed & tested use case demonstrators (final version)" - and evaluation activities in Task 5.3 ("Validation & evaluation") – to be documented in D5.6 – "Validation & evaluation (final version)" - which will also encompass the use & assessment of the Trust enablers detailed herein, in the context of IntellIoT's integrated framework & the corresponding Trust-focused scenarios defined within each of the 3 use cases. It should also be noted that many of the Trust enablers will be used by the OC2 winners of IntellIoT, thus providing further demonstration & validation evidence, in the context of additional use cases.

Furthermore, some of the enablers will be shared with the community for further uptake & exploitation. More specifically, the MTD, trust IDS and AAA components will be released as open source components and will be made available to the community through the official IntellIoT repository (https://gitlab.eurecom.fr/intelliot). The AAA is based on KeyCloak which is an open source solution, released under the Apache 2.0 license. Therefore, our extensions and customizations will be made publicly available with the same license to ensure that they can be easily adopted by any entity seeking to use the specific solution. At this point in time, the MTD and trustIDS components have only been released to select third parties (including all the Open Call 2 winners which have chosen to use them as part of their solutions). A public release of the two components is planned for the near future and it will include both source code and documentation as well as deployment packages (e.g. binaries and docker containers) to enable a smooth adoption path by any interested entity which may be willing to customise them, extend them or simply use them as part of a deployed security solution. To facilitate their adoption, TSI plans to release these tools under a permissive open source license (the exact license will be determined prior to public release).

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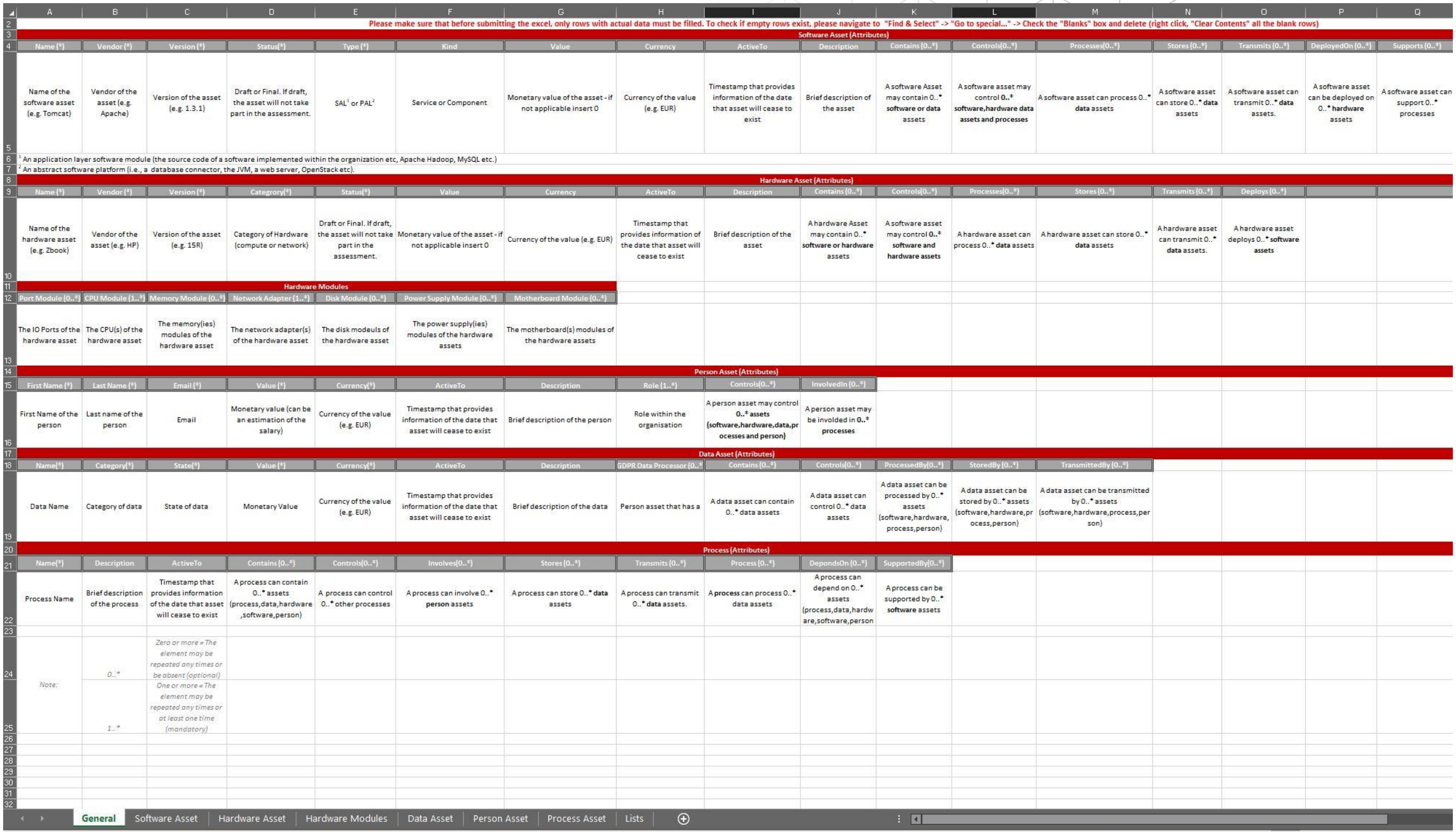
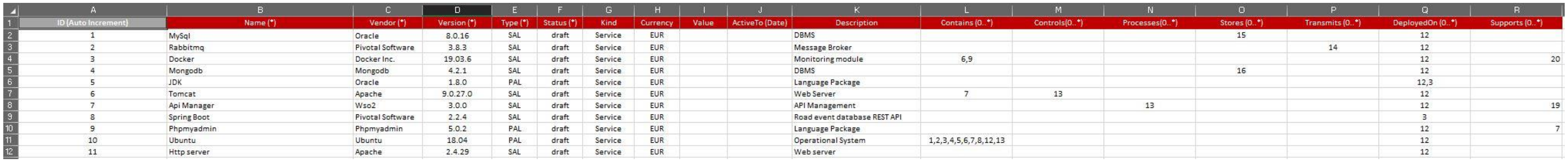
ANNEX A – INTELLIOT ASSET MODEL SPECIFICATION FORM

This Annex provides several screenshots of the Asset Model specification form that was used to define the IntellIoT asset model, covering the general tab (Figure 42), the tab for defining software assets (Figure 43), as well as the ones for data (Figure 44) and hardware assets (Figure 45).



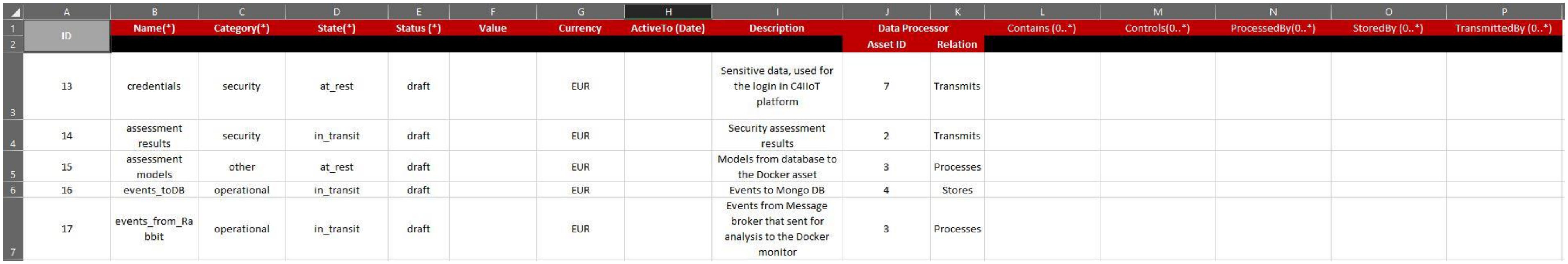
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
2	Please make sure that before submitting the excel, only rows with actual data must be filled. To check if empty rows exist, please navigate to "Find & Select" -> "Go to special..." -> Check the "Blanks" box and delete (right click, "Clear Contents" all the blank rows)																
3	Software Asset (Attributes)																
4	Name (*)	Vendor (*)	Version (*)	Status(*)	Type (*)	Kind	Value	Currency	ActiveTo	Description	Contains (0..*)	Controls(0..*)	Processes(0..*)	Stores (0..*)	Transmits (0..*)	DeployedOn (0..*)	Supports (0..*)
5	Name of the software asset (e.g. Tomcat)	Vendor of the asset (e.g. Apache)	Version of the asset (e.g. 1.3.1)	Draft or Final. If draft, the asset will not take part in the assessment.	SAL[1] or PAL[2]	Service or Component	Monetary value of the asset - if not applicable insert 0	Currency of the value (e.g. EUR)	Timestamp that provides information of the date that asset will cease to exist	Brief description of the asset	A software Asset may contain 0..* **software or data assets**	A software asset may control **0..* software,hardware data assets and processes**	A software asset can process 0..* **data assets**	A software asset can store 0..* **data** assets	A software asset can transmit 0..* **data** assets.	A software asset can be deployed on 0..* **hardware** assets	A software asset can support 0..* processes
6	[1] An application layer software module (the source code of a software implemented within the organization etc, Apache Hadoop, MySQL etc.)																
7	[2] An abstract software platform (i.e., a database connector, the JVM, a web server, OpenStack etc).																
8	Hardware Asset (Attributes)																
9	Name (*)	Vendor (*)	Version (*)	Category(*)	Status(*)	Value	Currency	ActiveTo	Description	Contains (0..*)	Controls(0..*)	Processes(0..*)	Stores (0..*)	Transmits (0..*)	Deploys (0..*)		
10	Name of the hardware asset (e.g. Zbook)	Vendor of the asset (e.g. HP)	Version of the asset (e.g. 15R)	Category of Hardware (compute or network)	Draft or Final. If draft, the asset will not take part in the assessment.	Monetary value of the asset - if not applicable insert 0	Currency of the value (e.g. EUR)	Timestamp that provides information of the date that asset will cease to exist	Brief description of the asset	A hardware Asset may contain 0..* **software or hardware** assets	A software asset may control **0..* software and hardware assets**	A hardware asset can process 0..* **data assets**	A hardware asset can store 0..* **data assets**	A hardware asset can transmit 0..* **data assets.**	A hardware asset deploys 0..* **software assets**		
11	Hardware Modules																
12	Port Module (0..*)	CPU Module (1..*)	Memory Module (0..*)	Network Adapter (1..*)	Disk Module (0..*)	Power Supply Module (0..*)	Motherboard Module (0..*)										
13	The IO Ports of the hardware asset	The CPU(s) of the hardware asset	The memory(ies) modules of the hardware asset	The network adapter(s) of the hardware asset	The disk modeuls of the hardware asset	The power supply(ies) modules of the hardware assets	The motherboard(s) modules of the hardware assets										
14	Person Asset (Attributes)																
15	First Name (*)	Last Name (*)	Email (*)	Value (*)	Currency(*)	ActiveTo	Description	Role (1..*)	Controls(0..*)	InvolvedIn (0..*)							
16	First Name of the person	Last name of the person	Email	Monetary value (can be an estimation of the salary)	Currency of the value (e.g. EUR)	Timestamp that provides information of the date that asset will cease to exist	Brief description of the person	Role within the organisation	A person asset may control **0..* assets (software,hardware,data,processes and person)**	A person asset may be involded in **0..* processes**							
17	Data Asset (Attributes)																
18	Name(*)	Category(*)	State(*)	Value (*)	Currency(*)	ActiveTo	Description	GDPR Data Processor (0..*	Contains (0..*)	Controls(0..*)	ProcessedBy(0..*)	StoredBy (0..*)	TransmittedBy (0..*)				
19	Data Name	Category of data	State of data	Monetary Value	Currency of the value (e.g. EUR)	Timestamp that provides information of the date that asset will cease to exist	Brief description of the data	Person asset that has a	A data asset can contain 0..* data assets	A data asset can control 0..* data assets	A data asset can be processed by 0..* assets (software,hardware, process,person)	A data asset can be stored by 0..* assets (software,hardware,process,person)	A data asset can be transmitted by 0..* assets (software,hardware,process,person)				
20	Process (Attributes)																
21	Name(*)	Description	ActiveTo	Contains (0..*)	Controls(0..*)	Involves(0..*)	Stores (0..*)	Transmits (0..*)	Process (0..*)	DependsOn (0..*)	SupportedBy(0..*)						
22	Process Name	Brief description of the process	Timestamp that provides information of the date that asset will cease to exist	A process can contain 0..* assets (process,data,hardware ,software,person)	A process can control 0..* other processes	A process can involve 0..* **person** assets	A process can store 0..* **data** assets	A process can transmit 0..* **data** assets.	A **process** can process 0..* data assets	A process can depend on 0..* assets (process,data,hardware,software,person	A process can be supported by 0..* **software** assets						
23																	
24	*Note:*	*0..**	*Zero or more = The element may be repeated any times or be absent (optional)*														
25		*1..**	*One or more = The element may be repeated any times or at least one time (mandatory)*														
26																	
27																	
28																	
29																	
30																	
31																	
32																	

Figure 42.General tab of the asset model specification form (overview & guidelines)



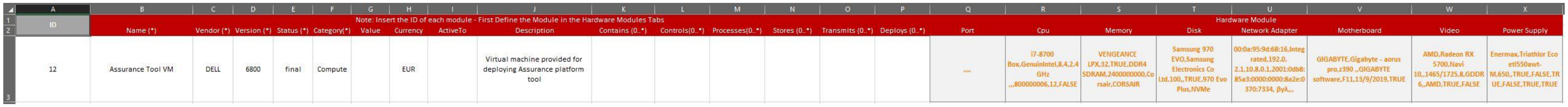
ID (Auto Increment)	Name (*)	Vendor (*)	Version (*)	Type (*)	Status (*)	Kind	Currency	Value	ActiveTo (Date)	Description	Contains (0..*)	Controls(0..*)	Processes(0..*)	Stores (0..*)	Transmits (0..*)	DeployedOn (0..*)	Supports (0..*)
1	MySql	Oracle	8.0.16	SAL	draft	Service	EUR			DBMS				15		12	
2	Rabbitmq	Pivotal Software	3.8.3	SAL	draft	Service	EUR			Message Broker					14	12	
3	Docker	Docker Inc.	19.03.6	SAL	draft	Service	EUR			Monitoring module	6,9					12	20
4	Mongodb	Mongodb	4.2.1	SAL	draft	Service	EUR			DBMS				16		12	
5	JDK	Oracle	1.8.0	PAL	draft	Service	EUR			Language Package						12,3	
6	Tomcat	Apache	9.0.27.0	SAL	draft	Service	EUR			Web Server	7	13				12	
7	Api Manager	Wso2	3.0.0	SAL	draft	Service	EUR			API Management			13			12	19
8	Spring Boot	Pivotal Software	2.2.4	SAL	draft	Service	EUR			Road event database REST API						3	
9	Phpmyadmin	Phpmyadmin	5.0.2	PAL	draft	Service	EUR			Language Package						12	7
10	Ubuntu	Ubuntu	18.04	PAL	draft	Service	EUR			Operational System	1,2,3,4,5,6,7,8,12,13					12	
11	Http server	Apache	2.4.29	SAL	draft	Service	EUR			Web server						12	

Figure 43. Software asset entries (indicative)



ID	Name(*)	Category(*)	State(*)	Status (*)	Value	Currency	ActiveTo (Date)	Description	Data Processor		Contains (0..*)	Controls(0..*)	ProcessedBy(0..*)	StoredBy (0..*)	TransmittedBy (0..*)
									Asset ID	Relation					
13	credentials	security	at_rest	draft		EUR		Sensitive data, used for the login in C4IIoT platform	7	Transmits					
14	assessment results	security	in_transit	draft		EUR		Security assessment results	2	Transmits					
15	assessment models	other	at_rest	draft		EUR		Models from database to the Docker asset	3	Processes					
16	events_toDB	operational	in_transit	draft		EUR		Events to Mongo DB	4	Stores					
17	events_from_Rabbit	operational	in_transit	draft		EUR		Events from Message broker that sent for analysis to the Docker monitor	3	Processes					

Figure 44. Data asset entries (indicative)



ID	Note: Insert the ID of each module - First Define the Module in the Hardware Modules Tabs															Hardware Module							
	Name (*)	Vendor (*)	Version (*)	Status (*)	Category(*)	Value	Currency	ActiveTo	Description	Contains (0..*)	Controls(0..*)	Processes(0..*)	Stores (0..*)	Transmits (0..*)	Deploys (0..*)	Port	Cpu	Memory	Disk	Network Adapter	Motherboard	Video	Power Supply
12	Assurance Tool VM	DELL	6800	final	Compute		EUR		Virtual machine provided for deploying Assurance platform tool							,,,,	i7-8700 Box,GenuinIntel,8,4,2.4 GHz ,,,800000006,12,FALSE	VENGEANCE LPX,32,TRUE,DDR4 SDRAM,2400000000,Corsair,CORSAIR	Samsung 970 EVO,Samsung Electronics Co Ltd,100,,TRUE,970 Evo Plus,NVMe	00:0a:95:9d:68:16,Integrated,192.0.2.1,10.8.0.1,2001:0db8:85a3:0000:0000:8a2e:0370:7334, βγλ,,,	GIGABYTE,Gigabyte - aorus pro,z390 ,,GIGABYTE software,F11,13/9/2019,TRUE	AMD,Radeon RX 5700,Navi 10,,1465/1725,8,GDDR6,,AMD,TRUE,FALSE	Enermax,Triathlor Eco etl550awt-M,650,,TRUE,FALSE,TRUE,FALSE,TRUE,TRUE

Figure 45.Hardware asset entry (indicative)

ANNEX B – ASSET MODEL GRAMMAR

Examples of the use of the Asset Model Grammar used in the SAP are provided below (examples for Person, Software and Hardware assets, specifically).

```
Person(firstName("Demo"),lastName("User"),email("demo@sphynx.ch"),project("IntellIoT"),organisation("Sphynx Analytics
Ltd."),roles(Project end-user))
```

```
SoftwareAsset(vendor("Oracle Corporation"),version("9.6"),name("MySQL
Server"),kind(Service),type(SAL),project("IntellIoT"),organisation("Sphynx Analytics Ltd."),description("Relational
Database"))
```

```
SoftwareAsset(vendor("Mongodb"),version("4.2.1"),name("Mongodb"),kind(Service),type(SAL),project(" IntellIoT"),organisation("
Sphynx Analytics Ltd."))
```

```
SoftwareAsset(vendor("Wso2"),version("3.0.0"),name("Api
Manager"),kind(Service),type(PAL),project("IntellIoT"),organisation("Sphynx Analytics Ltd."),owner("staff"),description("API
Manager")),
```

```
HardwareAsset(vendor("DELL"),version("6800"),name("Assurance ToolVM"),
value(3000.0),currency(EUR),hwType(compute),project("IntellIoT"),organisation("Sphynx Analytics Ltd."),CpuModule(name("Intel
i7-
8700"),manufacturer("GenuinIntel"),numberOfCores(4),numberOfThreads(8),baseClock(2.4),cache(12),MemoryModule(name("VENGEANCE
LPX"),size(32),type("DDR4"),speed(3200.0),manufacturer("Corsair")),NetworkAdapterModule(connectionType(Integrated),MAC("00:0
a:95:9d:68:16"),NetworkConfiguration(ipv4("195.201.62.1"),Subnet Mask("255.255.0.0"))))
```