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The European IoT Hub

Growing a sustainable and comprehensive ecosystem

for Next Generation Internet of Things

D3.4: Open-source Ecosystem Catalogue Version 2

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Abstract

This deliverable presents the final version of the IoT open-source projects and initiative catalogue developed in the scope of the EU-IoT project. It also illustrates a set of relevant coordination and support activities that aim at supporting the IoT community in their open-source adoption efforts. The deliverable builds over the first version of the catalogue, which comprises over 100 OSS projects that have been presented and analysed in the previous version of this deliverable. Specifically, as part of this deliverable the project enhanced the initial version of the catalogue with an additional number of OSS projects. Moreover, a segmentation of the projects of the catalogue in terms of their ability to support standardisation is presented. Also, the deliverable discusses the open-source developments and contributions of the ICT-56 projects, which are directly linked to the coordination and support activities of EU-IoT as direct and frequent collaborators.

Keywords: IoT, Open-source, Catalogue, Ecosystem, Eclipse, Linux Foundation, Apache, OSS projects, Github, OSS projects analysis, Standardisation, Open Standards, ICT-56 Projects, H2020

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Dissemination Level		
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CI	Classified, information as referred to in Commission Decision 2001/844/EC	
CO	Confidential to EU-IoT project and Commission Services	

* R: Document, report (excluding the periodic and final reports)

DEM: Demonstrator, pilot, prototype, plan designs

DEC: Websites, patents filing, press & media actions, videos, etc.

OTHER: Software, technical diagram, etc

EXECUTIVE SUMMARY

One of the main objectives of the EU-IoT project is to provide coordination, orientation and support to the IoT (Internet of Things) community in terms of the integration, use and development of IoT related Open-source Software (OSS). To this direction, EU-IoT has provided a map of IoT OSS initiatives and projects, while at the same time producing resources that help IoT researchers and engineers, to adopt, use, extend and fully leverage IoT OSS results. This deliverable is the second and final report on EU-IoT's efforts to provide a catalogue of the IoT part of the OSS ecosystem, along with other useful resources for IoT researchers and developers.

The deliverable builds on earlier deliverable D3.3 that has collected and analysed 100s of OSS projects and initiatives. The latter have been made publicly accessible through an on-line catalogue. Specifically, in the scope of this deliverable we have enhanced the list of IoT projects of the on-line catalogue. Moreover, we have analysed and segmented the projects in terms of their relevance to standards. Therefore, the present deliverable can serve as a mini guide to IoT stakeholders that are interested in using OSS projects to foster their standardisation activities, including both compliance to standards and contributions to standards development.

Overall, EU-IoT has produced the following open-source related resources for IoT developers, IoT researchers and IoT engineers:

- **An on-line, searchable, and extensible catalogue of IoT-related OSS projects**. This catalogue helps IoT stakeholders to locate OSS projects that suit their development or standardisation needs.
- **A whitepaper with a mapping and analysis of the IoT OSS ecosystem**. It is publicly available and has already attracted significant interested, as evident from the number of accesses to it. The whitepaper provides an analysis of available OSS projects, considering different attributes and characteristics, including for example their popularity, their support for different programming languages, as well as their support for different standards.
- **A report on OSS projects that implement or comply with certain IoT-related standards**. These projects include reference implementations of standards, as well as IoT platforms and tools that comply with certain standards.
- **A report on the more specific OSS activities of EU funded IoT projects**, notably the projects of the ICT-56 call that are closely collaborating and interacting with EU-IoT. The report provides insights on how these projects have contributed to existing OSS projects, as well as on which ones have initiated new OSS initiatives.

The above-listed results have been reinforced by other activities of the EU-IoT project, such as the dissemination, communication, and training activities of the project. Most importantly, they have been considered in the project's exploitation planning. The partners have defined a viable route to the sustainability and wider use of these results, leveraging on new EU projects of the partners, as well as on new EU funded CSAs.

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ABBREVIATIONS

AI	Artificial Intelligence
API	Application Programming Interface
AMQP	Advanced Message Queuing Protocol
AR	Augmented Reality
BSD	Berkeley Source Distribution
CB	Coordination Board
CC	Creative Commons
CESSDA	Consortium of European Social Science Data Archives
CoAP	Constrained Application Protocol
CSA	Coordination and Support Action
CSE	Common Services Entity
DDS	Data Distribution Service
DL	Deep Learning
DMP	Data Management Plan
DSA	Distributed Services Architecture
DSL	Domain Specific Language
FAIR	Findable, Accessible, Interoperable, Reusable
GPL	General Public License
HTML	HyperText Markup Language
HTTP	HyperText Transfer Protocol
HyperMAS	Hypermedia Multi-Agent System
IEC	International Electrotechnical Commission
IETF	Internet Engineering Task Force
IoT	Internet of Things
IIoT	Industrial Internet of Things
IP	Internet Protocol
ITU	International Telecommunication Union
JSON	Java Script Object Notation
LoRa	Long Range Radio
LoRaWAN	Long Range Radio Wide Area Network
LGPL	Lesser General Public License
M2M	Machine-to-Machine
MQTT	Message Queuing Telemetry Transport
MQTT-SN	MQTT for Sensor Networks

ML	Machine Learning
NAT	Network Address Translations
NFC	Near Field Communications
NSSMF	Network Slice Subnet Management Function
OASIS	Organisation for the Advancement of Structured Information **Standards**
OCF	Open Connectivity Foundation
OMA	Open Mobile Alliance
OMG	Object Management Group
ORDP	Open Research Data Pilot
OS-IoT	Open Source – Internet of Things
OSS	Open-source Software
OT	Operational Technology
PLC	Programmable Logic Controller
RAN	Radio Access Network
REST	Representational State Transfer
RFC	Request for Comments
ROS	Robotic Operating System
RoT	Root-of-Trust
RTOS	Real-Time Operating System
SBOM	Software Bill of Materials
SCADA	Supervisory Control and Data Acquisition
SDK	Software Development Kit
SDO	Standards Development Organisations
SPDX	Software Package Data Exchange
SoC	System-on-Chip
TCP	Transmission Control Protocol
TD	Things Description
TLS	Transport Layer Security
XR	Extended Reality

1 INTRODUCTION

1.1 Project Brief and Deliverable Scope

One of the main objectives of the EU-IoT Coordination and Support Action (CSA) is to support the European Internet of Things (IoT) community in their efforts to adopt and fully leverage open-source software, while at the same time fostering community's contributions to Open-source and standards. The open-source related outcomes of the project are aimed at supporting IoT vendors, IoT solution integrators and IoT end-users in Europe. Nevertheless, the project has a close relationship with several IoT-related EU-funded research and innovation projects, namely with the projects that have been funded in the scope of the H2020 ICT-56 call of the European Commission (EC). Specifically, EU-IoT supports these projects in their open-source adoption and use efforts, while also monitoring and disseminating their open-source developments.

EU-IoT acknowledges the importance of open-source software for the development, deployment, operation and standardisation of non-trivial IoT systems. This is because most IoT projects comprise one or more open-source components, and this hold true even for projects that comprise many components or modules with proprietary licenses. Moreover, EU-IoT considers open-source software as a very good opportunity to foster the adoption and maximise the impact of IoT products and services. Furthermore, IoT OSS empowers researchers', standards development organisations' (SDOs), and enterprises' efforts to adopt standards-based approaches in IoT development, but also in their attempts to contribute to the complex and heterogenous landscape of IoT standardisation. This is the reason why many standards-development processes use open-source software as a vehicle for standardisation activities such as reference implementations.

To support the IoT community in its open-source development, deployment, and standardisation efforts, EU-IoT has undertaken the following activities:

- Created a Catalogue of IoT initiatives and projects, which provides a map of the European and global IoT ecosystem.
- Analysed over 100 open-source projects towards extracting consolidated information about the community, the popularity, the supporting standards, and the overall positioning of each project in the IoT technology ecosystem.
- Provided a searchable on-line catalogue of OSS projects, which facilitates the community to discovery OSS IoT projects based on a variety of criteria.
- Collected and consolidated information about the OSS activities of EU-funded IoT projects, notably of the H2020 ICT-56 projects.
- Curated the analysed OSS projects in terms of their potential to support standardisation-related activities.

The above listed results in a set of tangible and useful outcomes of the IoT community. Some of these results (e.g., the development of the catalogue and the analysis of the projects) have been reported in the first version of this deliverable, namely deliverable D3.3 of the EU-IoT project. The present document is the project's second and final report on open-source ecosystem support activities. It reports on the final open-source activities of the ICT-56 projects and the final contents of the OSS projects catalogue. Most importantly, it provides a sub-list / sub-catalogue of projects that can be used to support the open-source activities of the community.

1.2 Purpose and Methodology

The present document is the final report on the coordination and support activities of the project for the open-source community. The deliverable builds on the outcomes of the first version of the open-source activities report (D3.3). Specifically, the project enhances some of the contents of the first version such as the OSS projects catalogue and provides updated information about the open-source activities of the ICT-56 projects. It also presents standards-related information that is focused on how specific OSS projects can be used to support researchers, enterprises and SDOs in their standardisation endeavours. Overall, the project has implemented the following the following open-source community support activities:

- **IoT OSS Projects Information Collection, Curation, and Structuring**: The initial activities of the EU-IoT project focused on the collection of information about the global IoT OSS ecosystem, notably information about the most prominent and most popular IoT OSS projects. This information was curated and analysed, leading to the creation of an IoT OSS projects catalogue. The catalogue is searchable, and publicly available on-line. Its public launch took place after the first year of the EU-IoT project's lifetime. The catalogue has been enhanced with new projects ever since.
- **IoT OSS Analysis to foster Standardisation**: The OSS projects that are best suited to support standardisation related activities (e.g., raising awareness about standards, increasing standards adoption, producing reference implementations) have been identified and analysed.
- **IoT OSS Projects Information Presentation and Dissemination**: In collaboration with the EU-IoT dissemination and communication work package (i.e., WP5), the project has disseminated IoT OSS projects information as widely as possible. In this direction, the project has also developed dissemination materials (e.g., blog posts, whitepapers) that foster the communication of the results to interested stakeholders.

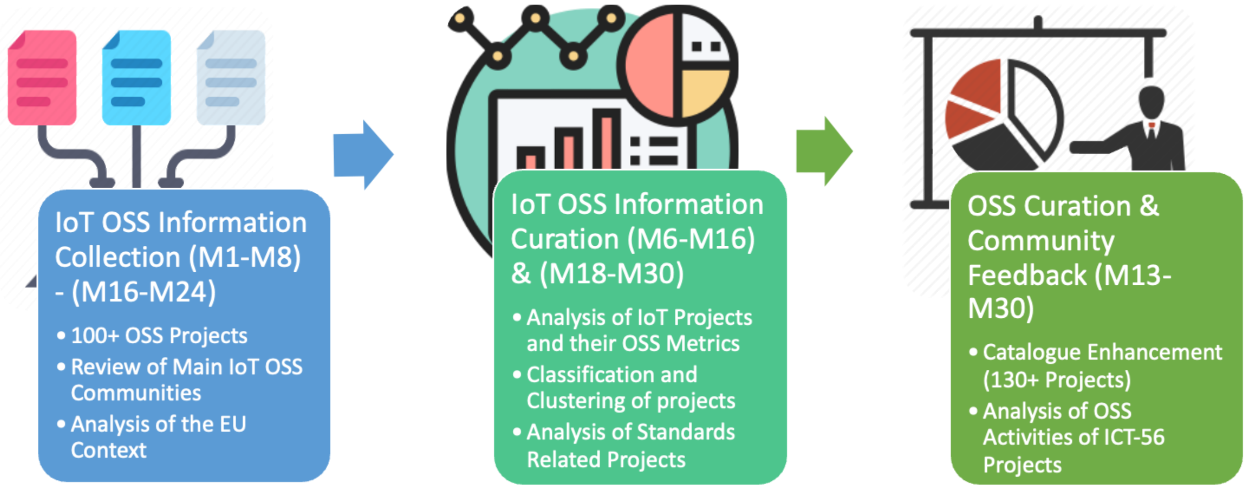

IoT OSS Information Collection (M1-M8) - (M16-M24)
• 100+ OSS Projects
• Review of Main IoT OSS Communities
• Analysis of the EU Context
IoT OSS Information Curation (M6-M16) & (M18-M30)
• Analysis of IoT Projects and their OSS Metrics
• Classification and Clustering of projects
• Analysis of Standards Related Projects
OSS Curation & Community Feedback (M13-M30)
• Catalogue Enhancement (130+ Projects)
• Analysis of OSS Activities of ICT-56 Projects

Figure 1: Phased Methodology for the EU-IoT OSS Support activities

The above listed activities have been undertaken in three main implementation phases as illustrated in Figure 1. Specifically:

- **Phase 1: Information Collection** activities were carried out during the first months of the project's lifetime (i.e., M1-M8), where information about IoT projects and communities was collected leveraging desk research. Following the dissemination of the open-source findings and services of the project, EU-IoT collected information (M16-M24) about additional projects, which will were accordingly used to updated the IoT project's catalogue.

- **Phase 2: Information Analysis and Curation** activities commenced after the first semester of the project, once a critical mass of IoT OSS projects and communities' information became available. Information analysis activities continued till the end of the project. Special emphasis was paid in the identification and documentation of a list of OSS projects that incorporate or implement standards. These projects can support standardisation activities for interested' stakeholders such as researchers and SDOs. The analysis of information about standards-related projects is included in the present deliverable. It was produced during the last semester of the project's lifetime i.e., during M24-M30.
- **Phase 3: Information dissemination and presentation activities** commenced at the end of the first year of the project's lifetime. They continued till the end of the project (M13-M30) in order to engage the community with the EU-IoT projects findings, including the findings of both deliverables i.e., the first version (D3.3) and the present version (D3.4). The present deliverable includes information about the latest OSS activities of the H2020 ICT-56 projects that collaborate closely with EU-IoT.

1.3 Enhancements and Updates from the Previous Version

The present deliverable builds on the findings and results of D3.3. This is the reason why it summarises some of the main outcomes that are reported in D3.3 such as the project's catalogue and its contents. Nevertheless, it also includes new content about the OSS projects that can be used for standards-based activities. Overall, the following enhancements and updates over D3.3 can be found in this deliverable:

- Updates regarding the contents of the IoT OSS ecosystem and projects catalogue, which is presented in Section 2. Note that the presented contents are provided in a summary form without the details given in D3.3.
- New information about OSS projects that can support and foster standardisation activities. This information can be found in Section 3.
- Updates regarding the open-source activities of the ICT-56 projects, which can be found in Section 4.

1.4 Structure of the Document

Following this introductory section, the deliverable is structured as follows:

- Section 2 provides updated information regarding the contents of the IoT OSS projects catalogue. It enhances information already provided in D3.3.
- Section 3 illustrates how certain OSS projects are linked to specific standards and SDOs. It also explains the positive implications of such a link.
- Section 4 reports the OSS activities of the ICT-56 project. It enhances the information provided by the projects in the first version.
- Section 5 concludes the deliverable. It mainly summarises the results of the open-source related outcomes of the project and assesses their potential impact on the IoT community.

2 EU-IOT OPEN-SOURCE CATALOGUE CONTENTS AND ECOSYSTEM MAPPING

2.1 Overview

In-line with the title of this deliverable, EU-IoT has provided a catalogue of OSS resources and entities for the IoT ecosystem. As already outlined in D3.3, this catalogue aimed at facilitating IoT actors to locate OSS resources and information through a single point of entry. The following paragraphs provide a summary of the entities that were catalogued with emphasis on IoT projects.

2.2 OSS Communities

Our ecosystem mapping effort has identified the main OSS communities that have a strong footprint in open-source developments and contributions. These communities are summarised in the Table 1.

IoT OSS Community	Short Description
Eclipse IoT Community	The IoT open-source community of the Eclipse Foundation. It includes over 45 projects covering different areas of IoT development.
Linux foundation	Hosts communities dedicated to IoT developments. Among the over 375 projects of the foundation, there are some popular state of the art IoT projects such as the EdgeX Foundry, an IoT Plug n' Play platform for edge computing.
Apache Software foundation	This community includes various IoT projects within its portfolio of over 350 projects. Prominent examples are IoTDB and the Camel project that is used for IoT integration.
FIWARE foundation and community	Provides a rich set of open-source components for building next generation internet applications, including components for IoT development such as the FIWARE Context Broker.
Communities of open-source companies like RedHat and Canonical	These companies have developed vibrant open-source communities around their IoT and cloud related open-source projects and solutions (e.g., Ubuntu core).
Enterprise Communities (e.g., Bosch Software Innovations, Eurotech, Dataart)	Bosch Software Innovations is one of the main contributors to the Eclipse IoT Working Group up to date, while being a user of open-source components as part of the Bosch IoT Suite. As another example, Eurotech's main IoT product, the Everyware Software Framework (ESF) is based on Eclipse Kura project. The latter has been contributed to Eclipse by Eurotech. There are also companies outside Europe that develop and release enterprise scale OSS for IoT. For instance, the Dataart New York City based firm has developed and launched DeviceHive, a prominent open-source cloud-based IoT development platform and M2M framework.

Table 1: IoT-related OSS Communities

2.3 Related EU Initiatives and Projects

EU-IoT has also identified EU initiatives and organisations with an active and important role in the development of the European and global IoT Open-source Ecosystem. These are listed in the following table.

European IoT OSS Initiatives	Short Description
Eclipse IoT working group	Initiative that is influenced to a significant extent by European developers and their organisations.
FIWARE community	Supports a significant number of IoT developments and deployments, including many applications and use cases developed in the scope of EU funded IoT projects such as the H2020 IoT Large Scale Pilot (LSP) projects.
OW2 community **and its FIiSSi Initiative**	Prominent OSS community in the European software ecosystem. It focuses on infrastructure software like service-oriented middleware, cloud services orchestration and other technologies that support the development and deployment of IoT applications. Within OW2, there is the OW2 Future Internet Software and Services Initiative (FISSi), which focuses on scalable technologies for the future internet. OW2 does not include many projects with an exclusive IoT focus, the FIiSSi initiative supports IoT developments in the cloud/edge continuum.
European Telecommunications Standards Institute (ETSI)	Engages very actively with IoT-related OSS projects like the oneM2M and the Open-source Mano (OSM). The OSM reflects the evolution of ETSI's Network Functions Virtualisation (NFV) standardisation efforts. This is also an example, where OSS boosts the development and validation of open standards.

Table 2: IoT OSS related Initiatives with a strong European Orientation

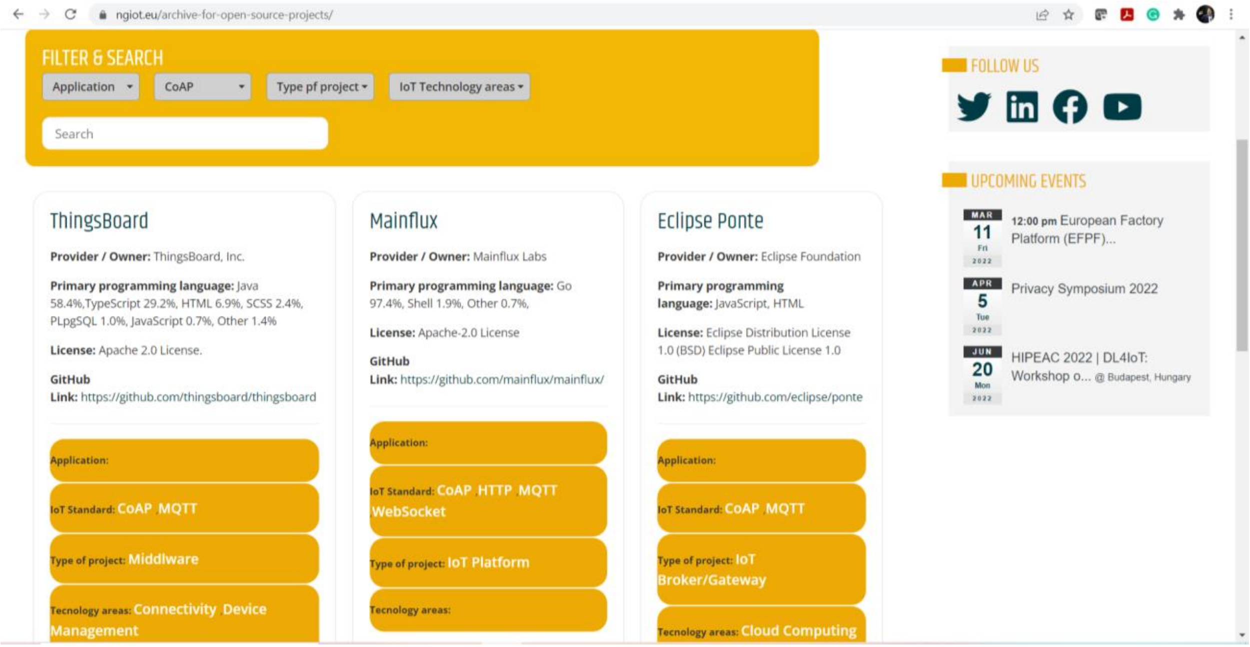
2.4 OSS Projects: The EU-IoT On-line OSS Projects Catalogue

The engagement of IoT stakeholders with OSS developments is usually done in the scope of some OSS project. For instance, IoT developers engage with OSS in the following ways:

- By (re)using open-source components from one or more OSS projects.
- By contributing to one or more OSS projects as part of their work. This is the case for example for extensions to OSS projects.
- By setting up new OSS projects i.e., OSS projects that are developed from scratch and used to host their developments.

As part of deliverable D3.3, EU-IoT has collected and analysed over IoT OSS 120 projects, including the projects of the most popular OSS IoT communities. Moreover, EU-IoT hosts these projects in a searchable and extensible on-line catalogue. The catalogue is available on-line at NGIOT/EU-IoT web site: https://www.ngiot.eu/archive-for-open-source-projects/.

It allows its users to search projects based on different criteria, including the IoT technology area of the project (e.g., cloud computing, edge computing), the type of project (e.g., development tool, middleware, open-source hardware related), the application area/sector (e.g., energy, manufacturing), as well as the standards that it supports or implements (e.g., CoAP, MQTT). A snapshot of the on-line catalogue is illustrated in Figure 2.



ngiot.eu/archive-for-open-source-projects/

FILTER & SEARCH

Application ▾ | CoAP ▾ | Type pf project ▾ | IoT Technology areas ▾

Search

ThingsBoard

Provider / Owner: ThingsBoard, Inc.

Primary programming language: Java 58.4%,TypeScript 29.2%, HTML 6.9%, SCSS 2.4%, PLpgSQL 1.0%, JavaScript 0.7%, Other 1.4%

License: Apache 2.0 License.

GitHub Link: https://github.com/thingsboard/thingsboard

Application:

IoT Standard: CoAP MQTT

Type of project: Middlware

Tecnology areas: Connectivity Device Management

Mainflux

Provider / Owner: Mainflux Labs

Primary programming language: Go 97.4%, Shell 1.9%, Other 0.7%,

License: Apache-2.0 License

GitHub Link: https://github.com/mainflux/mainflux/

Application:

IoT Standard: CoAP HTTP MQTT WebSocket

Type of project: IoT Platform

Tecnology areas:

Eclipse Ponte

Provider / Owner: Eclipse Foundation

Primary programming language: JavaScript, HTML

License: Eclipse Distribution License 1.0 (BSD) Eclipse Public License 1.0

GitHub Link: https://github.com/eclipse/ponte

Application:

IoT Standard: CoAP MQTT

Type of project: IoT Broker/Gateway

Tecnology areas: Cloud Computing

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UPCOMING EVENTS

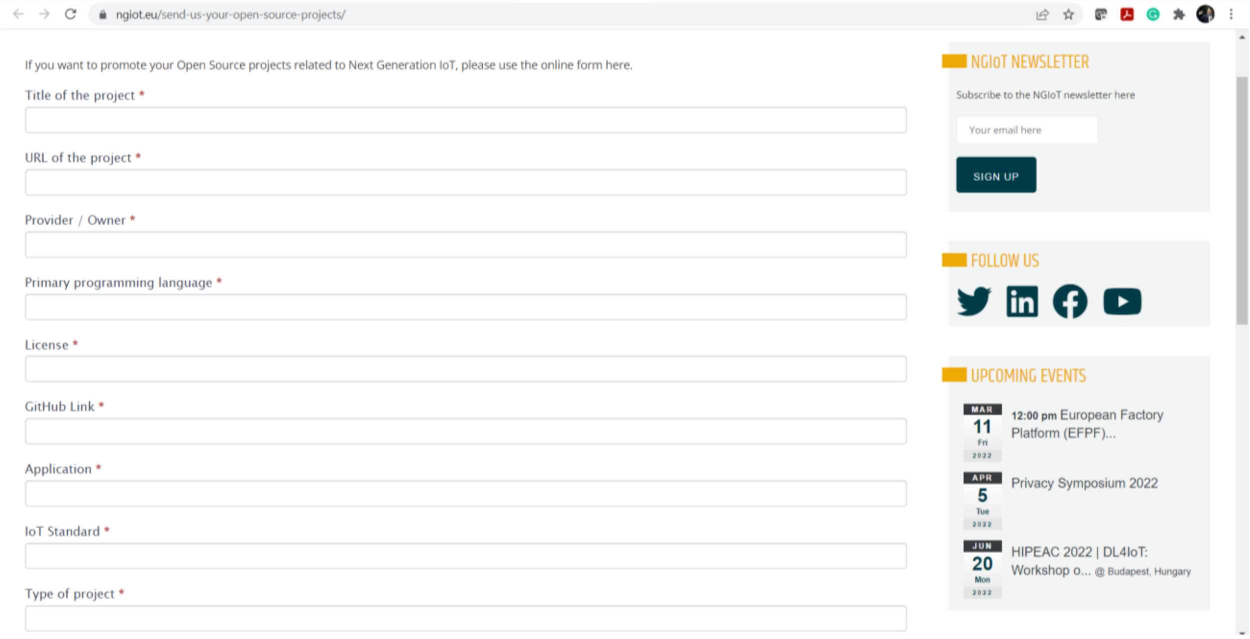
MAR 11 Fri 2022 — **12:00 pm** European Factory Platform (EFPF)...

APR 5 Tue 2022 — Privacy Symposium 2022

JUN 20 Mon 2022 — HIPEAC 2022 | DL4IoT: Workshop o... @ Budapest, Hungary

Figure 2: Snapshot of the IoT OSS projects catalogue

EU-IoT provides to the community a facility for extending the catalogue with new project entries. In this direction, a form-based service is also provided (see Figure 3). The contents of the form are submitted to the EU-IoT team, which performs quality control and if appropriate inserts the new entry to the catalogue. Since December 2021, several news entries have been included in the catalogue following respective submissions from founders of these projects, as well as following the extension of the catalogue by EU-IoT project members as part of WP3 work.



ngiot.eu/send-us-your-open-source-projects/

If you want to promote your Open Source projects related to Next Generation IoT, please use the online form here.

Title of the project *

URL of the project *

Provider / Owner *

Primary programming language *

License *

GitHub Link *

Application *

IoT Standard *

Type of project *

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Figure 3: On-line Form for new OSS projects entries

2.5 EU funded Projects

Emphasis has been paid in the identification of EU projects that have produced or essentially contributed to IoT OSS development. This analysis has considered projects beyond the ones of the above-outlined prominent communities. In this context, an initial analysis of the open-source developments of the ICT-56 projects has been also carried out. In this deliverable this analysis has been updated to reflect the evolution of the OSS activities of these projects. Relevant information is included in Section 4.

In general, EU projects have a good track record of open-source contributions. Many EU projects of the FP7 and H2020 frameworks have provided contributions to the analysed projects, like for instance some of the Eclipse foundation ones. Also, the FIWARE community was initiated within the EC Future Internet Private Public Partnership (FI-PPP) context. The following table presents some notably contributions of EU projects to the IoT OSS community.

EU Funded Project	Scope of OSS Contributions
FIWARE	FIWARE provides several open-source components that are widely used, including IoT components and platforms such as the FIWARE Context Broker that simplifies the development of IoT applications. It supports a significant number of IoT developments and deployments, including many applications and use cases developed in the scope of EU funded IoT projects such as the H2020 IoT Large Scale Pilot (LSP) projects.
FP7 OpenIoT project	The project established the OpenIoT open-source IoT middleware platform. It is one of the analysed projects that has still an active community and frequent mentions in the community.
FP7 WebInOS	The FP7 WebInOS (Secure WebOS Application Environment) also established an IoT-related open-source project that has a notable and active community.

Table 3: Examples of Notable IoT OSS projects that were initiated by EU Projects

2.6 Standards-Related OSS

As part of deliverable D3.3, EU-IoT identified the link of OSS projects to standardisation. Specifically, it has collected and listed the standards that are implemented and/or supported by several of the OSS projects that were anayzed in D3.3 and included in the EU-IoT OSS projects catalogue. In several cases OSS projects have been used to support reference implementation of standards, as well as broader standards development. For instance, a variety of OSS projects have focused on the implementation of different parts of the ETSI OneM2M standard. These projects range from general platforms like Eclipse OM2M that enables the implementation of horizontal OneM2M compliant M2M systems (i.e., servers, gateways, devices) and OpenMTC that provides an integration middleware based on the oneM2M standard, to projects focused on more specific aspects like oneM2MTester which is an OneM2M conformance testing tool. This link of the analysed OSS projects to standards is further elaborated and presented in the next section of the present deliverable, which details some of the most prominent IoT OSS projects that implement or support popular IoT standards. The latter include standards produced by SDOs and standards specified by the OSS community.

3 SUPPORTING STANDARDISATION THROUGH OPEN-SOURCE PROJECTS

3.1 Open-source and Standards

Open-source software is a catalyst for various standardisation activities, including:

- **Reference implementations by the OSS community**. OSS is a very popular approach to developing reference implementation of standards based on community engagement. It provides the means for increasing the adoption and maximising the impact of certain standards, while at the same time serving the purpose of collecting developers' and other stakeholders' feedback on a standard.
- **Pre-standardisation activities through early implementations**. OSS projects provide a playground for early implementation of proposed standards. Specifically, OSS implementations can offer demonstrations and feasibility studies of proposed standards, which can boost the adoption of standardisation proposals to SDOs and standards-related working groups.
- **Standards initiated in the scope of OSS projects**. There are many cases where the open-source community has initiated the specifications of standards that solve specific problems, while at the same time providing an open-source implementation of the specification. In this case, the standard is instigated by the OSS community rather than by some SDO.
- **Raising awareness and training stakeholders about standardisation**. OSS is an excellent way for increasing the engagement of IoT developers' and IoT solution integrators with standards. Likewise, general purpose information about specific OSS projects can be also a very good way for raising awareness about the standards that are promoted and supported by these projects.

3.2 Standards Addressed by Projects of the EU-IoT OSS Catalogue

The current IoT OSS landscape includes many standards-based projects i.e., projects that either implement standards or are based on implementations of standards. These projects cover many IoT standards, which cover a considerable part of the very broad IoT standardisation ecosystem. Table 4 lists the standards that are implemented or addressed in the list of over one hundred (100+) projects of the EU-IoT open-source catalogue.

Standard – Short Description - SDO
AMQP (Advanced Message Queuing Protocol) AMQP is an open-source standard for asynchronous messaging by wire. It facilitates encrypted and interoperable messaging between organisations and applications. AMQP is used for client/server messaging and IoT device management use cases. **SDO/Developed By: OASIS (AMQP working group)**
CoAP (Constrained Application Protocol) CoAP is a specialised web transfer protocol, which has been developed to facilitate access to constrained nodes and constrained networks in IoT use cases. **SDO/Developed By: IETF (RFC 7252)**
DDS (Data Distribution Service) DDS is an M2M protocol for dependable, high-performance, interoperable, real-time, scalable data exchanges among real-time systems. Using a publish–subscribe pattern.

SDO/Developed By: OMG (Object Management Group)
IEEE802.15.4e IEEE802.15.4e is a standard that enables the operation of low-rate wireless personal area network. It is used as the underlying layer for various other protocols like Zigbee, and 6LoWPAN. **SDO/Developed By: IEEE**
Ipv6 Ipv6 is the latest version of the Internet Protocol (IP), which specifies how local endpoint systems on a computer network can be identified, as well as how to route online traffic **SDO/Developed By: IETF**
LoRaWAN (Long Range Radio Wide Area Network) LoRaWAN is low-power, wide area networking protocol that leverages the LoRa radio modulation technique. **SDO/Developed By: ITU**
LWM2M (Lightweight M2M) LWM2M is an application layer communication protocol for IoT devices and gateways. It enables the management of IoT devices and the communication between IoT systems and IoT devices from different vendors **SDO/Developed By: OMA**
Modbus Modbus is a legacy data communication protocol that implements a request-response approach (i.e., master-slave protocol). It is used to support interactions between different IoT systems and devices. **SDO/Developed By: Modicon / Schneider Electric**
MQTT (Message Queue Telemetry Protocol) MQTT is a lightweight, machine to machine network protocol for the implementation of message queue protocols and message queuing services. It is based on the publish-subscribe paradigm **SDO/Developed By: OASIS**
NFC (Near Field Communication) NFC specifies a set of different communication protocols, which enable two electronic devices to communicate over small distances (i.e., distances less than 4 cm). **SDO/Developed By: ISO/IEC & NFC Forum**
OGSi (Open Gateway Services Interface) This standard specifies a modular system and a service platform that supports the integration and interaction of dynamic components in a single platform based on a plug n' play approach. It implements a complete and dynamic component model based on a service oriented approach. **SDO/Developed By: OSGi Alliance**
OneM2M Specifies a simple horizontal, platform architecture that comprises three layers. The latter are devoted to applications, services and networks. The details of the platform are described in four different releases of the standard. **SDO/Developed By: ITU-T (Y.4500 series) produced by 8 SDOs**
OPC-UA (OPC Unified Architecture)

OPC-UA is a cross-platform, open-source standard that supports the exchange of data between sensors and cloud applications. **SDO/Developed By: OPC Foundation; IEC62541**
RabbitMQ RabbitMQ is a standards-based messaging broker, which ensures that different platforms and devices (including IoT devices) can exchange messages in a safe and reliable manner **SDO/Developed By: RabbitMQ Technologies; Pivotal Software Inc (open-source protocol)**
ROS (Robot Operating System) Open-source library that is considered the de facto standard for the development of robotics applications. **SDO/Developed By: Willow Garage**
SPDX (Software Package Data Exchange) SPDX is an Open standard and Open format for communicating industrial information in industrial IoT applications, including software Bill of Materials (SBOM). **SDO/Developed By: SPDX Project under the auspices of the Linux Foundation**.
USB (Universal Serial Bus) USB provides specifications for cables, connectors and protocols for connection, communication and interfacing between computing devices, including IoT devices. **SDO/Developed By: Compaq, DEC, IBM, Intel, Microsoft, NEC, Nortel**
ZigBee ZigBee is a wireless protocol allows to communicate, exchange data and interact with each other over a Personal Area Network (PAN) **SDO/Developed By: IEEE**
Zwave Zwave is a wireless networking protocol for smart home, smart buldings and industrial automation applications **SDO/Developed By: Zensys**
6LoWPAN (IPv6 over Low-power Wireless Personal Area Networks.) 6LoWPAN enables wireless communications for low power wireless devices in Ipv6 networks. **SDO/Developed By: IETF**

Table 4: IoT-related Standards Addressed by the Projects of the IoT OSS Catalogue

The table includes only a fraction of the standards that can be found in the complex and heterogeneous IoT standardisation landscape. For instance, it covers a small subset of the SDOs that are depicted in the AIOTI WG03 map of IoT standards (Figure 4). Nevertheless, it covers standards with a strong footprint in the OSS community and the IoT developers' communities. For instance, standards like MQTT and CoAP are some of the most popular IoT protocols, which are commonly used in IoT implementations. Note also that driven by our approach in the collection and analysis of IoT OSS projects in D3.3., our standards analysis is focused on pure IoT standards (e.g., IoT protocols, devices messaging platforms, IoT gateways) rather that related standards that are commonly used in IoT applications, yet their scope extends beyond IoT. For instance, we have not focused on projects for Big Data, Machine Learning, 5G and Infrastructure Management, which are used in IoT applications.

Some of the above listed standards are not developed by some SDO. Rather they are very popular community standards that have been proposed and implemented by the open-source community. This is for example the case with ROS and RabbitMQ standards. We have opted to include these standards in the list given their popularity, but mainly because they provide examples of good practice about how the OSS community can boost standardisation.

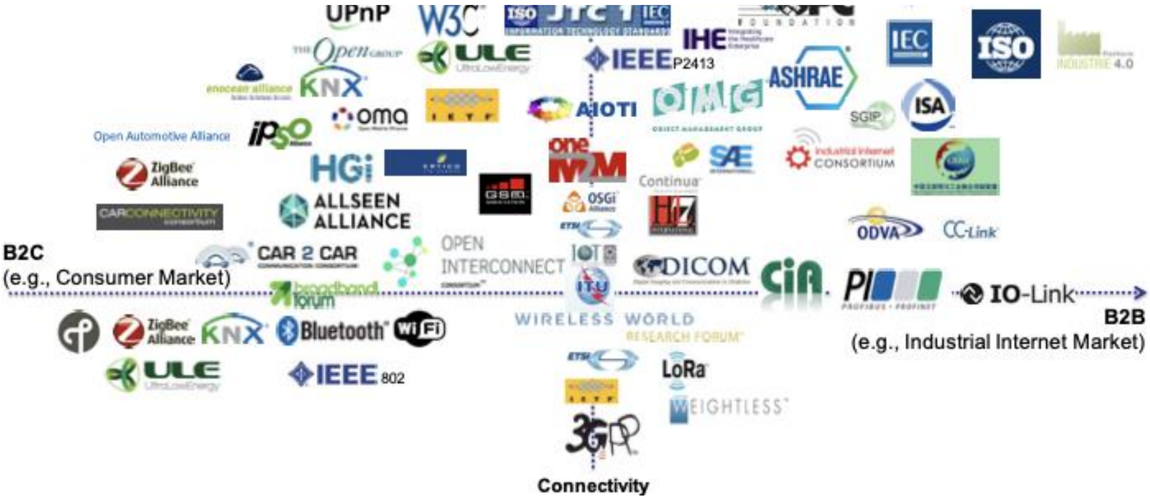


Figure 4: Snapshot of IoT Standardisation Landscape (source: AIOTI WG03 on IoT Standardisation)

3.3 Selected Open-Source Projects

Following paragraphs present OSS projects that address the above-listed standards. They also discuss how each standard is supported and/or used in the scope of the presented projects.

3.3.1 OSS Projects with MQTT

Table 5 presents a set of MQTT related OSS projects. The latter include projects that provide standards-based MQTT implementation such as Mosquitto and Paho. There are however other IoT projects that provide more complete IoT platforms, which support IoT connectivity based on MQTT, leveraging third-party MQTT implementations.

Projects Addressing MQTT
DeviceHive DeviceHive is an IoT Data Platform that provides support for various device integration options, including REST APIs, WebSocket, and MQTT. DeviceHive is considered a DeviceAgnostic platform. Hence, it can support the integration of an IoT device via MQTT or other IoT protocols.
Eclipse Ditto Eclipse Ditto is a novel project that enables the development and management of DigitalTwins. It offers a "Device as a Service" functionality that leverages devices' abstractions to develop and execute digital twin applications. The service supports synchronous and asynchronous APIs in order to interact with the physical devices that comprise the DigitalTwin. MQTT is one of the main protocols that are supported by Ditto to realise the interactions of the DigitalTwin with the devices. The project provides the means for consuming messages from MQTT brokers (via sources), as well as to send messages to MQTT brokers (via targets).
Eclipse Mosquitto Mosquitto implements different versions of the MQTT protocol (i.e., versions 5.0, 3.1.1 and 3.1).

It proides a lightweight implementation which supports the integration of a wider rangae of devices in IoT systems and applications.
Eclipse Paho Eclipse Paho is one of the best available MQTT implementations that supports both conventional MQTT and the MQTT-SN (MQTT for Sensor Networks) implementationsSpecifically, paho-mqtt is considered one of the best Python-based open-source client libraries for MQTT. Nevertheless, Paho supports other popular programming languages as well, including C++, Java, and JavaScript. Overall, Paho focuses on MQTT publish/subscribe client implementations for embedded IoT platforms and applications.
Eclipse Ponte This is an archived project of the Eclipse IoT community, which implements REST bindings for M2M protocols like MQTT and CoAP.
Mainflux Mainflux is an open-source IoT platform that supports connectivity over various protocols, including HTTP, MQTT, WebSocket and CoAP. It enables the bridging of these diverse protocols and as such it is well suited for developing heterogeneous IoT solutions. The platform is based on a modern software architecture that leverages microservices containerised by Docker and orchestrated with Kubernetes.
OpenRemote OpenRemote is an open-source IoT platform that enable the development of end-to-end applications i.e., from device data acquisition and device control to visualisation of applications data. It supports a variety of IoT protocols, including MQTT.
SiteWhere This is a scalable IoT platform based on a microservices architecture that can be scaled using Kubernetes. It offers support for various IoT protocols, including MQTT.
ThingsBoard This is one more complete IoT platform offering MQTT support. It enables the development of scalable end-to-end applications based on tools that are offered through a cloud-based paradigm (e.g., PaaS (Platform as a Service) like paradigm)

Table 5: OSS Projects using and/or implementing the MQTT Protocol for Devices' Interactions

3.3.2 OSS Projects with oneM2M and LWM2M

Table 6 lists projects that implement or adhere to oneM2M and LWM2M standards. Note that oneM2M is not a single standard, but rather based on a pool of inter-related standards. For instance, LWM2M servers are implemented over the CoAP standard. We can distinguish between projects that support the protocol (e.g., pass test cases) and projects that are destined to provide compliant implementations.

Projects Addressing oneM2M and LWM2M
Eclipse OM2M This project provided one of the first implementations of the oneM2M standard, including oneM2M concepts like a horizontal Common Services Entity (CSE) and support for M2M servers, gateways, and devices.
Eclipse Leshan

Provides an OMA LWM2M implementation, including M2M features and functionalities like an LWM2M Server, Access Control, Device, Connectivity, Firmware Update, Location, and Connectivity Statistics. Leshan leverages the Eclipse Californium CoAP implementation.
Eclipse Californium Primarily, Eclipse Californium provides an open-source CoAP implementation. Nevertheless, it has been successfully tested against OMA's LWM2M use cases, which makes it relevant and compliant to these standards as well.
Eclipse Wakaama This project provides an OMA LWM2M implementation in the C language. It provides APIs for a server application to send commands to registered LWM2M Clients.
Iotoasis This project provides an implementation of a oneM2M server.
oneM2MTester The project provides an IoT conformance test tool built on the Eclipse Titan project. It supports over 250 test cases.
OpenMTC This project provides a reference implementation of the oneM2M standard. It enables developers to implement oneM2M compliant applications such as applications for device and for IoT gateways.

Table 6: OSS Projects addressing oneM2M and LWM2M related standards

3.3.3 OSS Projects with CoAP

Table 7 presents projects that enable developers to access and control devices via the IETF standardised REST protocol.

Projects Addressing CoAP
Eclipse Californium Eclipse Californium is one of the most popular open-source implementations of the CoAP protocol. As such it is used as an API for RESTful Web services that provides support for a fully-fledged CoAP implementation (i.e., all CoAP features).
Eclipse Ponte The project exposes the CoAP protocol through the REST API. It is archived and also listed earlier as part of the list of MQTT related projects.
Contiki-NG The project provides an operating system for IoT devices, based on support for popular protocols for communicating with the devices such as IPv6/6LoWPAN and CoAP.
Mainflux Mainflux has been presented in the MQTT section/list. It is an open-source IoT platform that supports connectivity over various protocols, including HTTP, MQTT, WebSocket and CoAP.

Table 7: OSS Projects using the CoAP Protocol

3.3.4 OSS Projects with IPv6/6LoWPAN

Projects Addressing IPv6/6LoWPAN
Contiki-NG Already listed in the collection of CoAP related projects. Provides an operating system for IoT devices, including support for IPv6/6LoWPAN.
OpenWSN It provides the means for developing Wireless sensor network applications based on different resource constrained devices and related standards.

Table 8: OSS Projects addressing IPv6/6LoWPAN

3.3.5 OSS Projects with OGSi

Projects Addressing CoAP
Eclipse Concierge This archived project of the Eclipse community is currently Archived. Its main goal was to provide a framework compliant to OSGi core R5 specifications that would lead to an implementation with small footprint (e.g., 300-400 kB Jar file size). Thus, it provided ways for integrating OSGi into mobile and embedded system stacks.
Eclipse Kura Kura is based on the Java/OSGi framework. It supports extensible and flexible integration of devices into IoT gateways. It also provides support for industrial protocols (e.g., OPC-UA) as outlined in other tables.

Table 9: OSS Projects addressing OGSi

3.3.6 OSS Projects with OPC-UA, DDS, and Modbus

Table 10 presents OSS projects that implement or address industrial standards that are commonly used for field automation in industrial sectors like manufacturing. These standards fall in the broader class of industrial connectivity standards according to the Industrial Internet Communication Framework (IICF) of the IIC.

Projects Addressing OPC-UA, DDS and Modbus
Eclipse Kura This OSS project provides readily available support for field protocols, including Modbus and OPC-UA. As such it is important to the development of industrial automation applications. The overall architecture of the project adheres the Java/OSGi standards.
Eclipse Milo This project provides an open-source implementation of OPC UA targeting version 1.03 of the standard/protocol. It has implemented a high-performance stack along with client and server SDKs to be used on top of the stack.
Eclipse Cyclone DDS Eclipse Cyclone DDS™ is an implementation of the OMG DDS specification[1] and the related

[1] http://www.omg.org/spec/DDS/

specifications for interoperability[2]. There are not many OSS implementations of the DDS services. Nevertheless, DDS is very popular in the standardisation community, as it is commonly referenced and used in the standards of the Industrial Internet Consortium (IIC).

Table 10: OSS Projects addressing OPC-UA, DDS, and Modbus

3.3.7 OSS Projects with Other Standards

Table 11 presents a collection of projects that implement or address other standards that are not present in the above categories. These standards have a lesser number of relevant OSS implementations and are therefore clustered together in this "other standards" list.

Projects Addressing Other Standards (OCF, BLE, ROS, SPDX)
IoTivity The project provides an open-source framework for IoT connectivity that implements the specifications of the Open Connectivity Foundation (OCF).
Herald The project provides an infrastructure for proximity detection and data exchange between mobile phones, wearables, beacons and other devices. It implements the Bluetooth (BLE) standard.
Robotic Operating System (ROS) Collection of open-source software libraries and tools for the development of robot applications.
SPDX Open-source implementation of the SPDX open standard (ISO/IEC 5962:2021) that is used to communicate SBOM information.

Table 11: OSS Projects addressing Other Standards (OCF, BLE, ROS, SPDX)

[2] http://www.omg.org/spec/DDSI-RTPS/

4 OPEN-SOURCE ACTIVITIES OF ICT-56 PROJECTS

4.1 Scope and Types of ICT-56 Projects Contributions

4.2 ASSIST-IoT (https://assist-iot.eu/)

Project Summary	The project designs, implements and validates an open, decentralised reference architecture, associated enablers, services and tools, to assist human-centric IoT applications in multiple verticals. ASSIST-IoT will deliver, in a realistic, measurable, and replicable way, a unified innovative multi-plane (semi-)autonomous edge-to-cloud-continuum architecture for the future IoT deployments. ASSIST-IoT proposes to be hugely based on OSS technologies, relying on the most recent trends on microservice, containerisation and orchestration, supplemented by cross-cutting digital enablers. The architecture supports continuous integration and long-term sustainability of domain-agnostic, interoperable, self-* capable, intelligent, distributed, scalable, secure, and trustworthy IoT ecosystems.
OSS Developments	ASSIST-IoT has used open-source Linux-based hardware and software (e.g., containerisation, lightweight K8s). It has produced various open-source outcomes that the project is currently structuring in open-source project repositories. The results will become available based on licenses like Apache 2.0, GNU GPL or others that enable distribution of results to the community. At the time of writing the results have not been fully committed and integrated to the project's OSS repository, which is available at: https://github.com/assist-iot

Table 12: OSS Contributions and Activities of ASSIST-IoT as of March 2023

4.3 VEDLIOT (https://vedliot.eu/)

Project Summary	VEDLIoT builds a distributed Very Efficient Deep Learning IoT platform. Instead of traditional algorithms, artificial intelligence (AI) and deep learning (DL) are used to handle large complexity in IoT applications. Due to the distributed approach, VEDLIoT allows dividing the application into smaller and more efficient components and work together in large collaborative systems in the Internet of Things (IoT), enabling AI-based algorithms that are distributed over IoT devices from edge to cloud.
OSS Developments	VEDLIoT has built its results on several OSS projects and components including: • Linux and all surrounding items (U-Boot, Distris, etc.). • ML/DL projects including Tensorflow, ONNX, TVM, as well as models like different versions of Yolo and Darknet. • Various RISC-V parts including CFUs (+CFU-Playground), LiteX and Verilator. VEDLIoT has produced and/or extended the following open-source components: • Renode: Renode - Antmicro's virtual development framework for complex embedded systems.

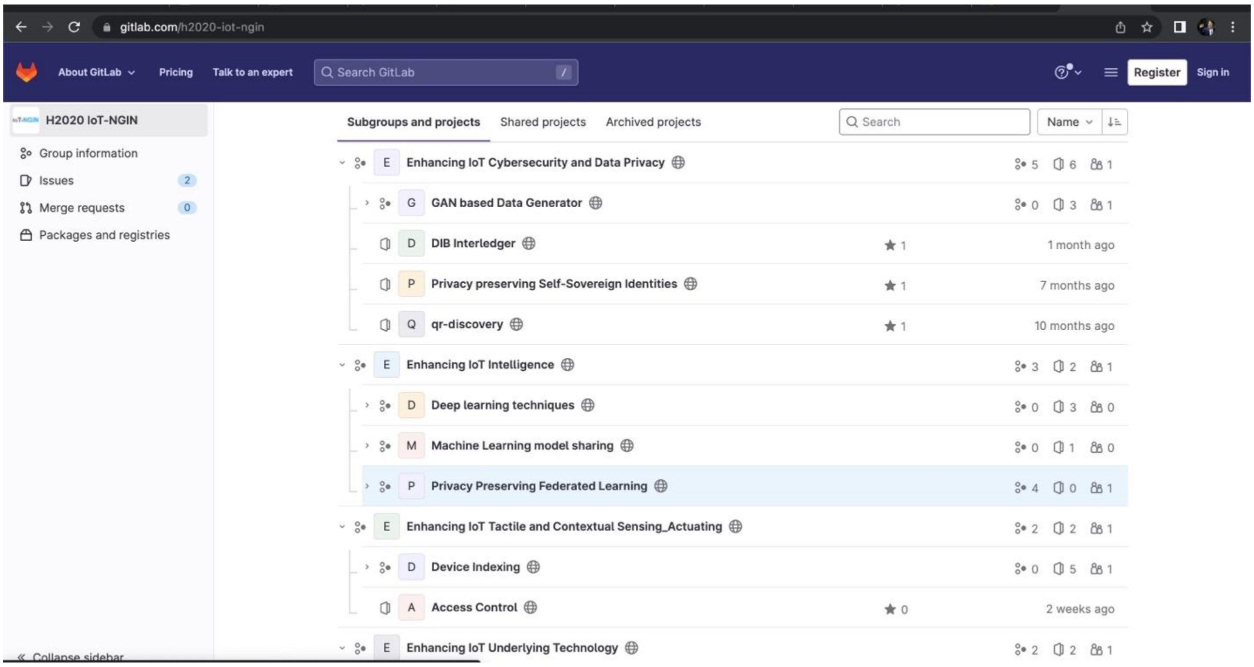
	- Kenning: A framework for creating deployment flows and runtimes for Deep Neural Network applications on various target hardware. - WaTZ: A Trusted WebAssembly Runtime Environment with Remote Attestation for TrustZon. - TWINE: An Embedded Trusted Runtime for WebAssembly. - PMP: A RISC-V memory protection unit.

Table 13: OSS Contributions and Activities of VEDLIoT as of March 2023

4.4 IoT-NGIN (https://iot-ngin.eu/)

Project Summary	IoT-NGIN introduces novel research and innovation concepts, acting as the "IoT Engine" which will fuel the Next Generation of IoT as a part of the European Next Generation Internet. IoT-NGIN uncovers a patterns-based meta-architecture that encompasses evolving, legacy, and future IoT architectures. The project also optimises IoT/M2M and 5G/MCM communications, including using secure-by-design micro-services to extend the edge cloud paradigm. Moreover, it enables user and self-aware, autonomous IoT systems through privacy-preserving federated ML and ambient intelligence, with AR support for humans.
OSS Developments	The OSS developments of the project are available in the project's GitLab (https://gitlab.com/h2020-iot-ngin) repository, which has the structure and comprises the projects that are depicted in Figure 5.

Table 14: OSS Contributions and Activities of IoT-NGIN as of March 2023



E	Enhancing IoT Cybersecurity and Data Privacy	5	6	1	
G	GAN based Data Generator	0	3	1	
D	DIB Interledger	★ 1			1 month ago
P	Privacy preserving Self-Sovereign Identities	★ 1			7 months ago
Q	qr-discovery	★ 1			10 months ago
E	Enhancing IoT Intelligence	3	2	1	
D	Deep learning techniques	0	3	0	
M	Machine Learning model sharing	0	1	0	
P	Privacy Preserving Federated Learning	4	0	1	
E	Enhancing IoT Tactile and Contextual Sensing_Actuating	2	2	1	
D	Device Indexing	0	5	1	
A	Access Control	★ 0			2 weeks ago
E	Enhancing IoT Underlying Technology	2	2	1	

Figure 5: Snapshot of the IoT-NGIN Gitlab Repository

4.5 INGENIOUS (https://ingenious-iot.eu/)

Project Summary	INGENIOUS designs and evaluates the Next-Generation IoT (NG-IoT) solution, with emphasis on 5G and the development of Edge and Cloud computing extensions for IoT, as well as providing smart networking and data management solutions with Artificial Intelligence and Machine Learning

	(AI/ML). The project embraces the 5G Infrastructure Association (5G IA) and Alliance for Internet of Things Innovation (AIOTI) vision for empowering smart manufacturing and smart mobility verticals.
OSS Developments	A variety of OSS components have been developed by iNGENIOUS. They are already available in OSS repositories or will be made available at the last stages of the project. Specifically, the main OSS components include: 1) **Enhnacements to 5G network slice management** Software implemented by partner Nextworks that will be made available as OSS after end of project, It supports Network Slice Management Function (NSMF); 5GCore Network Slice Subnet Management Function (NSSMF); O-RAN NSSMF; Flexible RAN NSSMF; and Emulated RAN NSSMF. 2) **Enhancements to the M³ hardware/software co-design platform** Software implemented by partnet Barkhausen Institut. It provides support for selected FPGA hardware building blocks and it will be open-sourced after the end of the project in the following repository: https://github.com/Barkhausen-Institut/M3 It is an enhancement to the M³ hardware/software co-design platform, which is a tile-based computer architecture and microkernel-based operating system targeted at high security and accelerator integration. Enhancements concern the following directions: • Generally improved system capabilities for core sharing and I/O support and • Software-based/simulated implementation of a Root-of-Trust (RoT) towards the goal of having an FPGA-based hardware implementation in the future. • Associated system-software integration to enable new core sharing and I/O capabilities, including to enable remote attestation together with Transport Layer Security (TLS) and support for secure software update process. 3) **Integration of Remote Attestation with Transport Layer Security (TLS) protocol** Software implemented by partner Barkhausen Institut. It is planned to become open-source after end of project, pending some publications. It provides remote attestation support that is integrated into Transport Layer Security (TLS). This combined protocol can be used as a drop-in replacement for the widely-used TLS, yet with additional security guarantees provided by remote attestation.

Table 15: OSS Contributions and Activities of iNGENIOUS as of March 2023

4.6 IntellIoT (https://intelliot.eu/)

Project Summary	IntellIoT focuses on the development of integrated, distributed, human-centered and trustworthy IoT frameworks applicable to agriculture, healthcare and manufacturing. Enabling technologies such as 5G, cybersecurity, distributed technology, Augmented Reality, and tactile internet, IntellIoT also champions end-user trust, adequate security and privacy by design.
OSS Developments	IntellIoT's result owners have identified the following projects and contributed to those by providing artifacts:

	• Hypermedia Multi-agent System (HyperMAS) (https://github.com/Interactions-HSG/yggdrasil) • Examples of thing descriptions (TDs) (https://github.com/Interactions-HSG/example-tds) • 5G Technology – OpenAirInterface ○ 5G RAN: https://gitlab.eurecom.fr/oai/openairinterface5g/ ○ 5G Core: https://gitlab.eurecom.fr/oai/cn5g • Mosaic5G: https://gitlab.eurecom.fr/mosaic5g • IAKM – A repository for AI models (https://gitlab.eurecom.fr/intelliot/iakm)

Table 16: OSS Contributions and Activities of IntellIoT as of March 2023

4.7 TERMINET (https://terminet-h2020.eu/)

Project Summary	The vision of TERMINET is to provide a flexible, open, and decentralised next generation IoT reference architecture based on cutting-edge technologies such as software-defined networking, multiple-access edge computing, and virtualisation for new real-time capable solutions. This goal will be achieved by enabling secure and privacy-preserving IoT services, user-aware solutions, semi-autonomous devices, and self-aware mechanisms, frameworks, and schemes, supported by distributed AI and new intelligent IoT devices within a virtualised edge-platform-cloud environment.
OSS Developments	Although IoT hardware (e.g., smart glasses, metering sensors, etc.) is typically proprietary, TERMINET's integrated platform leverages well-known open-source software across all the layers of the software stack to manage the IoT-to-cloud continuum in an efficient and maintainable manner. In the area of cloud computing, TERMINET leverages the Kubernetes container orchestration platform and open-source SDN container network interfaces (i.e., KubeOVN) to provide programmable cloud management and datacenter monitoring solutions respectively. At the network domain, TERMINET uses the Ryu SDN controller to provision hardware and/or software-based SDN-enabled IoT gateways, managed both by OpenFlow and the IRATI protocols. These initiatives are in line with best practices from the newly-established ETSI TeraFlowSDN open-source project. In the data layer, the Hyperledger Fabric is utilised for data sharing within TERMINET, while the EdgeX Foundry by the Linux Foundation is utilised for streaming analytics. One of TERMINET's security components that aims to verify the integrity of devices is also being developed based on an open-source project from MIT called KeyLIME. Finally, the open calls of the project are still looking to onboard new state-of-the-art open-source tools and to integrate them into the project's developments.

Table 17: OSS Contributions and Activities of TERMINET as of March 2023

5 CONCLUSIONS

During the 30 months of its lifetime, EU-IoT has supported the IoT community based on tangible activities and results that:

- Help IoT researchers and engineers to adopt and fully leverage IoT OSS in their development.
- Encourage the community to contribute to OSS projects.
- Foster the use of OSS to support IoT standardisation through reference implementations, as well as validation and use of existing standards-based solutions.
- Support IoT professionals in initiating their own OSS projects and initiatives, notably initiatives that can address gaps in the existing OSS landscape for the IoT.

Specifically, the project has produced and made publicly available the following results:

- **A Map of the IoT OSS Ecosystem in the form of a Whitepaper [Soldatos21].** The white paper provides an overview of the main initiatives of the IoT open-source community, along with an in-depth analysis of over 100 OSS projects. It analyses different aspects of the projects such as their technology focus, the standards to which they are related, their programming language(s), as well as their scale and community characteristics. The whitepaper has been disseminated to the IoT community and received considerable attention. It can be a useful tool for stakeholders that want to understand the status of the IoT OSS community.

- **The development of a searchable and extensible catalogue of OSS projects.** This catalogue is provided as a resource to the IoT community to ease the discovery of information about IoT OSS projects. It is also a channel for IoT project developers to promote and disseminate their OSS developments to the IoT community. The catalogue was established in late 2021 and enhanced with more IoT OSS ever since.

- **A Map of IoT OSS projects to different standards.** This aims at facilitating IoT stakeholders to locate standards-based OSS projects and more generally to use OSS development for their standards development and standards adoption activities.

- **A report on the open-source activities and results of the ICT-56 EU funded projects**. It provides an overview of the main activities of some of the most recent IoT-related projects. The report is of interest to the community of EU-funded projects. It raises awareness about the outcomes of theses EU projects, while at the same time boosting the exchange of OSS results across different IoT-related projects.

EU-IoT is committed to maintaining and updating these results towards ensuring their relevance to the IoT community. In this direction, the catalogue of project will be maintained and transferred to follow-up CSAs of the NGIOT community. Moreover, we plan to produce future reports as part of other relevant on-going projects of the partners. Specifically, all the OSS resources of EU-IoT will be reused and updated in the scope of the Horizon Europe CODECO project, which is committed to produce OSS and to support a community of OSS developers that will engage with the project's results. CODECO is coordinated by the EU-IoT WP3 leader (FOR), while INTRA and Eclipse Foundation are in charge of the OSS ecosystem development activities. This will ensure a smooth hand-over of the EU-IoT resources to CODECO, as well as the graceful continuity of OSS ecosystem support activities.

APPENDIX A: LIST OF OPEN-SOURCE PROJECTS COLLECTED AND ANALYSED BY EU-IOT

No.	Project	Short Description
1	ACME	An open-source CSE Middleware for Education, intended to provide an easy to install, extensible, and easy to use and maintain CSE. This CSE implements a subset of the oneM2M standard specialisations (see http://www.onem2m.org).
2	Advanced Message Queuing Protocol (AMQP)	AMQP is the Internet Protocol for Business Messaging. The Advanced Message Queuing Protocol (AMQP) is an open standard for passing business messages between applications or organisations. It connects systems, feeds business processes with the information they need and reliably transmits onward the instructions that achieve their goals.
3	Akraino	Akraino is a set of open infrastructures and application blueprints for the Edge, spanning a broad variety of use cases, including 5G, AI, Edge IaaS/PaaS, IoT, for both provider and enterprise edge domains.
4	AllJoyn	AllJoyn is an open-source software framework that makes it easy for devices and apps to discover and communicate with each other. Developers can write applications for interoperability regardless of transport layer, manufacturer, and without the need for Internet access.
5	Apache Camel	Apache Camel is a powerful open-source integration library based on Enterprise Integration Patterns. Rules for Camel's routing engine can be defined in either a Java based DSL or XML.
6	Apache Ignite	Apache Ignite is a distributed database for high-performance computing with in-memory speed.
7	Apache IoTDB	Apache IoTDB (Database for Internet of Things) is an IoT native database with high performance for data management and analysis, deployable on the edge and the cloud. Due to its light-weight architecture, high performance and rich feature set together with its deep integration with Apache Hadoop, Spark and Flink, Apache IoTDB can meet the requirements of massive data storage, high-speed data ingestion and complex data analysis in the IoT industrial fields.
8	Apache PLC4X	The universal protocol adapter for Industrial IoT. PLC4X is a set of libraries for communicating with industrial programmable logic controllers (PLCs) using a variety of protocols but with a shared API.
9	Apache Spark	Spark is a unified analytics engine for large-scale data processing. It provides high-level APIs in Scala, Java, Python, and R, and an optimised engine that supports general computation graphs for data analysis. It also supports a rich set of higher-level tools including Spark SQL for SQL and DataFrames, MLlib for machine learning, GraphX for graph processing, and Structured Streaming for stream processing.

10	Arduino	Arduino is an open-source electronics platform based on easy-to-use hardware and software. Arduino boards are able to read inputs - light on a sensor, a finger on a button, or a Twitter message - and turn it into an output - activating a motor, turning on an LED, publishing something online. You can tell your board what to do by sending a set of instructions to the microcontroller on the board. To do so you use the Arduino programming language (based on Wiring), and the Arduino Software (IDE), based on Processing.
11	Arduino Ethernet Shield	The Arduino Ethernet Shield 2 is open-source hardware that connects your Arduino to the internet in mere minutes. Just plug this module onto your Arduino Board, connect it to your network with an RJ45 cable (not included) and follow a few simple steps to start controlling your world through the internet. As always with Arduino, every element of the platform – hardware, software and documentation – is freely available and open-source. This means you can learn exactly how it's made and use its design as the starting point for your own circuits. Hundreds of thousands of Arduino Boards are already fueling people’s creativity all over the world, everyday.
12	Arduino Yún	The Arduino Yún is a microcontroller board based on the ATmega32u4 and the Atheros AR9331. The Atheros processor supports a Linux distribution based on OpenWrt named Linino OS. The board has built-in Ethernet and WiFi support, a USB-A port, micro-SD card slot, 20 digital input/output pins (7 of them can be used as PWM outputs and 12 as analog inputs), a 16 MHz crystal oscillator, a micro USB connection, an ICSP header, and 3 reset buttons.
13	ARM mbed	Arm Mbed OS is a free, open-source embedded operating system designed specifically for the "things" in the Internet of Things. It includes all the features you need to develop a connected product based on an Arm Cortex-M microcontroller, including security, connectivity, an RTOS, and drivers for sensors and I/O devices.
14	Artoo	Artoo is a micro-framework for robotics using Ruby. It specifies and implements a Domain Specific Language (DSL) for robotics applications.
15	Automotive Grade Linux	Automotive Grade Linux is a collaborative open-source project that is bringing together automakers, suppliers and technology companies to accelerate the development and adoption of a fully open software stack for the connected car. With Linux at its core, AGL is developing an open platform from the ground up that can serve as the de facto industry standard to enable rapid development of new features and technologies.
16	Awa LightweightM2M	The project provides an implementation of the OMA Lightweight M2M protocol. It offers an intuitive API that abstracts the complexity of M2M protocols.

17	BeagleBoard	Built on the proven BeagleBoard.org® open-source Linux approach, BeagleBone® AI fills the gap between small SBCs and more powerful industrial computers. Based on the Texas Instruments AM5729, developers have access to the powerful SoC with the ease of BeagleBone® Black header and mechanical compatibility. BeagleBone® AI makes it easy to explore how artificial intelligence (AI) can be used in everyday life via the TI C66x digital-signal-processor (DSP) cores and embedded-vision-engine (EVE) cores supported through an optimised TIDL machine learning OpenCL API with pre-installed tools.
18	BipIO	bip.io is a nodejs based web automation framework that runs 'bips'. A Bip is a web automation agent. A Bip can connect many different web services and perform useful work. It can act on your behalf or perform at your command. Bips can take actions in sequence or in parallel, and chain web services together as you like. They can be put to work via Web Hooks, Email or Trigger when something happens.
19	Constrained Application Protocol (CoAP)	The Constrained Application Protocol (CoAP) is a specialised web transfer protocol for use with constrained nodes and constrained networks in the Internet of Things. The protocol is designed for machine-to-machine (M2M) applications such as smart energy and building automation. The core of the protocol is specified in RFC 7252.
20	Contiki-NG	Contiki-NG is an operating system for resource-constrained devices in the Internet of Things. Contiki-NG contains an RFC-compliant, low-power IPv6 communication stack, enabling Internet connectivity. The system runs on a variety of platforms based on energy-efficient architectures such as the ARM Cortex-M3/M4 and the Texas Instruments MSP430. The code footprint is on the order of a 100 kB, and the memory usage can be configured to be as low as 10 kB.
21	Cylon.js	This is a JavaScript framework for robotics, physical computing, and the Internet of Things. It eases the implementation of programs that command robots and devices.
22	DeviceHive	Open-source IoT Data Platform with the wide range of integration options. Connects any device via REST API, WebSockets or MQTT. The DeviceHive team supports libraries written in various programming languages, including Android and iOS libraries which make the platform device-agnostic. You can even connect such low-end wi-fi enabled devices as ESP8266. DeviceHive gives you the foundation to quickly build analytics the way you want it leveraging the world's best big data solutions: ElasticSearch, Apache Spark, Cassandra and Kafka for real-time and batch processing.
23	DreamFactory	This is an open-source code automation software. It provides rapid API generation for any private, public, or hybrid cloud infrastructure and various types of applications, including IoT.
24	DSA	Distributed Services Architecture (DSA), is an open-source IoT platform that facilitates device inter-communication, logic and applications at every layer of the Internet of Things infrastructure. The objective is to unify the disparate devices, services and applications into a structured and adaptable real-time data model.
25	Dweet	Bug Labs offers a “dweet” messaging and alerts platform Dweet helps publish and subscribe to data. dweet.io doesn't require any setup or sign-up— just publish and go. It's machine-to-machine (M2M) for the

		Internet Of Things (IOT).
26	Eclipse 4DIAC	Eclipse 4diac™ in its current form has been started 2007 as open-source project fostering the further development of IEC 61499 for its use in distributed Industrial Process Measurement and Control Systems (IPMCS) and further distribute research results from the original contributors. From the beginning it provided everything necessary to program and execute distributed IPMCS.
27	Eclipse Agail	The Eclipse Agail is a language-agnostic, modular software and hardware gateway framework for the Internet of Things with support for protocol interoperability, device and data management, IoT application execution, trusted data sharing and external Cloud communication.
28	Eclipse Californium	Californium (Cf) is an open-source implementation of the Constrained Application Protocol (CoAP). It is written in Java and targets unconstrained environments such as back-end service infrastructures (e.g., proxies, resource directories, or cloud services) and less constrained environments such as embedded devices running Linux (e.g., smart home/factory controllers or cellular gateways). Californium (Cf) has been running code for the IETF standardisation of CoAP and was recently reimplemented from scratch having all the experience.
29	Eclipse Concierge	Eclipse Concierge is a small-footprint implementation of the OSGi Core Specifications R5 standard optimised for mobile and embedded devices.
30	Eclipse Cyclone DDS	Eclipse Cyclone DDS is an implementation of the OMG Data Distribution Service (DDS) specification (see http://www.omg.org/spec/DDS/) and the related specifications for interoperability (see http://www.omg.org/spec/DDSI-RTPS/) With 'DATA' being 'the currency of the IOT', having a proper data-sharing technology will be a key-asset in any IOT-platform. The OMG DDS standard is recognised as a highly applicable standard for reliable and robust data-sharing in business- and mission-critical environments (see http://www.iiconsortium.org/IIRA.htm and http://www.iiconsortium.org/IICF.htm) and with that a great fit with the Eclipse-IOT ecosystem. Eclipse Cyclone DDS offers unique data-sharing capabilities compared to the already existing Eclipse solutions (i.e., for messaging).
31	Eclipse Duttile	Eclipse Ditto is a framework for providing the "Digital Twin" pattern for IoT applications in order to interact with IoT devices. That means that Ditto mirrors physical devices as digital representations in the cloud.
32	Eclipse fog05	The End-to-End Compute, Storage and Networking Virtualisation solution. Eclipse fog05 is an open-source project that aims at providing a decentralised infrastructure for provisioning and managing compute, storage, communication and I/O resources available anywhere across the network. Eclipse fog05 addresses highly heterogeneous systems even those with extremely resource-constrained nodes.

33	Eclipse hawkBit	Project hawkBit aims to create a domain independent back end solution for rolling out software updates to constrained edge devices as well as more powerful controllers and gateways connected to IP based networking infrastructure. Devices can be connected to the hawkBit server either directly through an optimised interface or indirectly through federated device management servers.
34	Eclipse Hono	Eclipse Hono™ provides remote service interfaces for connecting large numbers of IoT devices to a back end and interacting with them in a uniform way regardless of the device communication protocol.
35	Eclipse iceoryx	In domains like automotive, robotics or gaming, a huge amount of data must be transferred between different parts of the system. If these parts are actually different processes on a POSIX based operating system like Linux, this huge amount of data has to be transferred via an inter-process-communication (IPC) mechanism.
36	Eclipse Ignite|IoT	The Ignite|IoT methodology has two main perspectives: (i) IoT Strategy Execution: This perspective looks at IoT strategy from an enterprise perspective, including IoT strategy definition, IoT opportunity identification, IoT business case and IoT programme management; (ii) IoT Solution Delivery: This perspective looks at the individual IoT solution and the related project. Note that it defines the interfaces to the related asset and its organisation, but usually excludes design and manufacturing of the asset itself.
37	Eclipse ioFog	Eclipse ioFog is a complete edge computing platform that provides all of the pieces needed to build and run applications at the edge at enterprise scale. The diversity and complexity of edge hardware is abstracted by ioFog Agent software. The management and orchestration of edge microservices is performed by ioFog Controller and its supporting set of components.
38	Eclipse Kapua	Modular IoT cloud platform to manage and integrate devices and their data. A solid integrated foundation of IoT services for any IoT application.
39	Eclipse Keti	Keti is a service that was designed to protect RESTfuls API using Attribute Based Access Control (ABAC). The solution itself is implemented as a cloud-native RESTful API that adheres to the guiding principles of the twelve factor app.
40	Eclipse Keyple	Eclipse Keyple is an open-source framework to facilitate the implementation of terminal processing operating smart card readers, and to defined advanced secure ticketing transaction.
41	Eclipse Kuksa	The open and secure Eclipse Kuksa project will contain a cloud platform that interconnects a wide range of vehicles to the cloud via in-car and internet connections. This platform will be supported by an integrated open-source software development environment including technologies to cope especially with software challenges for vehicles designed in the IoT, Cloud, and digital era.
42	Eclipse Kura	Eclipse Kura™ is an extensible open-source IoT Edge Framework based on Java/OSGi. Kura offers API access to the hardware interfaces of IoT Gateways (serial ports, GPS, watchdog, GPIOs, I2C, etc.). It features ready-to-use field protocols (including Modbus, OPC-UA, S7), an application container, and a web-based visual data flow programming to acquire data from the field, process it at the edge, and publish it to leading IoT Cloud Platforms through MQTT connectivity.

43	Eclipse Leshan	Eclipse Leshan is an OMA Lightweight M2M (LWM2M) implementation in Java. Leshan provides libraries which help people to develop their own Lightweight M2M server and client. The project also provides a client, a server and a bootstrap server demonstration as an example of the Leshan API and for testing purpose. Leshan relies on the Eclipse IoT Californium project for the CoAP and DTLS implementation.
44	Eclipse Milo	Milo is an open-source implementation of OPC UA. It includes a high-performance stack (channels, serialisation, data structures, security) as well as client and server SDKs built on top of the stack.
45	Eclipse Mita	Eclipse Mita is a programming language for the embedded IoT. We combine a declarative setup of system resources (e.g. Bluetooth connectivity or a temperature sensor) with a modern imperative language. We introduce first-class primitives for sensor access and connectivity to other systems, which allows for quick exploration and integration into IoT ecologies. We support embedded algorithm through powerful primitives, e.g. lists, vectors and statistic functions. In order to prevent problems at compile-time Mita has a static strong type-system. Lastly, we offer direct interaction with sensor data and in-situ developer support by integrating with the embedded software development toolchains.
46	Eclipse Mosquitto	Eclipse Mosquitto provides a lightweight server implementation of the MQTT protocol that is suitable for all situations from full power machines to embedded and low power machines. Sensors and actuators, which are often the sources and destinations of MQTT messages, can be very small and lacking in power. This also applies to the embedded machines to which they are connected, which is where Mosquitto could be run.
47	Eclipse MRAA	Conceived in 2014, the Eclipse MRAA project aims to deliver a high-level, easy-to-use set of APIs for I/O access on Linux* boards and systems, similar to Arduino* offerings for MCU boards. Initially, the project targeted support for platforms such as the Intel® Galileo, Intel® Edison and Raspberry Pi* boards, highly popular among IoT enthusiasts and makers. Over time, the project evolved substantially and won the appreciation of multiple IoT communities resulting in a number of new board and feature additions. In fact, the project's success prompted Arduino* to adopt the use of the library in the Arduino Create* cloud-based IDE when targeting x86 IoT platforms.
48	Eclipse NeoSCADA	Eclipse NeoSCADA (supervisory control and data acquisition) is a type of industrial control system (ICS). Simply speaking the primary target of Eclipse NeoSCADA is a way to connect different industrial devices to a common communication system and post-process as well as visualise the data to operating personnel.
49	Eclipse OM2M	The Eclipse OM2M project, initiated by LAAS-CNRS, is an open-source implementation of oneM2M and SmartM2M standard. It provides a horizontal M2M service platform for developing services independently of the underlying network, with the aim to facilitate the deployment of vertical applications and heterogeneous devices.
50	Eclipse Paho	The Eclipse Paho project provides reliable open-source implementations of open and standard messaging protocols aimed at new, existing, and emerging applications for Machine-to-Machine (M2M) and Internet of Things (IoT).

51	Eclipse Paho Incubator	A permanent incubator for Paho. A permanent incubator is a project that is intended to perpetually remain in the incubation phase. Permanent incubators are an excellent place to innovate, test new ideas, grow functionality that may one day be moved into another project, and develop new committers. Permanent incubator projects never have releases; they cannot participate in the annual simultaneous release. Permanent incubators may have builds, and downloads. They conform to the standard incubation branding requirements and are subject to the IP due diligence rules outlined for incubating projects. Permanent incubators do not graduate.
52	Eclipse Ponte	Ponte is a multi-transport Internet of Things / Machine to Machine broker. As the current state it supports MQTT and REST APIs over HTTP and CoAP.
53	Eclipse Tahu	Eclipse Tahu is a set of references implementations for the Sparkplug specification. It addresses the existence of legacy SCADA/DCS/ICS protocols and infrastructures and provides a much-needed definition of how best to apply MQTT into these existing industrial operational environments.
54	Eclipse Thingweb	The Eclipse Thingweb project currently hosts one sub-project and plans for a second one. Thingweb node-wot: node-wot is the official reference implementation of the W3C WoT Working Group and implements the so-called "Servient Architecture". node-wot provides a WoT Thing Description parser and serializer, several "Protocol Bindings" implementing the WoT Binding Templates, as well as a runtime system ("WoT Runtime") providing the WoT Scripting API for applications. It is based on Node.js and its fundamental module structure. node-wot also provides a browser bundle to visualise TDs and to enable the interaction with Things from the Web browser.
55	Eclipse tinydtls	tinydtls is a library for Datagram Transport Layer Security (DTLS) covering both the client and the server state machine. It is implemented in C and provides support for the mandatory cipher suites specified in CoAP.
56	Eclipse Unide	Eclipse Unide provides a lightweight Production Performance Management Protocol (PPMP) server-client implementations (using JSON, REST and other). The core of the protocol are two interface definitions: - PPMP Measurement Interface: This is a public REST API with the purpose of receiving time series and machine data. - PPMP Messages Interface: This is a public REST API with the purpose of receiving machine messages.
57	Eclipse UPM	The Eclipse UPM repository provides software drivers for a wide variety of commonly used sensors and actuators. These software drivers interact with the underlying hardware platform (or microcontroller), as well as with the attached sensors, through calls to Eclipse MRAA APIs. The Eclipse UPM project builds on the solutions of MRAA. While the MRAA project provides an abstraction layer for several IoT platforms, offering developer access to the physical pins and buses, UPM supplies developers with C/C++ sensor libraries with bindings to Java*, JavaScript* and Python*. UPM makes it easier to interface with

		the sensors bundled with the Intel® IoT Developer Kits and extends the MRAA library.
58	Eclipse VOLTTRON	VOLTTRON™ is an open-source platform for distributed sensing and control. The platform provides services for collecting and storing data from buildings and devices and provides an environment for developing applications which interact with that data. The Eclipse VOLTTRON software platform is Linux-based and capable of running on small, single-board computers as well as in the cloud. It deploys applications known as V-agents that gain access to energy data via automation systems, identifying and diagnosing problems such as erroneous temperature settings. The technology offers passive capabilities that report a problem, as well as active approaches that actually fix the problem. VOLTTRON can be configured to use any protocol needed to interface with devices or data sources.
59	Eclipse Vorto	Eclipse Vorto provides a language for describing models and interfaces for IoT Digital Twins. Digital twins are models of entities in the physical world such as a (multi) sensor device, smart power plant, and other entities that participate in IoT solutions. Modeling enables IoT solutions and IoT platforms to provision, use, and configure IoT devices and logical entities from multiple sources in a single solution. Using the vortolang and describing the entities's capabilities, IoT platforms and IoT solutions can leverage the semantics of these IoT entities.
60	Eclipse Wakaama	Wakaama is not a library but files to be built with an application. It is written in C and designed to be portable on POSIX compliant systems. Two compilation switches are used: LWM2M_CLIENT_MODE and LWM2M_SERVER_MODE. Defining LWM2M_CLIENT_MODE enables the LWM2M Client interfaces. Defining LWM2M_SERVER_MODE enables the LWM2M Server interfaces. Both can be defined at the same time. Wakaama is mono-threaded. An application can call a HandlePacket API to feed Wakaama with received LWM2M packets and a Step API to perform any pending LWM2M operations. Wakaama provides APIs for a server application to send commands to registered Clients. On client applications, Wakaama checks received commands for syntax and access rights and then dispatches them to the relevant objects.
61	Eclipse Yasham	Eclipse Yasham is an Open & Extensible Cloud-Native Smart Living Platform for Consumer IoT.
62	Eclipse zenoh	Eclipse zenoh provides is a stack designed to (1) minimise network overhead, (2) support extremely constrained devices, (3) supports devices with low duty-cycle by allowing the negotiation of data exchange modes and schedules, (4) provide a rich set of abstraction for distributing, querying and storing data along the entire system, and (5) provide extremely low latency and high throughput.
63	EdgeX Foundry	EdgeX Foundry is a vendor-neutral open-source middleware platform hosted by the Linux Foundation, providing a common framework for industrial IoT edge computing. At the core there is a set of loosely coupled microservices organised in different layers.

64	Ehcache	Ehcache is an open-source, standards-based cache that boosts performance, offloads your database, and simplifies scalability. It is the most widely used Java-based cache because it's robust, proven, full-featured, and integrates with other popular libraries and frameworks. Ehcache scales from in-process caching, all the way to mixed in-process/out-of-process deployments with terabyte-sized caches.
65	Exciting Printer	An open-source kit for exploring the possibilities of internet-of-things printing. In a nutshell, Printer is a software system that makes it easy for you to: build your own small internet-connected printers, produce customised content for them, and share that content with other people who also have small internet-connected printers.
66	Extensible Messaging and Presence Protocol (XMPP)	XMPP is the Extensible Messaging and Presence Protocol, a set of open technologies for instant messaging, presence, multi-party chat, voice and video calls, collaboration, lightweight middleware, content syndication, and generalised routing of XML data. XMPP was originally developed in the Jabber open-source community to provide an open, decentralised alternative to the closed instant messaging services at that time.
67	FarmBot	Open-source IoT toolkit for farming and gardening applications. It provides functionalities for visual application development based on drag and drop interfaces.
68	Fledge	Fledge developers build smarter, better, more cost-effective industrial manufacturing solutions to accelerate Industrial 4.0 adoption. Fledge is an open-source framework and community for the industrial edge focused on critical operations, predictive maintenance, situational awareness and safety. Fledge is architected to integrate Industrial Internet of Things (IIoT), sensors and modern machines with the cloud and existing “brown field” systems like historians, DCS (Distributed Control Systems), PLC (Program Logic Controllers) and SCADA (Supervisory Control and Data Acquisition). All sharing a common set of administration and application APIs.
69	Flogo	Open-source platform for the development and deployment of event driven applications, including IoT applications.
70	Flutter	Flutter is a programmable processor core for electronics projects, designed for hobbysits, students, and engineers. Flutter features a fast ARM processor, powerful long-range wireless communication, built-in battery charging, and an onboard security chip, making Flutter an ideal choice for robotics, wireless sensor networks, consumer electronics, and educational platforms.
71	Freeboard	Bug Labs' Freeboard is an open-source drag-and-drop tool for designing IoT dashboards and visualisations.
72	Gobot	Open-source framework for robots, drones, Internet of Things (IoT), and physical computing application. It is written in the Go language.
73	HabitatMap	HabitatMap is an environmental technology non-profit building open-source, free, and low-cost environmental monitoring and data visualisation solutions. Our tools empower organisations and citizen scientists to measure pollution and advocate for equitable solutions to environmental health issues. We focus on low-income communities and communities of colour living with disproportionate environmental burdens.

74	Hazelcast	Hazelcast is an open-source distributed in-memory data store and computation platform. It provides a wide variety of distributed data structures and concurrency primitives. Hazelcast IMDG: Open-source distributed In-memory object store supporting a wide variety of data structures such as Map, Set, List, MultiMap, RingBuffer, HyperLogLog. Cloud and Kubernetes friendly. Hazelcast Jet: Open-source distributed stream and batch processing with embedded in-memory storage and a variety of connectors such as Kafka, Amazon S3, Hadoop, JMS and JDBC.
75	Herald	Herald provides reliable Bluetooth communication and range finding across a wide range of mobile devices, wearables, and beacons allowing Contact Tracing and other applications to have regular and accurate information to make them highly effective.
76	Home Assistant	Open-source home automation that puts local control and privacy first. Powered by a worldwide community of tinkerers and DIY enthusiasts. Perfect to run on a Raspberry Pi or a local server.
77	InterUSS Platform Fund	The InterUSS Project enables trusted, secure, and scalable interoperability between UAS Service Suppliers (USSs) to further safe, equitable and efficient drone operations.
78	IOTA	Open-source platform that supports the development of many use cases, including Industrial IoT use cases.
79	IoTDM	The Internet of Things Data Management (IoTDM) on OpenDaylight project is about developing a data-centric middleware that will act as a oneM2M compliant IoT Data Broker and enable authorised applications to retrieve IoT data uploaded by any device.
80	IoTivity	IoTivity is an open-source software framework enabling seamless device-to-device connectivity to address the emerging needs of the Internet of Things. The IoTivity project delivers a reference implementation of the OCF standard specifications. The Open Connectivity Foundation (OCF) specifications are ISO/IEC recognised international standards.
81	IoTSyS	IoTSyS is an integration middleware for the Internet of Things. It provides a communication stack for embedded devices based on IPv6, Web services and oBIX to provide interoperable interfaces for smart objects. Using 6LoWPAN for constrained wireless networks and the Constrained Application Protocol together with Efficient XML Interchange an efficient stack is provided allowing using interoperable Web technologies in the field of sensor and actuator networks and systems while remaining nearly as efficient regarding transmission message sizes as existing automation systems. IoTSyS was started within the frame of the FP7 IoT6 European research project and is hosted and further maintained by the Automation Systems Group at the Vienna University of Technology. It is also supported through the Internet Foundation Austria within the NetIdee open-source grants and further developed within the project Secure and Semantic Web of Automation (SeWoA, FFG 840206).
82	IPPUSBXD	IPPUSBXD is a userland driver for IPP-over-USB class USB devices. It has been designed for Linux but uses a cross platform usb library allowing eventual porting to Windows and other non-POSIX platforms.

83	Kaa	The Kaa Cloud is an IoT platform-as-a-service (PaaS) accessible for all the registered users with KaaID. This is the Kaa Enterprise IoT Platform in the form of PaaS that you can start using in a matter of seconds! Designed for streamlined user experience, it gives you access to nearly all major Kaa capabilities, with no prior technical expertise required. That's why we believe that the Kaa Cloud is the easiest way to connect your devices to the cloud and enjoy the benefits of remote device management and analytics. It is perfectly suitable for enterprise-grade IoT applications as well as home-grown IoT projects and experiments.
84	KernelCI	kernelci.org is a community based, open-source distributed test automation system focused on upstream Linux kernel development. Their goal is to unify all upstream Linux kernel testing efforts in order to provide a single place where to store, view, compare and track these results. It is their mission to detect, bisect, report and fix regressions on upstream Kernel trees before they even reach «mainline».
85	Kinoma	Kinoma, a division of Marvell Semiconductor, is a software engineering group providing an open-source, cross-platform ECMAScript stack aimed at developing software for Internet of Things products and other embedded devices. Additionally, Kinoma provides Kinoma Create, a hardware prototyping platform aimed at the independent maker community.
86	Linux Vendor Firmware Service	The Linux Vendor Firmware Service is a secure portal which allows hardware vendors to upload firmware updates. This site is used by all major Linux distributions to provide metadata for clients such as fwupdmgr and GNOME Software.
87	LinuxBoot	LinuxBoot is a firmware for modern servers that replaces specific firmware functionality like the UEFI DXE phase with a Linux kernel and runtime.
88	Macchina.io Edge Device SDK	macchina.io Edge Device SDK provides a web-enabled, secure, modular and extensible C++ and JavaScript IoT application environment on top of Linux, consisting of middleware, protocols and rich APIs. macchina.io provides ready-to-use and industry proven software building blocks that enable applications to collect, process, filter, analyze and visualise sensor, machine and process data locally, directly where it originates, and where the action happens. macchina.io enables IoT edge and fog computing.
89	Macchina.io Remote Manager	macchina.io Remote Manager provides secure remote access to connected devices via HTTP or other TCP-based protocols and applications such as secure shell (SSH) or Virtual Network Computing (VNC). With macchina.io Remote Manager, any network-connected device running the Remote Manager Agent software (WebTunnelAgent, contained in this SDK) can be securely accessed remotely over the internet from browsers, mobile apps, desktop, server or cloud applications.
90	Mainflux	Mainflux is performant and secure open-source patent-free IoT platform with the complete full-scale capabilities for development of Internet of Things solutions, IoT applications and smart connected products. It accepts user and thing connections over various network protocols (i.e. HTTP, MQTT, WebSocket, CoAP), thus making a seamless bridge between them. It is used as the IoT middleware for building complex IoT solutions.

91	Mainspring	M2MLabs Mainspring is an open-source application framework for building machine to machine (M2M) applications such as remote monitoring, fleet management or smart grid. t is written in Java and runs on a standard J2EE6 application server like glassfish 4.1 and JBoss 7 and higher. Data storage is provided by the extremely scalable NoSQL database from the Apache Cassandra project.
92	Mango OS	Radix IoT's flagship platform, Mango OS, is a manufacturer-independent full-stack framework that allows clients – with one location to tens of thousands – to harness their data for better business outcomes. From data acquisition to remote facility monitoring and automation, Radix IoT users have access to an intuitive, out-of-the-box flexible platform to allow disjointed data to be turned into business solutions.
93	Node-RED	Node-RED is a programming tool for wiring together hardware devices, APIs and online services in new and interesting ways. It provides a browser-based editor that makes it easy to wire together flows using the wide range of nodes in the palette that can be deployed to its runtime in a single-click.
94	OASIS Message Queuing Telemetry Transport (MQTT)	Providing a lightweight publish/subscribe reliable messaging transport protocol suitable for communication in M2M/IoT contexts where a small code footprint is required and/or network bandwidth is at a premium.
95	OASIS SI	Part of Open-source Architecture Semantic IoT Service-platform project, SI oneM2M Server is a server framework (IN-CSE) that supports interworking of devices and applications based on oneM2M, IoT international standard. Using SI oneM2M Server source code, you can build oneM2M-based device and application interworking server, and you can develop various oneM2M components such as AE, MN-CSE using oneM2M core source code.
96	oneM2MTester	oneM2MTester is a oneM2M Conformance testing project aiming to develop and distribute an open source oneM2M Conformance testing tool as well as associated user manuals. The oneM2MTester is initialised by Korea Electronics Technology Institute (KETI) in January 2016, and it is a global collaboration project with 11 members.
97	Open Garden	Open Garden is an Open-source alternative to commercial home automation to remotely control your indoor and outdoor plants. The platform consists of three different kits, each ready for a specific kind of growing plant scenario: indoor (houses and greenhouses), outdoor (gardens and fields) and hydroponics (plants in water installations).
98	openHAB	The open Home Automation Bus (openHAB) is an open-source, technology agnostic home automation platform which runs as the center of your smart home. The open Home Automation Bus (openHAB) project aims at providing a universal integration platform for all things around home automation. It is a pure Java solution, fully based on OSGi.

99	OpenIoT	The OpenIoT middleware infrastructure supports flexible configuration and deployment of algorithms for collection, and filtering information streams stemming from internet-connected objects, while at the same time generating and processing important business/applications events. OpenIoT is a joint effort of prominent open-source contributors towards enabling a new range of open large scale intelligent IoT (Internet-of- things) applications according to a utility cloud computing delivery model. OpenIoT is perceived as a natural extension to cloud computing implementations, which will allow access to additional and increasingly important IoT based resources and capabilities. In particular, OpenIoT will research and provide the means for formulating and managing environments comprising IoT resources, which can deliver on-demand utility IoT services such as sensing as a service.
100	OpenMTC	OpenMTC is a reference implementation of the oneM2M standard, for conducting applied research and developing innovative M2M and IoT applications. Its horizontal service approach easily integrates devices from different Industrial IoT verticals, independent of the underlying hardware or network infrastructure. The OpenMTC SDK aims to provide developers with a convenient yet flexible tool to write oneM2M compliant applications. This includes network applications (NAs), gateway application (GAs), device applications (DAs), as well as interworking proxy entities (IPEs). The project is part of FIWARE.
101	OpenRemote	OpenRemote is a platform that simplifies connecting networked assets to mobile- and web applications. OpenRemote Protocol agents allow you to connect different data sources, live sensors, and even controls. Whether generic HTTP, MQTT, or very specific protocols like KNX, protocols shouldn't be in your way to create your business application. The OpenRemote rules engine allows for any automation, prediction or optimisation in your system. As it can be programmed with Groovy, Javascript, and a JSON or Flow rules object model, all your developers will quickly understand it. The Account management and Identity service gives you the means to decide who has access to which application or data source. Your applications are designed just once but simultaneously accessible on desktops, and mobile apps for iOS and Android. Designing in HTML5, adding our web components, and using our consoles, it's just an extension to your web strategy.
102	OpenThread	OpenThread released by Google is an open-source implementation of Thread®. Google has released OpenThread to make the networking technology used in Google Nest products more broadly available to developers, in order to accelerate the development of products for the connected home and commercial buildings. With a narrow platform abstraction layer and a small memory footprint, OpenThread is highly portable. It supports both System-on-Chip (SoC) and Co-Processor designs.
103	OpenWSN	The goal of the OpenWSN project is to provide open-source implementations of a complete protocol stack based on Internet of Things standards, on a variety of software and hardware platforms. This implementation can then help academia and industry verify the applicability of these standards to the Internet of Things, for those

		networks to become truly ubiquitous.
104	OS-IoT	ATIS Open Source – Internet of Things (OS-IoT) is an open-source software library that simplifies the development of IoT devices that connect to an open, interoperable ecosystem. OS-IoT has a unique focus in the oneM2M software ecosystem which is to support lightweight client applications that can be deployed on constrained devices
105	OSRF Gazebo	Gazebo accurately and efficiently simulates robots for your application, whether it's warehouse logistics, autonomous driving, or space exploration. You get a robust physics engine, high-quality graphics, and programmatic interfaces, including integration with (OSRF) ROS. And it's all open source.
106	OSRF ROS	ROS (Robot Operating System) is a software development kit that helps you build robot applications. From drivers to state-of-the-art algorithms, and with powerful developer tools, ROS has what you need for your next robotics project. And it is all open source.
107	Oxford Flood Network	Low-cost wireless sensors harness the power of the Internet of Things to give you updates about waterways, culverts, rivers, ditches and even groundwater. They're battery powered and connect wirelessly to a gateway which sends the data back to our system using the Internet. A web map visualises your waterways and their levels at https://map.flood.network
108	Particle	Particle is the edge-to-cloud IoT platform to connect, manage, and extract data from physical products.
109	Physical Web/Eddystone	The Physical Web is an open approach to enable quick and seamless interactions with physical objects and locations. The Physical Web is an effort to extend the superpower of the web - the URL - to everyday physical objects. Our premise is that you should be able to walk up to any “smart” physical object (e.g. a vending machine, a poster, a toy, a bus stop, a rental car) and interact with it without first downloading an app. The user experience of smart objects should be much like links in a web browser, just tap and use. At its base, the Physical Web is a discovery service: a smart object broadcasts relevant URLs that any nearby device can receive. This simple capability can unlock exciting new ways to interact with the Web.
110	Picos	Picos is an actor-based programming system that supports people-centric, reactive programming on the Internet of Things.
111	PlatformIO	PlatformIO is a cross-platform, cross-architecture, multiple-framework, professional tool for embedded systems engineers and for software developers who write applications for embedded products.
112	PrivateEyePi	Home Automation and Monitoring Projects for Raspberry Pi. This is a Raspberry Pi projects website aimed at the Raspberry Pi enthusiast wanting to build home security/automation systems and at the same time learn programming and electronics. All software and source code we provide is free of charge can be copied, shared and modified without restriction. There are no charges for the alarm system or any of the projects.

113	Px4	PX4 is an open-source flight control software for drones and other unmanned vehicles. The project provides a flexible set of tools for drone developers to share technologies to create tailored solutions for drone applications. PX4 is hosted by Dronecode, a Linux Foundation non-profit.
114	RabbitMQ	RabbitMQ is the open-source message broker. RabbitMQ is lightweight and easy to deploy on premises and in the cloud. It supports multiple messaging protocols. RabbitMQ can be deployed in distributed and federated configurations to meet high-scale, high-availability requirements. RabbitMQ runs on many operating systems and cloud environments, and provides a wide range of developer tools for most popular languages.
115	Raspberry Pi OS	Operating System of the popular Raspberry Pi platform that can be used to support the development of IoT applications.
116	Raspbian	Raspbian is a free operating system based on Debian optimised for the Raspberry Pi hardware. An operating system is the set of basic programs and utilities that make your Raspberry Pi run. However, Raspbian provides more than a pure OS: it comes with over 35,000 packages, pre-compiled software bundled in a nice format for easy installation on your Raspberry Pi. The initial build of over 35,000 Raspbian packages, optimised for best performance on the Raspberry Pi, was completed in June of 2012. However, Raspbian is still under active development with an emphasis on improving the stability and performance of as many Debian packages as possible.
117	RIOT	RIOT is a free, open-source operating system developed by a grassroots community gathering companies, academia, and hobbyists, distributed all around the world. RIOT supports most low-power IoT devices and microcontroller architectures (32-bit, 16-bit, 8-bit). RIOT aims to implement all relevant open standards supporting an Internet of Things that is connected, secure, durable and privacy friendly.
118	seL4	seL4 is a high-assurance, high-performance operating system microkernel. It is unique because of its comprehensive formal verification, without compromising performance. It is meant to be used as a trustworthy foundation for building safety- and security-critical systems. It is available as open source on GitHub and supported by the seL4 Foundation.
119	SiteWhere	SiteWhere is an industrial strength, open-source IoT Application Enablement Platform which facilitates the ingestion, storage, processing, and integration of IoT device data at massive scale. The platform leverages a microservices architecture which runs on top of cutting-edge technologies such as Kubernetes, Istio, and Kafka in order to scale efficiently to the loads expected in large IoT projects.
120	SPDX	SPDX is an open standard for communicating software bill of material information, including provenance, license, security, and other related information. SPDX reduces redundant work by providing common formats for organisations and communities to share important data, thereby streamlining, and improving compliance, security, and dependability.

121	State of the Edge	State of the Edge is a vendor-neutral platform for open research on edge computing that is dedicated to accelerating innovation by crowdsourcing a shared vocabulary for edge. The project develops free, shareable research that is widely adopted and used to discuss compelling solutions offered by edge computing and the next generation Internet.
122	Tessel	Tessel 2 is a robust IoT and robotics development platform. Leverage all the libraries of Node.JS to create useful devices in minutes with Tessel.
123	The Thing System	The Thing System is a set of software components and network protocols that claims to support true automation rather than simple notifications. Its self-learning AI software can handle many collaborative M2M actions without requiring human intervention.Its steward software is written in node.js making it both portable and easily extensible. It can run on your laptop, or fit onto a small single board computer like the Raspberry Pi.
124	ThingBox	The ThingBox is a set of software ready to use, already installed and configured on an SDCard. for Raspberry Pi featuring Node-RED and The Internet of Things technologies, easy to use with a graphical interface. The ThingBox allows anyone to graphically create new unlimited applications interacting with connected objects from a simple web-browser.
125	Thinger.io	Ready to go scalable cloud infrastructure for connecting millions of devices. You can control them with easy-to-use admin console, or integrate them in your business logic with our REST API.
126	Thingful	Thingful is a search engine for the Internet of Things, enabling secure discoverability & interoperability between millions of public & private connected objects around the world. Our mission is to enable an interoperable Internet of Things, in which connected objects find and use each other's data with the active consent of their owners. Thingful enables IoT data owners to control how their data is used and empowers them to make more valuable and effective decisions through secure cross-domain IoT search & access.
127	ThingsBoard	ThingsBoard is an open-source IoT platform for data collection, processing, visualisation, and device management. It enables device connectivity via industry standard IoT protocols - MQTT, CoAP and HTTP and supports both cloud and on-premises deployments. ThingsBoard combines scalability, fault-tolerance and performance so you will never lose your data.
128	ThingSpeak	ThingSpeak™ is an IoT analytics platform service that allows you to aggregate, visualise and analyse live data streams in the cloud. ThingSpeak provides instant visualisations of data posted by your devices to ThingSpeak. With the ability to execute MATLAB® code in ThingSpeak you can perform online analysis and processing of the data as it comes in. ThingSpeak is often used for prototyping and proof of concept IoT systems that require analytics.
129	Tinq Project	Tinq is completely based on the Qeo publish/subscribe framework produced by Technicolor. Tinq is a software framework that allows devices to easily exchange data with other devices on the same network based on a publish-subscribe paradigm.

130	Tizen	Tizen is an open and flexible operating system built from the ground up to address the needs of all stakeholders of the mobile and connected device ecosystem, including device manufacturers, mobile operators, application developers and independent software vendors (ISVs). Tizen is developed by a community of developers, under open-source governance, and is open to all members who wish to participate.
131	Ubuntu	Ubuntu Core is Ubuntu for IoT and embedded environments, optimised for security and reliable updates. It's easy to deploy, tamper-resistant, and hardened against corruption. Its read-only root filesystem is built from the same packages used to build the wider set of Ubuntu distributions, and only differs in the way packages are delivered, and crucially, updated. This is all handled by snaps, a secure, confined, dependency-free, cross-platform Linux packaging system.
132	UDOO	UDOO is a family of Open-source Arduino-powered Mini PC compatible with Windows, Android and any Linux Distro. You can exploit both as embedded systems for DIY-electronics projects and as low power consumption, fanless computers for everyday use. The product line involves five single board computers: UDOO QUAD/DUAL (2013), UDOO NEO (2015), UDOO X86 (2016), UDOO BOLT (2019) and UDOO BOLT GEAR (2020).
133	Very Simple Control Protocol (VSCP)	VSCP (Very Simple Control Protocol) is a framework for IoT/m2m tasks. The framework defines methods to have a common device discovery, a common configuration, a common way to interface with remote devices and a common way to update firmware of devices built on different architectures. A server is available that runs on many platforms that have a webserver/websocket/rest/driver and tcp/ip interface with ssl security.
134	Waspmote	Waspmote is an Open-source sensor device to develop Internet of Things projects.
135	webinos	The webinos EU FP7 project defined and delivered an Open-source Platform and software components for the Future Internet in the form of web runtime extensions, to enable web applications and services to be used and shared consistently and securely over a broad spectrum of converged and connected devices, including mobile, PC, home media (TV) and in-car units.
136	WeIO	WeIO is an innovative open-source hardware and software platform for rapid prototyping and creation of wirelessly connected interactive objects using only popular web languages such as HTML5 or Python. WeIO consists of the development board and WeIO IDE, locally served (directly from the board) web application that lets you program and control all inputs and outputs on the board from any browser.
137	WIZnet	WIZnet (Wizard of Internet) is the IoT Device Platform company. It's unique technology – Hardwired TCP/IP provides better performance and stability than any other software Internet connectivity solutions. We can summarise the main features of Hardwired TCP/IP as Unattackable, High Performance and Easy to Use

138	Yaler	Yaler is a relay infrastructure for secure access to embedded systems. The Yaler relay infrastructure enables secure Web access to embedded systems behind a firewall, NAT or mobile network gateway. All you need on your device is a TCP socket. A simple HTTP handshake makes your Web service running on the device accessible from any Web browser, cURL or other HTTP client, allowing you to remotely monitor and control your device.
139	Yocto	The Yocto Project is an open-source collaboration project that helps developers create custom Linux-based systems regardless of the hardware architecture. The project provides a flexible set of tools and a space where embedded developers worldwide can share technologies, software stacks, configurations, and best practices that can be used to create tailored Linux images for embedded and IOT devices, or anywhere a customised Linux OS is needed.
140	Zephyr	The Zephyr Project is a scalable real-time operating system (RTOS) supporting multiple hardware architectures, optimised for resource constrained devices, and built with security in mind. The Zephyr OS is based on a small-footprint kernel designed for use on resource-constrained systems: from simple embedded environmental sensors and LED wearables to sophisticated smart watches and IoT wireless gateways.
141	Zetta	Zetta is an open-source platform built on Node.js for creating Internet of Things servers that run across geo-distributed computers and the cloud. Zetta combines REST APIs, WebSockets and reactive programming – perfect for assembling many devices into data-intensive, real-time applications.

REFERENCES

[Biasin20] Biasin, E and Kamenjašević, E. 2020. Open Source Hardware and Healthcare Collaborative Platforms: Common Legal Challenges. Journal of Open Hardware, 4(1): 7, pp. 1–8. DOI: https://doi.org/10.5334/joh.31

[EC-OSS20] COMMUNICATION TO THE COMMISSION, OPEN SOURCE SOFTWARE STRATEGY 2020 – 2023, Think Open, C(2020) 7149 final, Brussels, 21.10.2020

[Eclipse18] Eclipse Foundation, "IoT Developer Survey 2018 Results" April 2018, Copyright (c) 2018, Eclipse Foundation, Inc. | Made available under a Creative Commons Attribution 4.0 International License (CC BY 4.0).

[Eclipse19] Eclipse Foundation, "IoT Developer Survey 2019 Results", April 2019, COPYRIGHT (C) 2019, ECLIPSE FOUNDATION, INC. | MADE AVAILABLE UNDER THE ECLIPSE PUBLIC LICENSE 2.0 (EPL-2.0)

[Eclipse20] Eclipse Foundation, "IoT Commercial Adoption Survey 2019 Results", March 2020, COPYRIGHT (C) 2020, ECLIPSE FOUNDATION, INC.

[ECOSS20] European Commission, OPEN SOURCE SOFTWARE STRATEGY 2020 – 2023, C(2020) 7149 final, Brussels, 21.10.2020

[Joshi18] Rajive Joshi, Stephen Mellor, Paul Didier, "The Industrial Internet of Things Volume G5: Connectivity Framework", V1.01, Ferbuary 2018, IIC:PUB:G5:V1.01:PB:20180228, available at: https://www.iiconsortium.org/IICF.htm

[Nagel21] Lars Nagel (ed), "Design Principles for Data Spaces", Position Paper, International

[Qutqut18] Qutqut, Mahmoud & Al-Sakran, Aya & Almasalha, Fadi & Hassanein, Hossam. (2018). Comprehensive Survey of the IoT Open Source OSs. IET Wireless Sensor Systems. 8. 10.1049/iet-wss.2018.5033.

[Soldatos20] John Soldatos, "A 360-Degree View of IoT Technologies", Artech House, ISBN: 9781630817527, December 2020.

[Soldatos21] Soldatos, John, Calisti, Monique, Sofia, Rute, & Rublova, Dariya. (2021). The Internet-of-Things Open Source Ecosystem in 2021 (1.2). Zenodo. https://doi.org/10.5281/zenodo.5838130