# A Vision on Smart, Decentralised Edge Computing Research Directions

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**Main author:**

Rute Sofia *(fortiss)*

**Additional Contributors:**

**ASSIST-IoT:** E. Garro *(Prodevelop),* Ignacio Lacalle *(Valencia University)*

**IoT-NGIN:** Terpsi Velivassaki *(Synelixis Solutions SA),* Dmitrij Lagutin *(Aalto University)*

**TERMINET:** Anna Triantafyllou, Panagiotis Sarigiannidis, Thomas Lagkas *(University of Western Macedonia)*

**EU-IoT:** John Soldatos *(INTRASOFT International),* Roberto Pomohaci *(Bluspecs),* Emilie Mathilde Jakobsen *(Aarhus University)*

**The European IoT Hub**

Growing a sustainable and comprehensive ecosystem for Next Generation Internet of Things

n g i o t . e u

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## Acronyms

| | |
|---|---|
| AI | Artificial Intelligence |
| AIOTI | The Alliance for the Internet of Things Innovation |
| AR | Augmented Reality |
| BDVA | European Big Data Value Strategic Research Innovation Agenda |
| D2D | Device to Device |
| EC | European Commission |
| ETSI | European Telecommunications Standards Institute |
| H2020 | Horizon 2020 |
| IoT | Internet of Things |
| IP | Internet Protocol |
| MEC | Mobile Edge Computing |
| ML | Machine Learning |
| NIST | National Institute of Standards and Technology |
| NGIoT | Next Generation Internet of Things |
| RAN | Radio Access Network |
| RAT | Radio Access Technology |
| RNC | Radio Network Controller |
| SDN | Software Defined Networking |
| SDR | Software Defined Radio |
| TSN | Time Sensitive Networking |
| VR | Virtual Reality |
| WoT | Web of Things |

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# 1 INTRODUCTION

Organisations across a variety of industries rely today on the *Internet of Things (IoT)* to, on the one hand, increase operational efficiency and, on the other hand, to improve the overall decision making processes and increase the value-add of their products/business.

From a computer science perspective, IoT is a system of interconnected cyber-physical devices, software, data, and people. The aim is to allow data to be accessible anywhere and anytime, so IoT relies on Cloud computing to provide this support from a storage perspective. The data accessibility and computational power that the Cloud provides has led to an increase in the generated data, which had, as consequence, an increase in energy consumption, among other aspects.

Cloud-based services are highly relevant in case an organisation aims at extending storage capacity, or to allow for remote work operations. These are aspects that IoT systems require, but in addition to **data storage**, the key aspects in IoT are **data processing** and **analysis**. The data processing and analysis are therefore provided via the Cloud, in a centralised way.

IoT, being based on the Internet, requires support for service and data space decentralisation, to further evolve. Predictions point out to having 75% of enterprise data supported by Edge computing in 2025[1]. Relevant to this evolution is to discuss the different perspectives of Edge computing and Edge-Cloud; and to have a perspective on the most recent developments in Europe concerning Next Generation IoT and Edge computing.

Among other aspects, the *Cooperation and Support Action (CSA)* EU-IoT aims at assisting in a clearer definition of the Cloud-Edge continuum by facilitating the cross-exploration and topics and tooling to Next Generation IoT projects. For this purpose, the EU-IoT methodology considers scope areas that are common to any end-to-end IoT system, as illustrated in *Figure 1*: Tactile Internet/Human-centric interfaces; far and near Edge; infrastructure, and data spaces.

This white paper is therefore a tool expected to assist in such cross-exploration, via the clarification of Edge computing notions, a brief introduction to NGIoT flagship projects, their current standardisation and pre-standardisation efforts. For this purpose, this white paper provides the following contributions.:

- To provide an overview on different Edge computing concepts, contributing to a better understanding of concepts such as “far Edge”, or “near Edge”.
- To explain the EU-IoT Edge computing functionality in terms of the 4 identified EU-IoT scope areas: Human/IoT interfaces; far Edge; near Edge; Infrastructure; Data Spaces.
- To discuss existing Edge research directions in active NGIoT European projects that are under the umbrella of EU-IoT.
- To provide an initial perspective on current Edge standardisation efforts being taken by the projects under the umbrella of EU-IoT.

[1]https://www.gartner.com/smarterwithgartner/what-edge-computing-means-for-infrastructure-and-operations-leaders

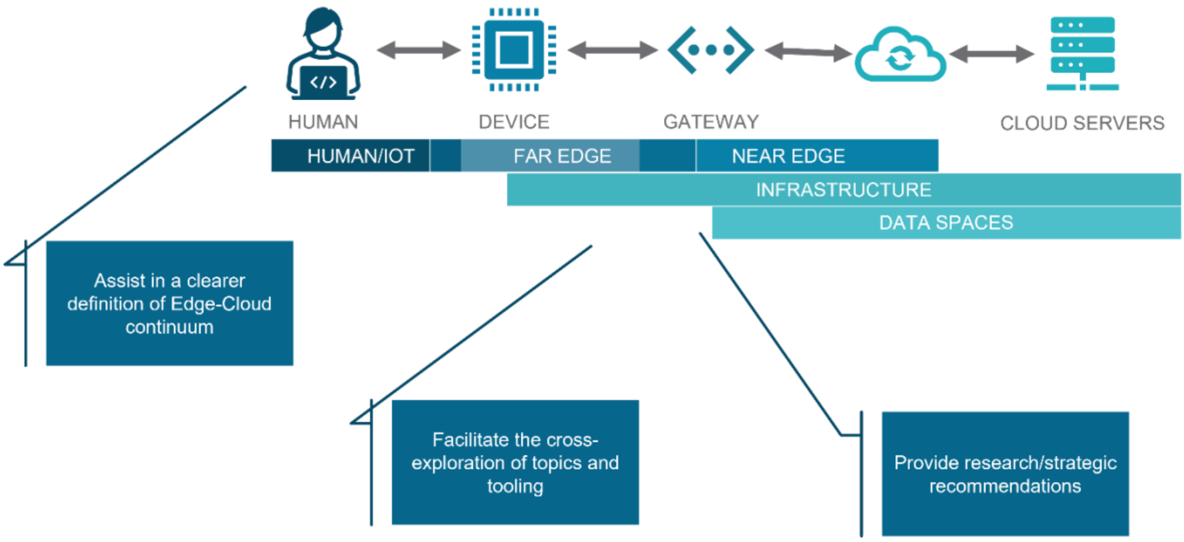


*Figure 1, EU-IoT Scope Areas.*

The paper is organized as follows: Section 2 provides an overview on key notions of Edge computing; Edge-Cloud continuum. Section 3 covers Edge computing research directions being developed on six projects under the umbrella of EU-IoT. Section 4 provides a perspective on the current contributions being planned by the different EU-IoT supported projects, and an analysis of such contributions in terms of EU-IoT scope areas; European competitiveness domains. Section 5 provides an overview on the status of current Edge standardisation directions provided by the NGIoT flagship projects. Section 6 concludes the paper, providing a perspective on future steps to be taken in EU-IoT regarding Edge research recommendations, and standardisation/pre-standardisation.

# 2 EDGE COMPUTING NOTIONS

The development and expansion of IoT is giving rise to alternative ways to support data exchange, being the paradigm of Edge computing on the rise. Edge computing is a set of distributed computational and networking functions that aim at supporting a smooth migration of data processing, storage, and analysis "closer" to IoT data sources, to best meet IoT service requirements. The notion of Edge is, however, quite flexible, and has different interpretations. For instance, one can refer to the "Edge" of a device or to the "Edge" of a network, e.g., Internet.

The Edge can then be referred to from a network perspective (*downlink*) or from a device perspective (*uplink*). Different models on how the computational and networking functions are distributed define implementations of such Edge layer, and of its services.

This section provides a debate on the notions of Edge, first addressing the concepts of "near" and "far" Edge, and then goes over the most popular Edge architectures: Fog, Mist, Mobile Edge Computing, Cloudlets. Detailed information about the different architectures can be found in the following surveys: [1]–[6].

## 2.1 Edge and the Internet, Near and Far Edge

The notion of "Edge" relates with the Internet as a complex, decentralised system. Edge architectures integrate flexible or less flexible notions of what an Edge is.

In a simplified way, IoT is a complex system based on the Internet of highly heterogeneous interconnected data spaces, data sources, and a transport core (*infrastructure*). The reach of the different Edge architectures varies with the different implementations available and relates with what can be foreseen as an Edge on the Internet. Different data spaces, private or public, are used by Internet stakeholders to store, analyse, manage and to disseminate their data. To assist this discussion, Figure 2 provides an illustration of the so-called Edge-Cloud continuum.

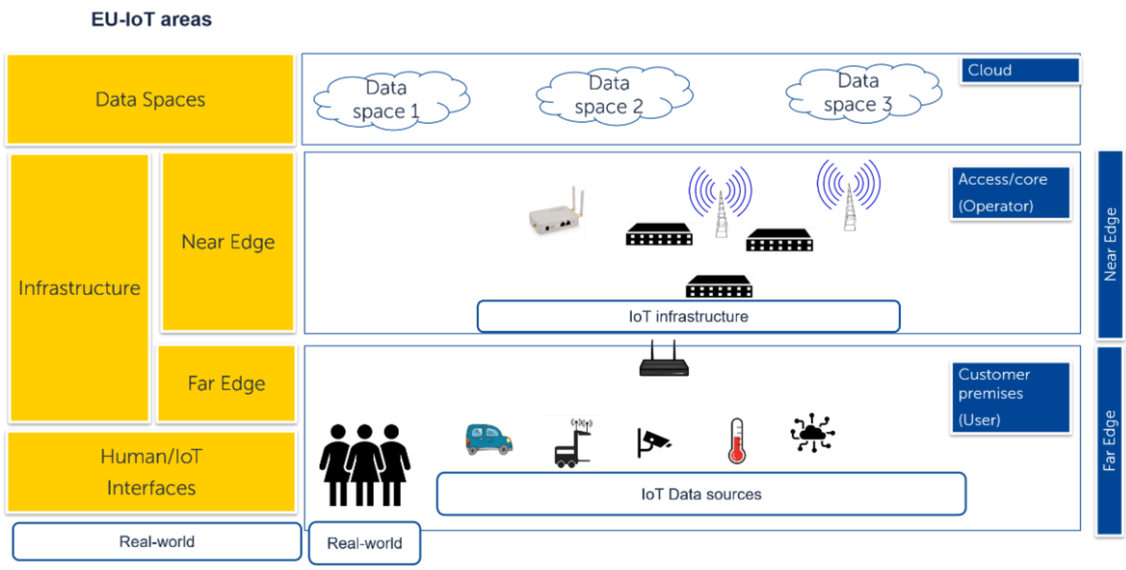


*Figure 2: Illustration of the Edge-Cloud continuum, where local decisions are supported on customer premises; partial data processing/analysis and storage is provided on Edge devices, and Cloud decisions are provided via Cloud-based data/app centres.*

Figure 2 represents a simplified infrastructure of the Internet from an IoT device/end-user device until the service backbone (Cloud), the Edge-Cloud continuum is composed of three main areas:

- **Customer premises**, which integrate terminal and associated equipment located at a service subscriber premises. Examples of customer premises can be a residential location, a factory, a shop-floor, a public area. Customer premises are usually served via a short-range wireless technology (e.g., Wi-Fi, Bluetooth) which can complement a long-range wireless/cellular (e.g., 5G) or wired solution (e.g., Fibber, carrier-grade Ethernet). The operator does not have access to the end-user equipment placed in customer premises. Examples of equipment on the customer premises are IoT devices (sensors, actuators); brownfield equipment; IoT gateways; set-top-boxes, residential gateways; APs, etc.

- **Access/Core network,** which comprises the equipment required to transport data between the end-user devices (IoT data sources) and the respective data/app centre (on the Cloud). Examples of equipment concern eNodeBs, specific servers (caching, storage), switches, routers. This transport layer is required to move data around. It comprises heterogeneous interconnections, but also different software/hardware communication protocols.
- **Cloud**, corresponding to the IP backbone where Cloud-based data centers are located. Cloud services can be offered via public or private models, as well as via hybrid models.

On the customer premises and in addition to IoT devices (sensors, actuators) it is relevant to highlight the role of people and of the surroundings (real-world), for which specific interfaces are a must. The notion of **far Edge** therefore reflects the elements located on customer premises, covering not only the existing cyber-physical systems but also the interfaces to the real-world, as well as context-awareness (e.g., situational awareness) required to perform local/partial decisions (storage, processing, analysis decisions) upon data collected.

The **near Edge** relates with the Edge elements and services that are in the access/core regions.

In addition to the placement (infrastructure perspective) of specific Edge functions across near and far Edge, the far Edge comprises additional aspects. Specifically, the far Edge embodies a full intertwining to the real-world which can only be provided via some form of context-awareness, behaviour inference and learning, i.e., integration of intelligence. Therefore, the far Edge relies on *Machine Learning (ML)* to provide a better interfacing to the real-world and to people, based on different types of context-awareness (e.g., situational awareness, human behaviour awareness and inference). While the near Edge reflects the integration of ML to best support resource managements and to best orchestrate the applications to be served.

## 2.2 Edge, Fog and Mobile Edge Computing

A key component of Edge computing concerns virtualization. The Edge comprises both network virtualization functions (e.g., *Software Defined Networks, SDN*[2]; Software *Defined Radio, SDR*) as well as computational virtualization functions (e.g., virtual machines, containers, etc.). The current definition of Edge computing has therefore gained flexibility, and today, different architectures have emerged under the notion of Edge computing.

Out of the different available Edge architectures, the most popular discussed are Fog computing, Mist computing, Mobile Edge Computing, and Cloudlets. The next sections go over each of these models.

### 2.2.1 The NIST Fog Computing Conceptual Model

*Fog computing* (2012) [7][8][5] has been defined as a distributed architecture capable of providing low-latency and location awareness; widespread geographical distribution; mobility support; very large number of nodes, ideally interconnected via wireless; support for real-time applications. The

[2] https://sdn.ieee.org/standardization

key concept concerns decentralization of applications and their management, as well as data analytics across the network itself, e.g., via federated computer models.

The current NIST Fog computing model has as its cornerstone the *Fog node*. Fog nodes are cyber-physical systems but can also be virtual components (e.g., virtual machines, a container), that interact with smart end-devices and access networks, supporting computing.

Fog therefore comprises a notion of virtual node within a cluster, with the definition of a logical location. Data management and communication are integrated into the notion of node, and fog nodes can operate in a centralized or decentralized way.

Fog nodes provide computing services to smart end-nodes, being the most relevant ones:

- **Contextual location awareness, and low latency.** The fog nodes are placed closer to end-devices, and support data analysis, storage, etc. Therefore, it is feasible to provide faster answers and integrate location awareness, to best support applications.
- **Geographical distribution.** The placement of Edge nodes closer to the smart end-devices allow for a better geographical distribution, including supporting applications to mobile devices.
- **Heterogeneity.** By providing an abstraction for nodes, Fog computing supports a variety of networking technologies, assisting interoperability.
- **Interoperability and federation**. Seamless support of certain services (real-time streaming services is a good example) requires the cooperation of different providers. Hence, *fog computing* components must be able to interoperate, and services must be federated across domains.
- **Real-time interactions**. *Fog computing* applications involve real-time interactions rather than batch processing.
- **Scalability and agility of federated, fog-node clusters.** Fog computing is adaptive in nature, at cluster or cluster-of-clusters level, supporting elastic compute, resource pooling, data-load changes, and network condition variations, to list a few of the supported *adaptive* functions.

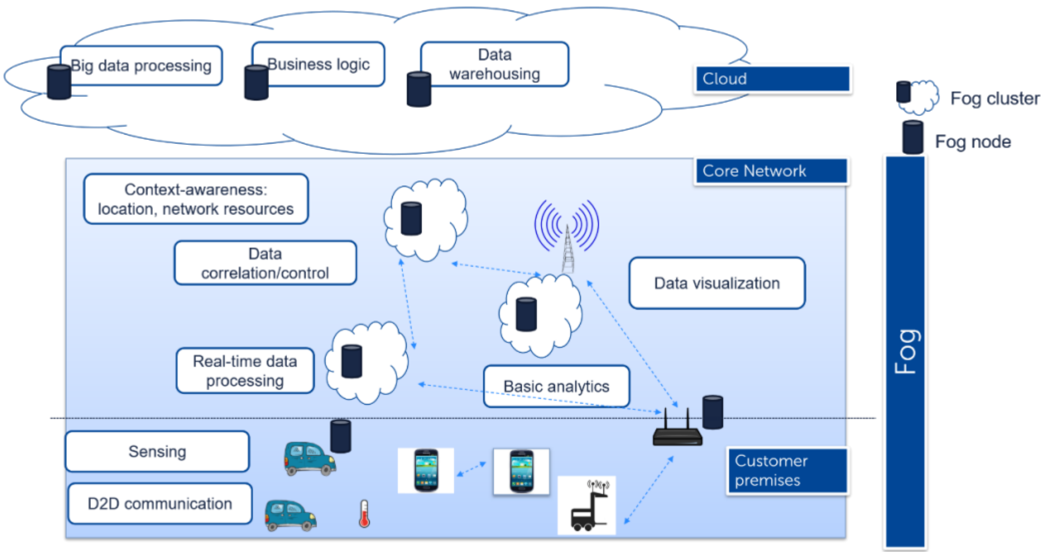


*Figure 3: Fog architecture example. Fog nodes are placed within customer premises, e.g., co-located to APs, and in the core region, e.g., co-located with eNodeB.*

### 2.2.2 Mist Computing

Mist computing (2017) [9] concerns an evolution of the Fog paradigm, to be integrated into end-user devices. The key difference between Fog and Mist is context-awareness, which for the case of Mist relates with situational awareness ("making Things aware of the situation" [9]). Specifically, the Mist layer has access to the physical environment and to local situations, to better support IoT applications. Context-awareness is therefore integrated into Access devices, thus pushing the realm of applications beyond the customer premises: usually, IoT applications are run locally. A representation is provided in *Figure 4*.

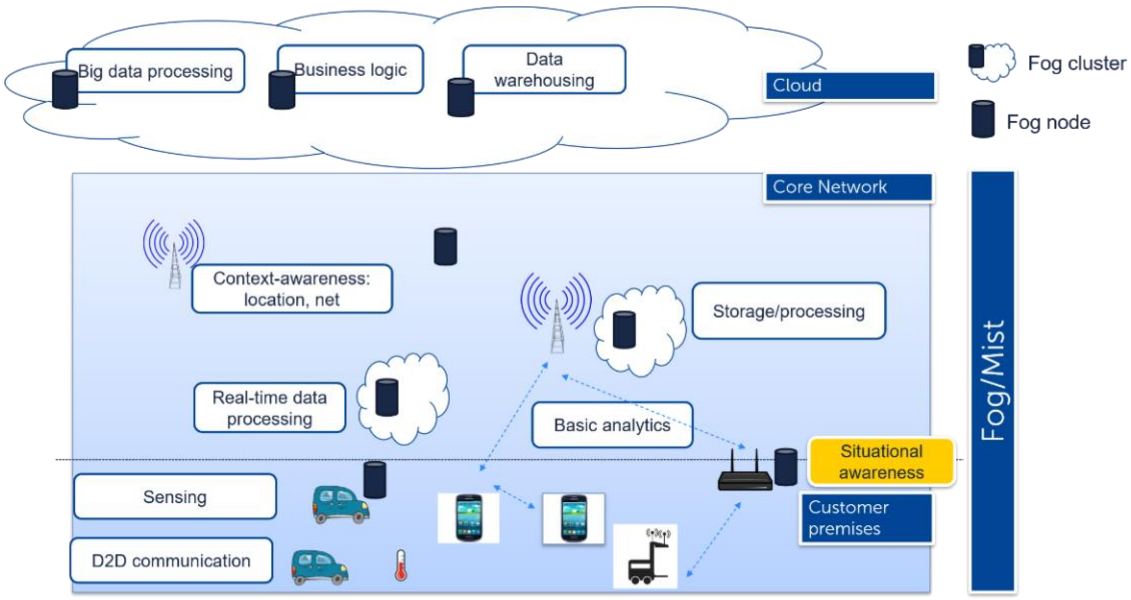


*Figure 4: Mist layer illustration. Situational awareness is brought to the Edge (Fog) nodes in the access and core, thus extending the reach of applications.*

### 2.2.3 The ETSI Mobile Edge Computing Framework

The *European Telecommunication Standards Institute (ETSI) Mobile edge computing (MEC, 2014)* standard considers the perspective of the network Edge, placing computational and network management functions (MEC servers) in co-location with mobile base stations. The MEC architecture provides seamless integration for different service providers in different vertical segments and is today a key component in 5G [10].

The MEC standards are supported by the ETSI MEC ISG[3], open to members and non-members of ETSI.

*Figure 5* provides a simplified representation of the MEC model [10]. MEC is based on a framework that relies on virtualization to enable applications to run at the edge of the network. This allows to provide low latency, high bandwidth and to support real-time monitoring of aspects such as radio network information or location awareness.

[3] https://www.etsi.org/technologies/multi-access-edge-computing

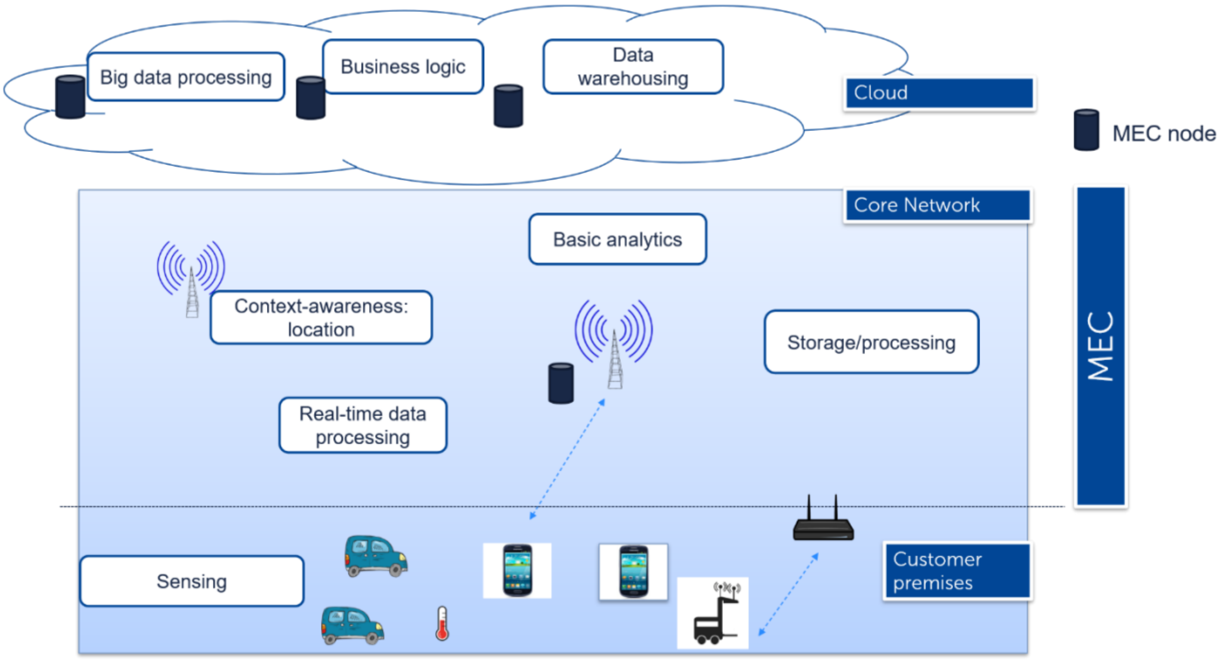


*Figure 5: MEC representation [10].*

The key component of a MEC server (or MEC node) can be deployed in several different locations. Usually, it is deployed at an eNodeB (LTE macro base station). It can also be deployed at a 3G *Radio Network Controller (RNC)* or at a multi-*radio Access Technology (RAT)* cell aggregation site. It can also be placed in other locations, indoor or outdoor. The deployment of a MEC platform is usually performed based on specific requirements, including the need for scalability.

MEC servers run multiple instances of MEC hosts, which are controlled via a MEC Orchestrator which handles information on the services offered by each MEC host, resources available, network topology. MEC servers receive service requests provided via the Mobile Edge Orchestrator and coming from mobile devices (end-user). The MEC Orchestrator keeps a catalogue of applications available on the servers and gets available resources from the ME Platform manager. This allows for active applications to be only called once from the Cloud.

MEC is today available as an ETSI standard and deployed by different vendors. In order to assist a global deployment, there are also several Proofs of Concept available[4] and the methodology to deploy a proof of concept is specified in GS MEC-IEG 005 [11], which states the need to involve at least 1 Mobile Network Operator, 1 infrastructure vendor, and one content or application provider.

### 2.2.4 Cloudlets

Cloudlets [4][12] correspond to a mini-Cloud platform which is placed closer to IoT data sources. Similarly, to Edge computing platforms, Cloudlets assist in doing the processing and computing for the offloaded process from a device to the network. A Cloudlet can be defined as a trusted cluster of computers, with resources available to use for nearby mobile devices. A standard definition for Cloudlets is: "*Cloudlets are mobility-enhanced small scale Cloud data centers located at the Edges of the network*" [12]. It is therefore a local data center, with specific resource provisioning. A Cloudlet Agent monitors the Cloudlet and its nodes and provides more resources if required, by instantiating new virtual machines. Services based on Cloudlets are provided over

[4] http://mecwiki.etsi.org

a 1-hop access, with dedicated bandwidth and specific security policies.

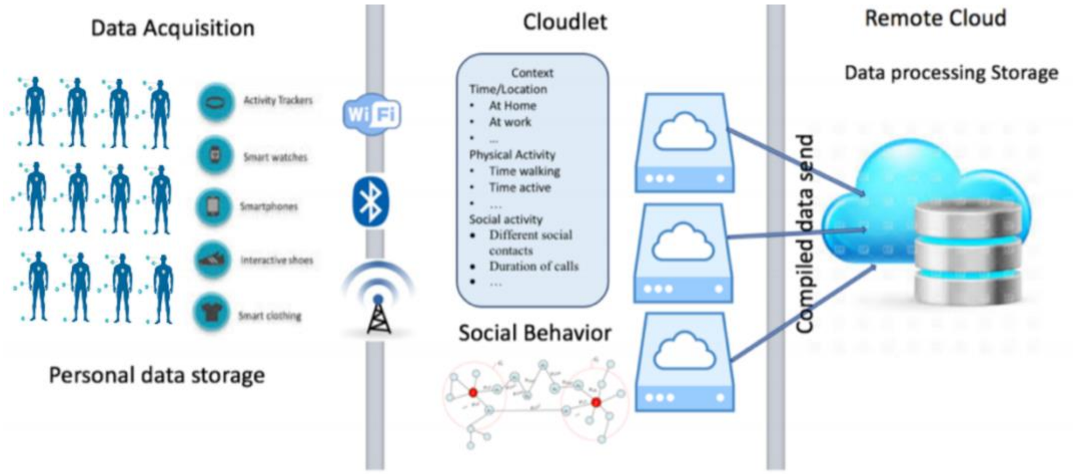


*Figure 6: Cloudlet positioning and functions example.*

# 3 CLOUD-EDGE AND THE EU-IOT SCOPE AREAS

*Table 1* provides an overview on the different EU-IoT scope areas and their relation to the Edge architectures described in section 2.2, with the aim of understanding whether the current architectures can support the needs of next generation IoT systems and services. The table provides, on the second column, the SDO that is currently developing the respective model, followed by a description on the specific functions of the architecture that relate with each of the EU-IoT scope areas. The Mist concept is placed together with Fog, as it derives from this architecture.

Starting with the **IoT interfaces** scope area and specifically focusing on the access control and management, currently the interface to IoT is provided via cellular and wireless assuming MEC and Cloud. While with Fog/Mist, short-range wireless and semantic interfacing is also considered in the architectural concept.

**Far Edge** features are only supported in Fog/Mist architectures, and Cloudlets. Cloudlets are an architecture envisioned for the Far Edge, assuming a replication of data centers. While Fog nodes provide far Edge support.

**Near Edge** features are supported equally by MEC and Fog/Mist.

*Table 1: EU-IoT scope areas and the different Edge architectures functions.*

| Concept | SDO | IoT interface Access | Far Edge | Near Edge | Infrastructure | Data Spaces |
|---|---|---|---|---|---|---|
| Cloud | - | Cellular, long-range wireless management access | - | - | 3G/4G, fixed, long-range wireless (e.g., LoRaWAN)<br>D2D not supported<br>2 or more hops to devices | Centralised data centers |
| Fog<br>Mist | NIST | Short-range wireless (e.g., Bluetooth, Wi-Fi); semantic technologies | Fog nodes, IoT devices and gateways, APs<br>Context-awareness only via Mist | Fog nodes: Access equipment, Cloud servers | Wi-Fi, 4G<br>D2D supported<br>1 or more hops to device | Decentralised data centers, Fog abstraction layer |
| MEC | ETSI | 4G/5G; support for specific domain models | - | MEC nodes (mobile networks) | 4G/5G<br>D2D not supported<br>1 hop to devices | Hierarchical, based on mobile orchestrator |
| Cloudlet | - | Short-range wireless (e.g., Bluetooth, Wi-Fi); local domain models | Cloudlet agent and nodes: IoT devices, gateways, APs etc. | - | Heterogeneous, Wi-Fi, fixed, short-long range<br>1 hop to devices<br>D2D not supported | Data center in a box, managed via a Cloudlet Agent (centralised) |

In terms of **infrastructure** support, Cloud relies on long-range heterogeneous networking technologies, e.g., 4G, fixed networks, LoRa/LoRaWAN. Device-to-device communication is not intrinsically supported, and the infrastructure usually considers the notion that there are 2 or more hops to the IoT data sources. Fog/Mist focuses on wireless/cellular infrastructures, integrating D2D communication support, and assuming that data sources are one or more hops away. MEC provides support for 4G/5G, not supporting D2D communication. MEC integrates support for paths with one or more hopes (between IoT device and MEC server, co-located with eNodeB). The Cloudlet concept considers the use of heterogeneous short and long-range wireless networking technologies as well as heterogeneous wired technologies. It assumes, however, 1-hop distances to IoT data sources and does not support D2D communication by design.

Regarding data spaces, both Cloud and Cloudlets rely on centralized approaches, while Fog/Mist considers a decentralized approach (for data storage), and MEC considers a hierarchical data space approach, where resources are managed via the mobile orchestrator.

# 4 EDGE RESEARCH DIRECTIONS IN ACTIVE PROJECTS

This section starts by describing the NGIoT flagship projects being supported by EU-IoT. Each sub-section provides a brief description of a project, covering duration, main goals, use-cases covered.

The section concludes with an overall perspective on the projects' contributions to standardisation/pre-standardisation; European competitiveness domains addressed; and contributions in the context of the EU-IoT scope areas.

## 4.1 NGIoT Flagship Projects

### 4.1.1 ASSIST-IoT

assist-iot

**URL**: https://assist-iot.eu

**Duration**: November 2020, 36 months

**ASSIST-IoT:** Architecture for scalable, self-*, human-centric, intelligent, secure, and tactile next generation IoT

**Description:** The main goal of ASSIST-IoT is to design a new blueprint architecture for the Next Generation IoT, building on previous work (done by several ASSIST-IoT partners in projects) such as INTER-IoT, 5GENESIS, GHOST or ACTIVAGE. Although ASSIST-IoT's decentralised architecture will be developed from specific use cases, it will be vertical agnostic, aimed at any IoT application domains. The starting point will be the 3D architecture model devised in CREATE-IoT, enhanced by the introduction of decentralisation, network virtualization and microservices distribution. The end-goal is to make exchanges smarter, more secure, trustable, efficient, and to bring intelligence closer to the event, either to the Edge or, preferably, to the Far Edge or device level where possible. A remarkable element of ASSIST-IoT, is the adoption of a DevSecOps methodology, which introduces privacy and security features by design on top of the traditional DevOps paradigm.

The ASSIST-IoT project will design, implement, and validate such an architecture, with their 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 microservices, containerisation, and orchestration, supplemented by cross-cutting digital enablers. ASSIST-IoT proposed architecture supports continuous integration and long-term sustainability of domain-agnostic, interoperable, self-* capable, intelligent, distributed, scalable, secure, and trustworthy IoT ecosystems.

**PILOTS AND USE-CASES**

**Logistics:**

- Port Automation, including automated alignment and remote control of complex tasks; yard fleet asset tracking; AR and Tactile HMIs for fleet drivers.

**Manufacturing (Construction):**

- Smart Safety of Workers, including smart actuation of IoT devices based on user behaviour; optimization of safety and health plans with AR; identification of abnormal behaviour.

**Transportation:**

- Cohesive Vehicle Monitoring and Diagnostics, including advanced powertrain monitoring and diagnostics; vehicle condition monitoring.

 

### 4.1.2 VEDLIOT

**URL**: https://vedliot.eu

**Duration**: November 2020, 36 months

**VEDLIOT:** Very efficient deep learning in IoT

**Description:** VEDLIoT is focused on supporting cognition on IoT devices, focusing on open hardware and integration of ML on the hardware. Working with embedded deep learning, combining hardware, accelerators, two-flow, and mapping to enable a seamless mapping of new applications.

**PILOTS AND USE-CASES**

**Manufacturing**:

- Factory maintenance. Industrial IoT, developing low-power devices, using deep learning, and modifying architecture in a power plant with deep learning, by considering architecture; practically looking at the electrical arcs seen when opening and closing switches to decide if they need maintenance or not, with a specific type of camera, and process image; recording a small amount of information at a high rate, as is typical of embedded application, focus on doing it here rather than in cloud or a data center.

**Transportation**:

- Autonomous driving. Applying distributed learning to the ECUs of cars, processing in ECUs to decide if to work at sensor or central processor, how to shift workload across networks, where best to do computing in Edge nodes or mobile servers, how to work when no network coverage is available. To use VEDLIOT hardware for tests, and then when implementing to test with industry standard ECUs and test for vibration, temperature, etc

**Home Automation**:

- Smart mirror, developing a smart mirror interface, monitor with reflective surface, based on an existing prototype (TRL4).

### 4.1.3 IntellIoT

**URL**: https://intelliot.eu

**Duration**: October 2020, 36 months

**IntellIoT:** Intelligent, distributed, human-centered and trustworthy IoT environments

**Description:** IntellIoT is a Pan-European project focusing on the development of integrated, distributed, human-centered and trustworthy IoT frameworks applicable to healthcare, manufacturing, and agriculture. 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.

**PILOTS AND USE-CASES**

**Agriculture**:

- Explore with us how farming machinery (e.g. tractors) can be semi-autonomously operated in conjunction with supporting devices such as drones, so augmented remote operation of an intelligent agricultural fleet is possible.

**Healthcare**:

- With the help of AI and IoT technologies, patients with cardiovascular diseases will be treated remotely: easier, faster and with higher quality. We will enable effective and safe patient rehabilitation and recovery.

**Manufacturing**:

- Learn how plants can be automated and shared by multiple tenants who utilize machinery from third party vendors – Manufacturing as-a-service applying smart contracts for more production flexibility and disruptive business models.

### 4.1.4 IoT-NGIN

**URL**: https://iot-ngin.eu

**Duration**: October 2020, 36 months

**IoT-NGIN :** Next generation IoT as part of next generation internet

**Description:** It is well known that the Internet of Things (IoT) has been identified as one of the next big concepts to support societal changes and economic growth. To address this opportunity, the EU-funded project IoT-NGIN introduces novel research and innovation concepts to establish itself as the 'engine' that will fuel the Next Generation of IoT as a part of the European Next Generation Internet.

IoT-NGIN uncovers a pattern-based meta-architecture that encompasses evolving, legacy, and future IoT architectures. At the same time, it optimizes IoT/M2M and 5G/MCM communications, including using secure-by-design micro-services to extend the edge cloud paradigm. IoT-NGIN also enables user and self-aware, autonomous IoT systems through privacy-preserving federated ML and ambient intelligence, with AR support for humans. Finally, the project research towards distributed IoT cybersecurity and privacy, for example, using Self-Sovereign Identities and interconnected DLTs to implement Meta-Level Digital Twins.

IoT-NGIN will be validated through more than 30 types of heterogeneous IoT devices, ranging from tiny resource-constrained IoT sensors to intelligent, autonomous buses, drones and robots, deployed in one of the most prestigious OneLab and five Living Labs: the “Twin Cities” Living Lab in Helsinki/Tallinn, a fully customizable Smart Agri Living Lab in Greece, the BOSCH and the ABB employee-friendly Industry 4.0 facilities in Barcelona and Helsinki, and a hybrid field-lab facility focused on Smart Energy, via cooperation between ASM Terni and Ericsson Eurolab in Aachen.

**PILOTS AND USE-CASES**

**Smart cities:**

- Human-centered twin smart cities. Mobility as a service-based solutions, allowing people to pick an electric car up in Helsinki, go by ferry to Talinn, resulting in co-commuting solutions based on social networks. We will also test traffic flow prediction, parking prediction and crowd management here.

**Agriculture:**

- Smart agriculture, focus on prediction of crop diseases, through smart irrigation and precise aerial spraying; also sensor aided crop harvesting, an Automated Guided Land Vehicle (AGLV) comes over to take the data and by modelling serves as a carrier machine, by locating and avoiding workers (for safety reasons) and trees (for operating reasons). 5G is not currently widespread, especially in rural areas so it will not be used in this case.

**Manufacturing:**

- Factory of the Future, worker awareness, a safety-oriented deployment of a co-bot in relation with the human for ambient awareness, AR-assisted assembly process.

**Energy:**

- Smart grid management, here with 3 use cases, moving from reactive to proactive management; dispatchable EV charging AI assisted (notify drivers where to park in city and take energy from where lowest used on grid to power traffic lights or just stabilise network with battery of the car, find the best time and location for the grid to dispose excess energy).

### 4.1.5 Ingenious

**URL:** https://ingenious-iot.eu

**Duration:** September 2019, 36 months

**Ingenious :** Next-generation IoT solutions for the universal supply chain

**Description:** INGENIOUS aims to design and evaluate 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.

**PILOTS AND USE-CASES**

**Manufacturing:**

- Improved driver's safety with Mixed Reality and haptic solutions enables remote control transportation of goods with Automated Guided Vehicles (AGVs) thanks to tactile internet, edge computing and immersive enablers (Mixed-Reality (MR) engines, haptic gloves) so that employees will be safe, away from hazardous working locations such as fuel port terminals

**Transportation:**

- Transportation platforms health monitoring demonstrates that asset health tracking can lead to lower operational costs and higher asset availability with new data-based service provided by low-power edge distributed network and intelligent sensor modules installed in the transportation platforms. Privacy of sensor data and software updates dependability will be guaranteed with LoRa blockchain, componentised OS with tile-based HW architecture
- Inter-modal asset tracking via IoT and satellite technology aims to provide End-to-End (E2E) intermodal asset tracking with satellite connectivity for enabling enhanced real-time monitoring of shipping containers when sailing through oceans without connectivity to terrestrial IoT networks. Smart IoT gateways will be installed allowing interoperability between heterogeneous IoT tracking devices.

**Logistics:**

- Situational understanding and predictive models in smart logistics develops analytical and predictive models to estimate and optimise truck turnaround times for optimising the access and reducing the wait for vehicles at the port accesses, leading to corresponding savings on direct costs for carriers. Data will be collected from Broadband IoT cameras, Massive IoT sensors, trackers, PCS and AIS at the edge for data fusion and analytics.
- Supply chain ecosystem integration overcomes the absence of a virtual interoperability IoT and DLT layer that will be capable of securely and semantically exchanged information flows allowing to virtually access, manage, and deliver data along multiple IoT and DLT platforms.

### 4.1.6 TERMINET

**URL:** https://terminet-h2020.eu

**Duration**: November 2020, 36 months

**TERMINET:** NexT GeneRation Smart InterconnectEd IoT

**Description**: 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 virtualized edge-platform-cloud environment.

**PILOTS AND USE-CASES**

**Agriculture:**

- User-centric Devices in Smart Farming: In this use case. the goal is to optimise the performance and the scalability of the smart farming paradigm by utilizing new delay-sensitive devices such as AR/VR add-ons. Multi-collected and heterogeneous data coming from crops, livestock, or even better from mixed farming systems and coupled with AI capabilities is a promising approach that enhances agriculture systems' sustainability, boosts their production and diminishes risks by identifying systems vulnerabilities before they harm it.

**Healthcare**:

- Pathway of Personalised Healthcare: The aim is to provide a higher level of medical education to health practitioners, leverage diagnosis and improve patient satisfaction and safety.
- Group Training Surgery using VR-enabled IoT Technologies: In this use case, the understanding of treatment will be enhanced by efficiently providing a virtual training environment for medical personnel.

**Energy**:

- Smart, sustainable and efficient building management: In this use case, the aim is to transform buildings into smart buildings and optimize their energy consumption and harvesting.

**Logistics**:

- Prediction and Forecasting System for Optimising the Supply Chain in Dairy Products: The goal is to provide efficient supply chain forecasting, based on different types of production and sales data.

**Manufacturing**:

- Mixed Reality and ML Supported Maintenance and Fault Prediction in IoT-based Critical Infrastructure: This use case aims to reduce the operational costs of the end user and the burden of maintenance engineers.

## 4.2 Project Contributions Analysis

This section provides an overall analysis concerning Edge computing contributions provided by the projects described in section 4.1. The section starts with a summary of specific contributions per EU-IoT scope area, summarized in *Table 2* and provided by the projects.

*Table 2* shows that there are projects contributing to similar fields within each scope area, e.g., tactile Internet, AR/VR interfacing (interfaces). All projects address near Edge topics, in particular the integration of intelligence (ML) into hardware and software. Regarding near Edge, local AI decisions and decentralized learning are topics being addressed.

Regarding infrastructure, the most common topics concern integration with the 5G core and SDN/NFV orchestration aspects. As for data spaces topics, the common concern relates with semantic interoperability, involving the use of SAREF and WoT concepts.

Quantitatively (rf. to *Figure 7*), projects contribute with topics related with far Edge and data space (25% of the total contributions); 20% towards near Edge features; 15% towards infrastructure and data spaces' features.

*Table 2: Project contributions towards the scope areas of EU-IoT.*

| Project | Human/IoT interfaces | Far Edge | Near Edge | Infrastructure | Data Spaces |
|---|---|---|---|---|---|
| ASSIST-IoT | AR/VR, secure tactile support, novel smart wearable | Device/user Self-awareness, novel Far Edge gateway (ASSIST-IoT Far Edge node or Smart Device) | Intelligent IoT gateways, ASSIST-IoT Edge Node | 5G core integration, SDN and NFV all along the network, Multi-link connection | Edge data space based on semantic orchestration |
| VEDLIoT | - | ML integrated into open hardware to allow the support of more complex functions on the Edge | ML integrated into open hardware to allow the support of more complex functions on the Edge | - | - |
| IntellIoT | Tactile interface | Local AI decisions: distributed AI to assist learning from IoT data sources; offloading between near and Far edge | Intelligent offloading (e.g., due to energy consumption) between Near and Far Edge | 5G core; TSN on the Edge | WoT interoperability integrated |
| IoT NGIN | Tactile internet and intelligent ambient monitoring | - | Device or edge side intelligence<br>Supporting federated ML | 5G, D2D / improvements to resource management, VFN based on MANO; integration of federated AI into networking nodes; TSN interconnection for real-time application support | SAREF ontologies for data modelling |

| | | | | | |
|---|---|---|---|---|---|
| Ingenious | Tactile and immersive interfaces | Neuromorphic computing | Integration of the developed solutions with MEC | 5G core and VFN orchestration based on MANO; 5G TSN | Data virtualisation Layer to support the data exchange on highly heterogeneous data spaces interconnected via 5G |
| TERMINET | R/VR, tactile IoT, smart wearable devices | SDN interfaces to provide a better integration to the infrastructure; new Edge node based on open hardware acceleration and ML software integration | SDN-enabled vMEC | Private 5G RAN, SDN infrastructure | Semantic and abstraction mechanisms, data visualization |

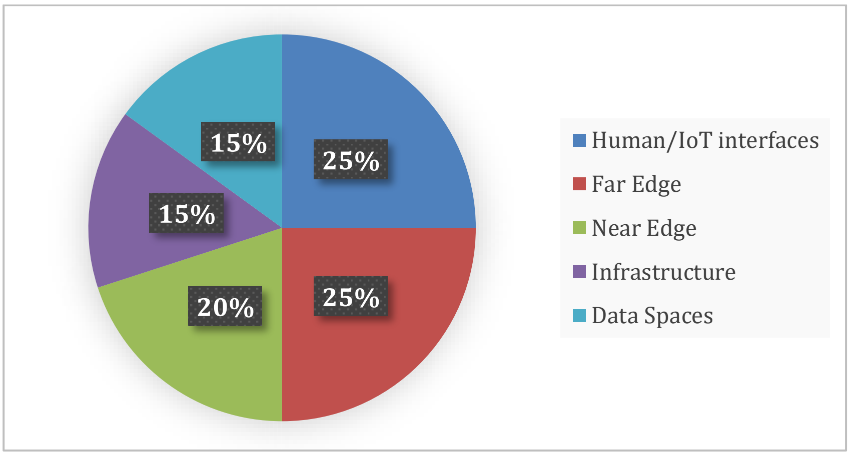


*Figure 7: Quantitative perspective of the contributions under development in the NGIoT flagship projects, for each EU-IoT scope area.*

In terms of domain applicability and expected use-cases or pilots per European competitiveness domain, a summary of the current contributions is depicted in *Figure 8*. Most contributions (23% of all pilots/use-cases provided by the projects) fall into Logistics and Manufacturing, followed by Transportation (15%) and Healthcare (11%).

The domains with a lower number of contributions are Smart Cities (4%) and Home automation (4%).

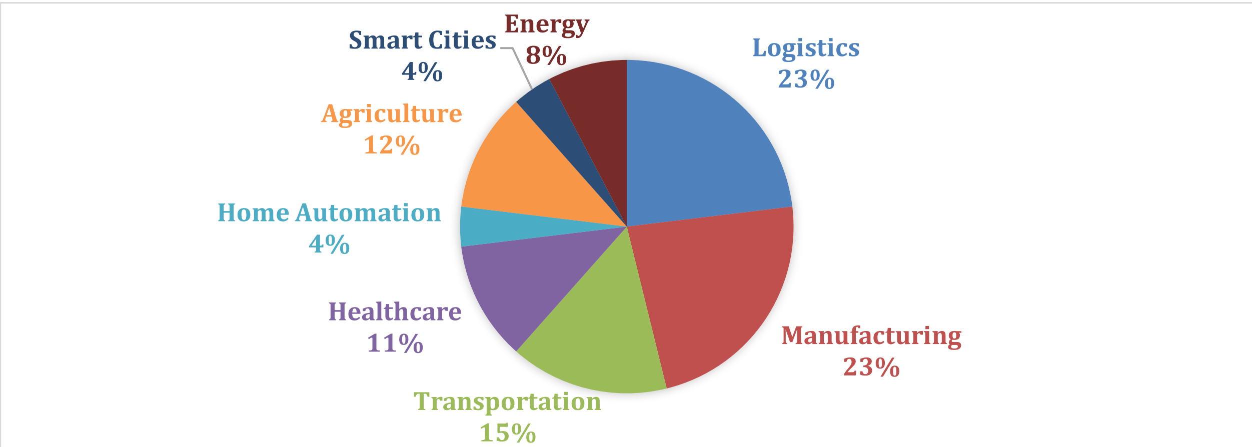


*Figure 8: Project contributions in terms of pilots/use-cases expected per European competitiveness domain.*

# 5 CURRENT EDGE STANDARDISATION DIRECTIONS

Based on input provided by each project, the starting point for expected contributions to **relevant SDOs** by each project is provided in Table 3. Pre-standardisation contributions are provided in Table 4. Relevant contributions are expected to SAREF, W3C as well as 3GPP and IEEE (Region 8). Additional efforts regarding standardisation contributions are being developed by the projects in the context of AIOTI, BDVA, 5GPPP and ITF.

*Table 3: Expected starting points for standardisation contributions by projects supported in EU-IoT.*

| Project | SAREF | W3C | ETSI | ISO | ITU-T | 3GPP | IEEE | IETF | RISC-V |
|---|---|---|---|---|---|---|---|---|---|
| ASSIST-IoT | Ontologies | | Use cases on STF601, ENI, MANO | | Monitoring, SG-13, SG-16, SG-17, SG-20, | interoperability, IoT | WGs focused on AI and Edge computing (IEEE SA), specially IEEEP2961 | Contributions to existing standards | |
| VEDLIoT | | | | | | | | | Open hardware focus: SPGA and accelerator development |
| IntellIoT | | W3C WoT, multi-agent system | | TC42 | | | TSN | | |
| IoT NGIN | Ontologies | | MANO, and M2M | | | IoT | TSN | | |
| Ingenious | | | | | | Collaborating with 3GPP on release 17 and beyond for the use of satellite 5G communications in IoT | | | |
| TERMINET | | W3C WoT | GS MEC 003 | Trusted Platform Module | | | | | |

*Table 4: Contributions to pre-standardisation and standards related associations/Fora.*

| Project | AIOTI | BDVA | 5G PPP/5G IA |
|---|---|---|---|
| ASSIST-IoT | Contributions to existing white papers on use cases and semantics and about “Beyond 5G”and collaboration with Standardisation WG | Member, Monitoring | Interoperability, Federated Learning |
| VEDLIoT | | | |
| IntellIoT | Contributions within the Standardisation WG | | Monitoring via partner liaison |
| IoT NGIN | | | |
| Ingenious | | | Expected contributions to the 5G TSN standard |
| TERMINET | Monitoring activities via associated partners | | |

# 6 SUMMARY AND FUTURE STEPS

This white paper provides a global perspective on recent developments in Europe concerning Next Generation IoT and Edge computing focusing on the EU-IoT scope areas.

The paper starts by assisting in defining common notions of "Edge" and provides an overview on different Edge computing architectures, then providing specific features of each concept in terms of the 5 identified EU-IoT scope areas: Human/IoT interfaces; far Edge; near Edge; infrastructure; data spaces.

The white paper then describes the key Edge computing research directions being taken by the six projects supported by EU-IoT (ICT-56 projects), providing a global perspective also in terms of domains and Edge use-cases that the projects expect to explore.

Finally, this white paper provides input concerning initial efforts being undertaken by the different projects regarding standardisation/pre-standardisation contributions.

Future work in EU-IoT concerning standardisation shall be focused in providing the projects with additional SDOs/pre-standardisation and associations interconnection, where the projects may be interested in contributing. Based on joint work developed with the projects, we shall develop a coordinated view on relevant standardisation efforts, and relevant Edge research guidelines towards SDOs.

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