Landscape Analysis

EGDE

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Technology	EDGE
Last update	2020-11-30
Status	draft
URL	https://documents.egi.eu/document/3699

DOCUMENT LOG

Issue	*Date*	*Comment*	*Author*
v0.1	2020-09-24	Initial Version	Enol Fernández
v0.2	2020-10-15	Review of sections 2, 3 & 4	Enol Fernández
v0.3	2020-11-27	Ready to review version	Enol Fernández
v0.4	2021-02-21	Final draft	Enol Fernández
v0.5	2021-03-12	Improved Executive summary	Diego Scardaci

TERMINOLOGY

For the purpose of this document, the following terms and definitions apply:

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", “MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119. For a complete list of term definitions see the EGI Glossary (http://wiki.egi.eu/wiki/Glossary).

Contents

Executive Summary

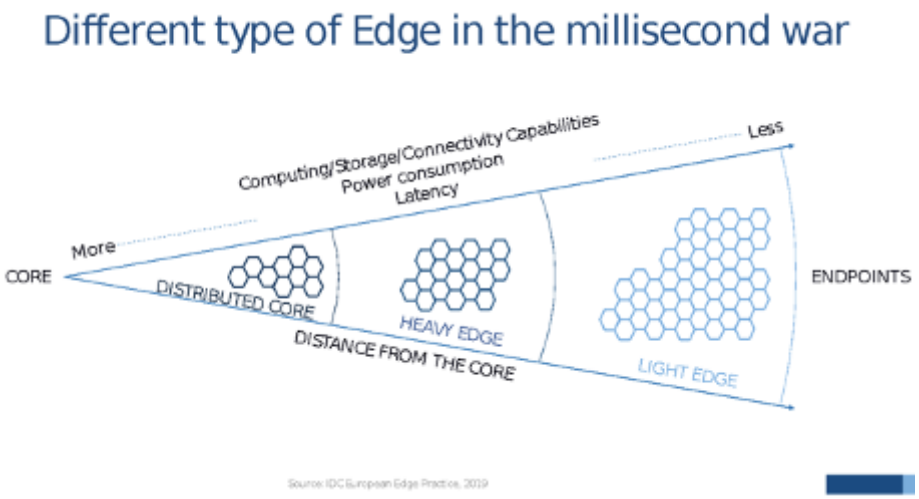
This document reports a landscape analysis of the edge computing area in relation to EGI e-Infrastructure. Edge computing is a distributed computing paradigm that brings computation and data storage closer to the network edge, thus improving response times and avoiding unnecessary data transfers. Edge covers any applications and computing devices running outside the traditional datacenter, from the less capable IoT-related computing processes to more powerful edge nodes and infrastructure that spans the space between the IoT devices and the cloud. This kind of computing near the location where it is needed is expected to increase significantly in the coming years, co-existing with cloud computing. This cloud-edge computing continuum is created by combining the ability of running smaller, localized applications at the edge with the high-capacity from the cloud. Modern edge relies on the use of virtualisation and container technologies at the edge to facilitate the deployment of a wide range of applications that run through multiple layers of the computational infrastructure (cloud and edge).

The report identified several use cases applicable to existing EGI communities that can be served by the Edge computing such as data collection from a large set of IoT devices, real-time analysis close to where the data has been generated, and automation of traditional manufacturing and industrial practices. An overview of tools and services to support Edge computing is presented, they have been classified in 4 main groups: (1) Generic computing on edge integrated with cloud platforms, (2) Edge managed-computing, (3) Generic applications at edge, and (4) Specialised applications at edge.

After depicting the current technology trends and the existing standardisation effort in the area, the document presents main relevant partners and projects (chapters 7 and 8) and possible integration scenarios in the EGI infrastructure. The EGI Cloud Federation can become a component of the cloud-edge continuum sitting in between the central massive clouds and the edge servers and devices forming a distributed cloud or distributed core reinforcing its capacities to provide a common approach to manage computing power and data across multiple distributed datacenters. The EGI Cloud Federation can also integrate Generic computing on Edge management platforms acting as a hosting platform both for the central/management and the edge services of these tools.

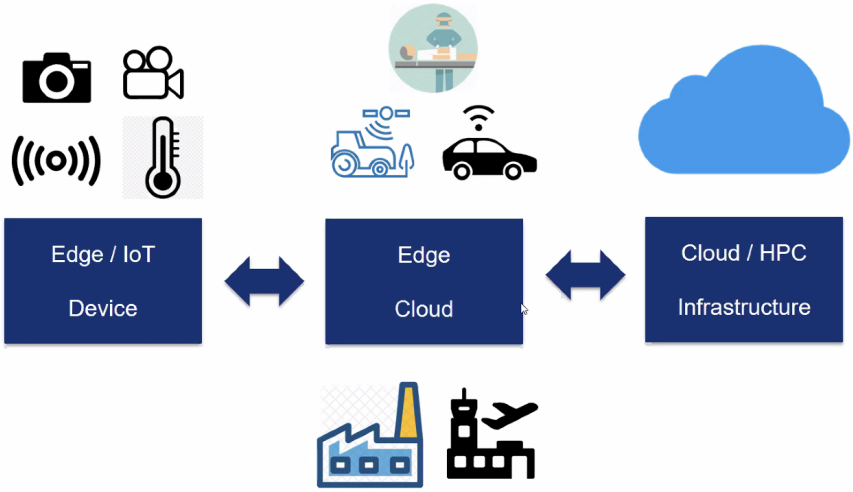
1 Introduction

Edge computing, according to wikipedia, is a *distributed computing paradigm that brings computation and data storage closer to the location where it is needed, to improve response times and save bandwidth*[1]. Edge is normally a term used to cover any computing happening outside the cloud (and probably at the edge of the network): cloud computing operates on big central data centers, edge operates on everything else. Processing and storing data closer to their source (at the edge) brings as main advantages the reduced latency and network usage, and the increased data security and governance. IoT (Internet of Things) is often related to the edge. IoT refers to *the network of physical objects—"things"—that are embedded with sensors, software, and other technologies for the purpose of connecting and exchanging data with other devices and systems over the internet*[2].



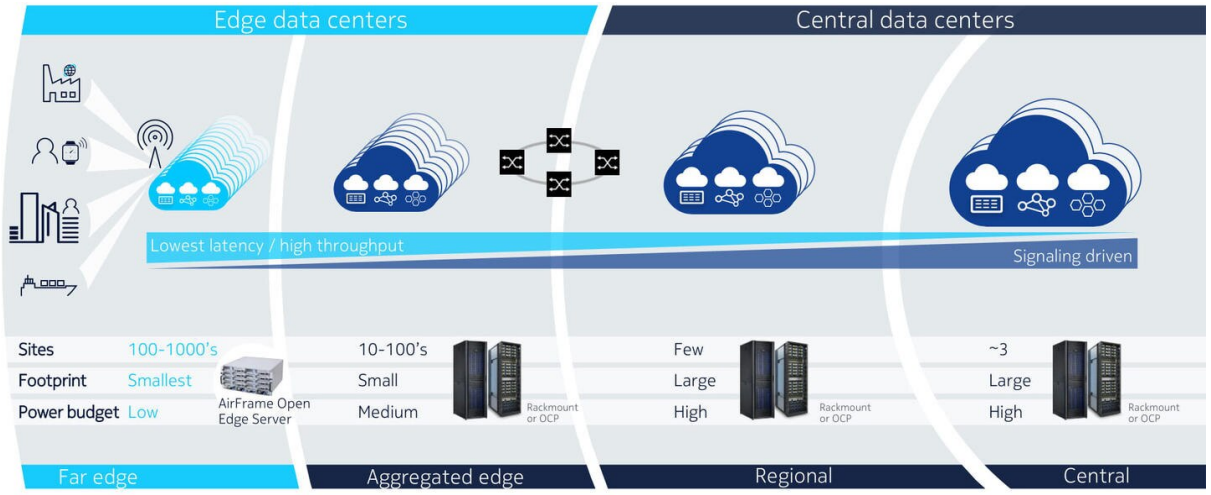
The edge computing paradigm focuses on enabling localized data processing, and thus it is related to a wide number of use cases and market segments. Depending on the scenario and related demands, different levels of edge may be involved in the continuum from the cloud core, to the devices at the edge of the network, including user's devices (such as mobile phones). Thus there are different types of edges in this continuum, with different computational capacity, power consumption and network latency.

[1] https://en.wikipedia.org/wiki/Edge_computing
[2] From Wikipedia: https://en.wikipedia.org/wiki/Internet_of_things



Source: IoT and Edge Computing Rolf Riemenschneider, Head of Sector, IoT, DG CONNECT, European Commission (IoT and Edge Computing: Future directions for Europe Workshop)

The European Commission uses the terms Edge/IoT Device and Edge Cloud for the different types of computing in the edge-cloud continuum.



Source: Nokia https://www.nokia.com/networks/solutions/edge-cloud/

This document is organised as follows. It introduces the main concepts behind edge computing (chapter 2) and describes several use cases applicable to existing EGI communities (chapter 3). These introductory chapters are followed by an analysis of the services and tools to deliver edge capabilities (chapter 4), the current technology trends (chapter 5) and the existing standards in the area (chapter 6). The report also includes the main relevant partners and projects (chapters 7 and 8) and possible integration scenarios in the EGI infrastructure (chapter 9).

1.1 Terms

Some common terms used to describe the different types of computing in the edge-cloud continuum area:

- **Cloud:** hyper-scale, public clouds and private clouds deployed in data centers on-premises and off-premises.
- **5G network:** 5G is the fifth generation technology standard for broadband cellular networks, which cellular phone companies began deploying worldwide in 2019. During the transition to 5G, many public network providers are expanding their infrastructures to include general-purpose computing services. The edge network itself is potentially multitiered and composed of regional data centers, central offices and hub micro-data centers. Telcos are transforming these tiers in their core network to host application workloads using cloud technologies within the network edge.
- **Edge servers:** servers, gateways and controllers acting as edge servers are often deployed in factories, warehouses, hotels and retail stores to provide local compute capacity for operations. These resources may or may not be clustered, but still support critical business processes.
- **Edge devices:** the number of devices that contain enough computational capacity to do work is growing rapidly. These devices commonly have sufficient CPU power, RAM and local storage to run Linux.
- **IoT devices:** most traditional IoT devices are closed, fixed-function devices. They are typically integrated with sensors for collecting data that is transmitted upstream to other aggregation points — traditionally the cloud.
- **Mobile devices:** mobile devices play an important role in edge networks. They are distinct from other edge devices because they typically belong to an individual who assumes personal responsibility for them. Mobile devices that run iOS or Android operating systems may refuse to run container software that was not acquired through their app stores.
- **Fog computing:** Fog computing is a layered model for enabling ubiquitous access to a shared continuum of scalable computing resources. The model facilitates the deployment of distributed, latency-aware applications and services, and consists of fog nodes (physical or virtual), residing between smart end-devices and centralized (cloud) services. The fog nodes are context aware and support a common data management and communication system. They can be organized in clusters - either vertically (to support isolation), horizontally (to support federation), or relative to fog nodes latency-distance to the smart end-devices.

2 Demand, use cases and fields of applicability

Any research disciplines that gather data from remote sensors in the physical world will benefit from edge computing, common examples are environmental sciences, agriculture and life sciences. Specially for those disciplines where sensitive data is collected (e.g. medical data from patients) the edge can bring additional data security and policy compliance.

IoT is specially relevant for industry - there is a specific acronym IIoT (Industrial internet of things) - and can be used to control and analyse industrial processes. IIoT is used in manufacturing, energy management, digital twins and many others. Latency and data security are specially relevant here too.

Predictions claim that 80% of the computing in the coming years will move to the edge, with 20% still at the central cloud, so demand is likely to increase.

2.1 Use cases

2.1.1 Data Collection and (Real-time) Analytics

Edge computing can help whenever there is data collection from a large set of IoT devices: it avoids sending data over limited network connections to the central cloud which may not be responsive enough. IoT devices can also produce massive amounts of data that cannot be moved in a cost-effective manner to the central cloud and need to be analysed near the source. The central cloud would probably just receive some condensed information/reduced data. Real-time analytics that need to have processing done near the data sources are also suited for edge computing.

Existing EGI communities/projects

- ENVRI-FAIR: according to ENVRI+ D8.4 "Interoperable cataloguing and metadata harmonisation for environmental RIs: prototype"[3], there is some further work to be done to reduce network usage and movement of data and perform processing at the nodes. "This plays into the European agenda for future cloud computing including Fog and Edge computing. Further work in the ENVRI community – partly in the project ENVRI-FAIR – will address these issues."
- In general those communities/e RIs with extensive sensor networks and technology that needs to be connected to the broader e-infrastructure are susceptible to adopt edge computing technologies (EMSO, LifeWatch).
- Plant phenotyping (e.g. https://emphasis.plant-phenotyping.eu/) may require edge-computing capabilities.

[3] http://www.envriplus.eu/wp-content/uploads/2015/08/D8.4-Interoperable-cataloguing-and-metadata-harmonisation-for-environmental-RIs-prototype-.pdf

2.1.2 Industry 4.0

The Fourth Industrial Revolution (or Industry 4.0) is the ongoing automation of traditional manufacturing and industrial practices, using modern smart technology. Large-scale machine-to-machine communication (M2M) and the internet of things (IoT) are integrated for increased automation, improved communication and self-monitoring, and production of smart machines that can analyze and diagnose issues without the need for human intervention.

The amount of data processing and computational power needed to support these technologies is increasing by orders of magnitude. Many applications move the data from the factory floor to a public or private cloud, but in many cases the latency impacts and transmission costs can lead to disruptions on the assembly line. To fulfill the high performance and low latency communication needs, at least some of the data processing and filtering needs to stay within the factory network, while still being able to use the cloud resources more effectively. Further processing of the data collected by various sensors is done in the centralized cloud data center. Reusable portable microservices located at the edge nodes fulfill tasks that are part of new vision applications or deep learning mechanisms.

Existing EGI communities/projects

- DIGITbrain seeks to support cloud/fog/edge computing for industry.
- StarwAI will enable AI into the cloud/fog/edge computing.
- EUHubs4Data links with IDSA that's referred to as relevant for edge.
- BD4NRG will deliver reference architecture for Smart Energy providing "full interoperability of leading-edge big data technologies with smart grid standards and operational frameworks".

2.1.3 Security / Compliance requirements / Privacy

Edge computing offers the ability to move security elements closer to the originating source of data, enables higher performance security applications, and increases the number of layers that help defend the core against breaches and risk. It would help to meet compliance requirements, like geofencing, data sovereignty, and copyright enforcement. Restricting access to data based on geography and political boundaries, limiting data streams depending on copyright limitations, and storing data in places with specific regulations are all achievable and enforceable with edge computing infrastructure. Edge can also provide extra privacy, for example, medical applications that need to anonymize personal health information (PHI) before sending it to the cloud.

Existing EGI communities/projects

- Communities and projects dealing with sensitive data that should not leave premises or with strong regulations:
    - Health-related cases: BBMRI, ELIXIR, LETHE, HealthyCloud.
    - Policy-related cases: AI4PublicPolicy.

3 Available tools/services

3.1 Generic computing on edge integrated with cloud platforms

Cloud hyperscalers provide platforms and tools that enable execution of any kind of applications on the edge by either installing some software that makes the edge server/device visible and manageable from the cloud or by providing a complete edge server/device that can be deployed at the location. Besides hyperscalers, other vendors provide similar solutions to manage the edge devices from a central location.

Technology	License	Description	Origin
Azure IoT Edge	OS + Proprietary	Enables execution of containers at edge devices managed in Azure	US
AWS IoT Greengrass	Proprietary	Execute Lambda functions and container at edge devices	US
AWS Outposts/Snow family	Proprietary	Extend AWS to on-prem (Outposts), devices with storage + compute to deploy on edge (Snow)	US
GCP Anthos	Proprietary	Hybrid cloud to extend GCP to on-prem or other clouds	US
NuvlaBox	OS	NuvlaBox software turns any ARM or x86 single board computer into a smart edge device, managed from Nuvla.io.	CH
ZEDEDA	OS/Proprietary	Cloud-based IoT edge orchestration solution that delivers visibility, control and security for the distributed edge with the freedom of deploying and managing any app on any hardware at scale and connecting to any cloud or on-premises systems. With ZEDEDA customers can seamlessly deploy and manage any edge compute node to instantly unlock the value of IoT data and make real-time decisions.	US

3.2 Edge managed-computing

These are services that allow users to run applications on a managed-edge infrastructure.

Technology	License	Description	Origin
CloudFare Workers	Proprietary	Serverless code deployed at CDN locations of cloudfare	US
Equinix	Proprietary	Datacenter company offering several edge computing capabilities (metal IaaS and NFV)	US
AWS Wavelength	Proprietary	AWS computing services at edge locations (5G). Capable of creating VMs, volumes, VPCs plus related services.	US

3.3 Generic applications at edge

Cloud/Edge platforms can be installed into edge servers/devices and allow for execution of generic applications. Some of these are adapted from generic cloud solutions to play nicely with edge computing environments.

Technology	License	Description	Origin
OpenStack	OS	Cloud Management Framework with dedicated working group for Edge	Global
OneEdge	OS	OpenNebula initiative for edge. Good contacts with GAIA-X.	EU
StarlingX	OS	StarlingX is a complete cloud infrastructure software stack for the edge used by the most demanding applications in industrial IOT, telecom, video delivery and other ultra-low latency use cases.	Global
EVE	OS	The Edge Virtualization Engine (EVE) combines a type-1 hypervisor (currently Xen) with a hardened root-of-trust operating system that provides a runtime for edge containers.	US

Akraino	OS	This open source software stack provides critical infrastructure to enable high performance, reduce latency, improve availability, lower operational overhead, provide scalability, address security needs, and improve fault management.	US

3.3.1 Kubernetes at edge

Kubernetes has become the de-facto standard for container orchestration. It provides powerful primitives to handle any kind of container-based application on a set of hosts (VM or bare metal). Several projects exist to adapt Kubernetes to run or to integrate edge devices mostly by reducing the footprint of a full-blown Kubernetes distribution.

Technology	License	Description	Origin
K3s	OS	Lightweight Kubernetes distribution meant to be run at the edge.	US[4]
KubeEdge	OS	KubeEdge is an open source system for extending native containerized application orchestration capabilities to hosts at Edge	Global (CN)
OpenYurt	OS	An open platform that extends upstream Kubernetes to Edge	Global (CN)
k0s	OS	K0s is a lightweight distribution with a full set of features but with very lightweight installation.	Global

3.4 Specialised applications at the edge

Applications that run on the user-managed edge devices/servers and deliver specific features

Technology	License	Description	Origin
AlwaysAI	Proprietary	Computer-vision focused applications that can be installed on edge devices	US
FogHorn Edge AI	Proprietary	Deliver ML and AI capabilities at edge devices/servers with cloud integration	US

[4] Rancher is now part of SUSE, which is an German company

4 Analysis on the current adoption and usage of the technology

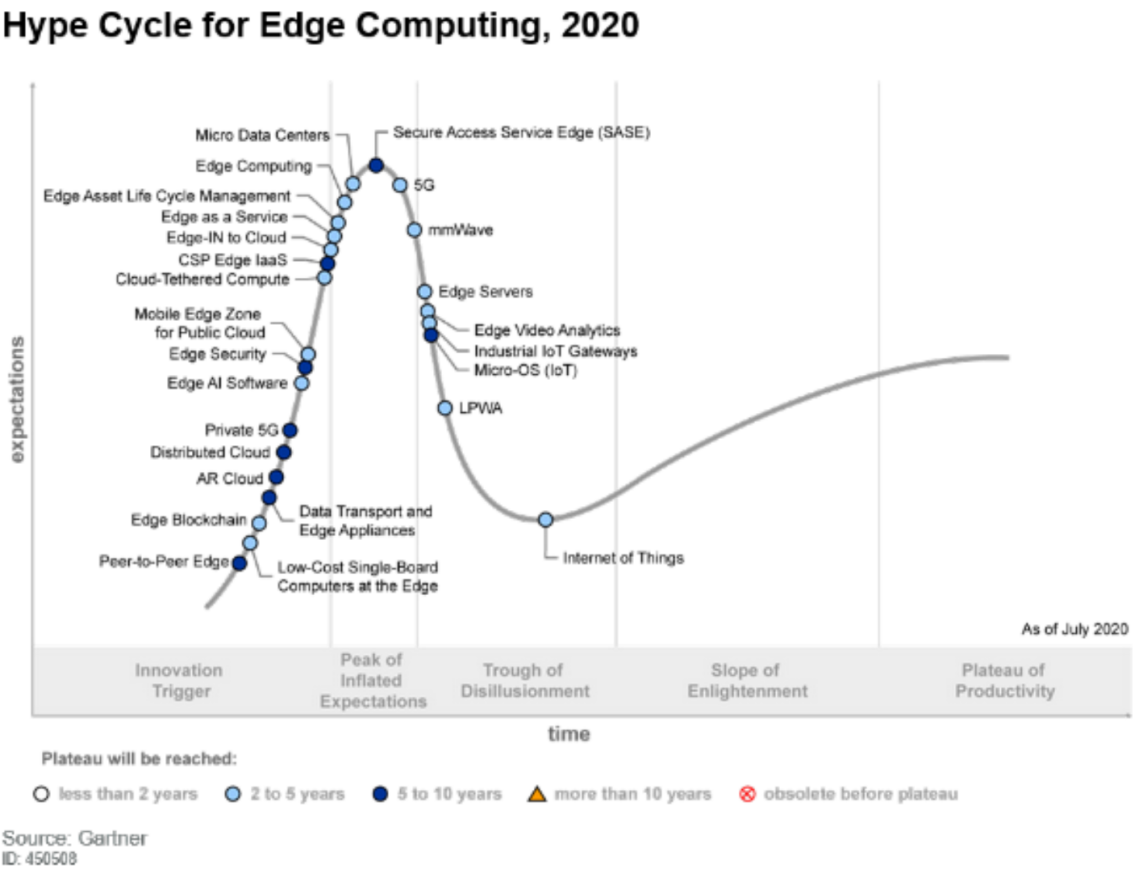
The move of computing towards the edge is expected to increase in the coming years, Gartner predicts 75% of the enterprise-generated data will be created and processed outside a traditional centralized data center or cloud[5]. Gartner also includes “The empowered edge” as one of the top 10 strategic technology trend for 2021[6]. “The distributed cloud” which can be considered some sort of edge is also listed in the Gartner report as a trend for 2021.

Forrester predicts a increase of the edge cloud service market by 50%[7], with the hyperscalers, telcos, platform providers, CDNs, and data center colocation providers will offer edge-oriented IaaS and PaaS.

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

[6] https://www.gartner.com/smarterwithgartner/gartner-top-10-strategic-technology-trends-for-2020/

[7] https://www.redhat.com/cms/managed-files/forrester-edge-computing-2020-predictions-analyst-material-f24304-202006-en.pdf



According to Gartner, the technologies and models expected to mature over the next two to five years include:

- Edge AI software
- Edge video analytics
- Cloud-tethered compute
- 5G
- Edge as a service
- Edge-IN to cloud

Containers and Kubernetes are the basis of many of the Open Source solutions targeting edge computing specially to provide generic computing capabilities.

5 Standardisation activities & policies

The edge computing ecosystem is still very dynamic with many new initiatives from various organizations and companies. There is no industry standard agreed as yet covering all aspects of edge computing. Standards bodys, open source initiatives and industry alliances are active in this area.

The Multi-Access Edge Computing (MEC) specification[8] is particularly relevant for edge computing in telecom operators offerings (e.g. delivering 5G). There is a recent harmonisation effort[9] between ETSI and 3GPP[10]. ETSI MEC is currently studying MEC federations to enable shared usage of MEC services and applications across MEC systems in support of a multi-operator / multinetwork / multi-vendor environment.

Remote execution of Data Apps in data sources by Data Consumers is contemplated in the IDSA Reference Architecture Model[11]. This can be considered a form of edge computing if the Data Provider is located at the edge of the network (e.g. being an edge server/edge device).

LF Edge[12] is an organization that aims to establish an open, interoperable framework for edge computing independent of hardware, silicon, cloud, or operating system. Closely related to the CNCF (Cloud Native Computing Foundation), it brings several projects related to edge computing together.

OpenStack has a dedicated group on edge computing[13] with a list of use cases[14] and reference architectures[15].

OGC has developed a white paper on "The Role of Geospatial in Edge-Fog-Cloud Computing"[16]. This may be relevant to communities relying on Earth Observation data/processing at the edge.

There are also IoT-related standards, that may not be fully relevant to EGI or applicable to edge computing in general:

- ISO/IEC 30141:2018 Internet of Things (IoT) — Reference Architecture
- ITU-T Y.4460 Architectural reference models of devices for Internet of things applications

6 Relevant partners in the field

The lists in this section should not be considered exhaustive. They mainly show potential relevant partners for EGI that have been currently identified.

6.1 Major technology providers

[8] See https://www.etsi.org/committee/1425-mec
[9] See https://www.etsi.org/images/files/ETSIWhitePapers/ETSI_wp36_Harmonizing-standards-for-edge-computing.pdf
[10] See https://www.3gpp.org/
[11] https://www.internationaldataspaces.org/wp-content/uploads/2019/03/IDS-Reference-Architecture-Model-3.0.pdf
[12] See https://www.lfedge.org/
[13] https://www.openstack.org/use-cases/edge-computing/
[14] https://wiki.openstack.org/wiki/Edge_Computing_Group/Use_Cases
[15] https://wiki.openstack.org/wiki/Edge_Computing_Group/Edge_Reference_Architectures
[16] http://docs.opengeospatial.org/wp/18-004r1/18-004r1.html

Partner	Expertise	Tools
OneEdge	OpenNebula applied to the EDGE	OneEdge
Sixsq	Developers of Nuvla.io and Nuvlabox	NuvlaBox
OpenStack	OpenStack edge-tailored solutions	OpenStack
Kubernetes	Kubernetes is a container orchestration framework that can be adapted to edge	Kubernetes

6.2 Interested partners of the EGI Federation

Partner	Expertise	Tools
SZTAKI	Developer of MICADO, to be extended to edge in DIGITBrain	MICADO

6.3 Involvement of other e-infrastructures

e-Infrastructure/ Partner	Expertise	Tools
FIWARE	Open Source platform components for smart solutions, including ege	FIWARE

7 Projects, Initiatives and partnerships

7.1 Current EGI Projects

Project	Relation to edge
DIGITBrain	The DIGITbrain project aims to enable customised industrial products and to facilitate cost-effective distributed and localised production for manufacturing SMEs, by **means of leveraging edge-, cloud- and HPC-based modelling, simulation, optimisation, analytics, and machine learning tools** and by means of augmenting the concept of digital twin with a memorising capacity towards a) recording the provenance and boosting the cognition of the industrial product over its full lifecycle, and b) empowering the network of DIHs to implement the smart business model "Manufacturing as a Service".

BD4NRG	The project is starting in January 2021 with a duration of 3 years, and has as objectives: ● deliver a reference architecture for Smart Energy, which aligns BDVA SRIA, IDSA and FIWARE architectures, SAREF standard and extend COSMAG specification to enable B2B multi-party data exchange, while **providing full interoperability of leading-edge big data technologies** with smart grid standards and operational frameworks ● evolve and upscale a number of TRL 5-6 technology enablers, such as scalable sovereignty preserving hybrid DLT/off-chain data governance, big data elastic pipeline orchestration, **IoT/edge AI-based federated learning** and multi-resource sharing tokenized marketplace, loosely integrate and deploy them within the TRL 7-8 BD4NRG framework ● validate such framework through the **delivery of predictive and prescriptive edge AI-based big data analytics** on 13 large scale pilots, deployed by different energy stakeholders (TSOs and DSOs power network operators, aggregators, storage/renewable assets operators, local energy communities, ESCOs, power market operators, municipalities, financial institutions and ENTSO-E), fully covering the energy value chain
StarwAI	The StairwAI project targets low-tech users with the goal of facilitating their engagement on the AI on-demand Platform. This will be achieved through a new service layer enriching the functionalities of the on-demand platform and containing: (1) a multi-lingual interaction layer enabling conversations with the Platform in the user's own language, (2) a horizontal matchmaking service for the automatic discovery of AI assets (tools, data sets, AI experts, consultants, papers, courses etc.) meeting the user business needs and, (3) **a vertical matchmaking service that will dimension and provision hardware resources through a proper hardware provider (HPC, Cloud and Edge infrastructures).**

7.2 Other projects

Project	Relation to edge
Elastic	ELASTIC has the three main objectives: 1. ELASTIC will develop a software architecture incorporating a new elasticity concept, that will enable smart systems to satisfy the performance requirements of extreme-scale analytics workloads. The new elasticity concept will efficiently distribute the workloads across the

	compute continuum, whilst guaranteeing real-time, energy, communication quality and security non-function properties inherited from the system domain. 2. The vision of ELASTIC is that by extending the elasticity concept across the compute continuum in a fog computing environment, combined with the **usage of advanced hardware architectures at the edge side**, can significantly increase the capabilities of the extreme-scale analytics integrating both responsive data-in-motion and latent data-at-rest analytics into a single solution. 3. ELASTIC will consider a realistic yet visionary smart mobility use-case, which will elaborate of huge amounts of data coming from a large set of IoT sensors distributed along the Florence tramway network. ELASTIC will adopt a very innovative federated/distributed fog architecture, supporting elasticity across the compute continuum whilst fulfilling real-time, energy, communication and secure properties.
mF2C	The mF2C sets the goal of designing an open, secure, decentralized, multi-stakeholder management framework, including novel programming models, privacy and security, data storage techniques, service creation, brokerage solutions, SLA policies, and resource orchestration methods. The proposed framework is expected to set the foundations for a novel distributed system architecture, developing a proof-of-concept system and platform, to be tested and validated in real-world use cases, as envisioned by the industrial partners in the consortium with significant interest in rapid innovation in the cloud computing sector.
SynchroniCITY	Building upon a mature European knowledge base derived from initiatives such as OASC, FIWARE, FIRE, EIP-SCC, and including partners with leading roles in standardization bodies, e.g. ITU, ETSI, IEEE, OMA, IETF, SynchroniCity will deliver a harmonized ecosystem for IoT-enabled smart city solutions where IoT device manufacturers, system integrators and solution providers can innovate and openly compete. With an already emerging foundation, SynchroniCity will establish a reference architecture for the envisioned IoT-enabled city market place with identified interoperability points and interfaces and data models for different verticals.

7.3 Other initiatives

Initiative	Description
IoT ESP projects	The Next Generation Internet of Things (NGIoT) initiative is a community of projects and related initiatives at work to maximise the power of IoT made in Europe. The link contains a list of IoT projects in the cluster
European Edge Computing Consortium	The European Edge Computing Consortium (EECC) aims at supporting small, medium-sized and large enterprises in Europe and all around the world to adopt related technologies and in particular with a focus on the augmentation of Operational Technologies (OT) with Information and Communication Technologies (ICT). Its mission is to drive adoption of the Edge Computing paradigm within the manufacturing and other industrial markets.

8 Integration scenarios in the EGI Infrastructure

8.1 EGI Cloud Federation as part of the cloud-edge continuum

As part of the cloud-edge continuum, EGI Cloud Federation can be considered sitting in between the central massive clouds and the edge servers and devices forming a distributed cloud or distributed core. As such, the EGI Cloud federation should reinforce its capacities to provide a common approach to manage computing power and data across multiple distributed datacenters with:

- Secure, high-performance global connectivity across sites.
- Distribution of applications and data across sites.
- Interoperability with edge standards for the execution of applications (e.g. providing Kubernetes APIs for application orchestration).
- Discovery and aggregation of sites and applications, allowing to manage and understand the computing and data assets available at each location.
- Improved definition and enforcement of security policies uniformly across sites (e.g. looking at OPA[17]).

EGI services can also provide some of the advantages of the edge computing:

1. Reduced latency and network usage as they allow moving computation to the data sources.
2. Data security and governance. EGI sites follow European regulations on data protection and some of them also have ISO 27000K certification.

[17] https://www.openpolicyagent.org/

8.2 EGI Cloud Federation integrated with edge management platforms

The EGI Cloud can act as a hosting platform for the technologies listed in the Generic computing on edge integrated with cloud platforms section, both for the central/management platform of the tool as for the edge services of these tools. As an IaaS, EGI Cloud can potentially host any of these platforms (although many of the edge-oriented tools may use non-x86 architectures which are not widely available in EGI providers).

EC3 can provide automatic deployment and automatic scaling of these platforms whenever it makes sense.