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Edge Computing and Post-Cloud Perspectives

Opportunities and implementations

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Overview

Today, large companies and public administrations are transforming themselves in order to exploit the value of data from various sources – sensors, complex machines/systems, human experts, environmental, etc. – gathered within the ecosystem created by their suppliers, customers, vendors and partners. At present, this business-generated data is mainly processed in the cloud. However, the exponential growth of such data raises the question of where it is to be stored and processed. For the cloud has several limitations: physical (latency, bandwidth, etc.), legal (data ownership and liability) and economic (transfer costs, storage, processing costs). Hence the emergence of edge computing, which is developing to meet these challenges. Edge computing enables data to be processed as close as possible to its source, either directly by the object itself that produces and captures the data (the car, telephone, etc.), or nearby in small local datacenters; in other words, on the periphery, or "edge", of the network. Edge computing, although not always directly linked to cloud computing, offers options that are complementary to it. Indeed, some edge computing solutions are completely independent of the cloud. The "post-cloud" era does not mean the decline of the cloud; far from it! But in this era, there will be an even faster growth in data stored and processed as close as possible to their source. Although the cloud continues to be the heart of the network, we already know that not all data will pass through it.

Edge computing is an architecture that provides **storage and processing capacity** at the edge with **analytical features**, **decentralised intelligence and automation**. This architecture makes it possible to take into account the issues of data sensitivity, cyber threat management, real-time management for very low latencies and local data management, and provides a response to issues of bandwidth or network connection, resilience and local decision-making management. However, edge computing projects will face several challenges in extracting value from various data sources, regardless of whether or not these are cross-referenced with one other: recovering data, managing it interoperably, maintaining network connectivity, ensuring optimal security, deploying on a large scale, managing complex systems and reducing the carbon footprint of digital technologies.

The participants in Cigref's "Post-cloud and edge computing perspectives" working group have listed the following criteria to be considered when assessing whether the best type of architecture for a particular service or use case is indeed an edge computing solution:

- benefit of using data locally versus in the cloud;
- latency time required;
- bandwidth required for connectivity;
- transfer costs;

- computing and processing capacity;
- safety constraints;
- data sensitivity;
- resilience;
- carbon accounting / carbon footprint.

Next, the participants recommended several steps for deriving maximum value from the implementation of the edge computing project, from a technical, economic and human point of view. These include:

- searching for and identifying the service or added value provided by the product;
- building robust business cases;
- determining key competencies for deriving value;
- supporting change related to edge projects and managing the impact of such projects on the organisation and its employees through the implementation of strong governance. The importance of data availability and quality requires all teams to adopt a "technology and data" mentality.

This report – a summary of the findings of Cigref's "Post-cloud and edge computing perspectives" working group – is intended for all employees who wish to gain a better understanding of this subject in order to be able to identify possible implementations of edge computing as applied to processes, services or customer offers.

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Context & definitions

As they seek to become more agile and innovative, large companies and public administrations are upgrading their Information System (IS) by opening up their enterprise architecture to their internal teams and their ecosystem (suppliers, customers, vendors, partners, etc.). They started this open process several years ago, using the various cloud computing services. **Cloud computing** is the use of computer servers dispersed throughout a network to store data in a distributed manner or to exploit it. Cloud computing enables the industrialisation and massification of the information system, and thus provides opportunities for scale effects and pay-per-use billing. For the foreseeable future, the cloud and datacenters will be essential, and will continue to grow rapidly to meet the demand for services, applications and storage space.

The production of data is increasing at a dizzying rate, and this phenomenon is set to accelerate all the more because the vast majority of this data will soon no longer be created by humans, but by objects and machines, in real time. According to Atos, by 2025, 30% of the data produced will be real-time data. We are therefore now entering a transitional phase with regard to data exploitation. While cloud computing has made it possible to organise data processing centrally and remotely in huge datacenters, edge computing offers a data computing, storing and processing architecture that is **distributed at the edge of the network**, i.e. on servers or datacenters belonging to the company or to a service provider, geographically close to their production site. Edge computing therefore ensures that data is processed close to the components and information sensors that generate it, thus reducing traffic to the cloud or data centres and minimising information processing time. Developments in 5G and IoT technologies, and AI tools such as machine learning and computer vision – including video analytics – accelerate the adoption of edge computing by facilitating its implementation and operational processing.

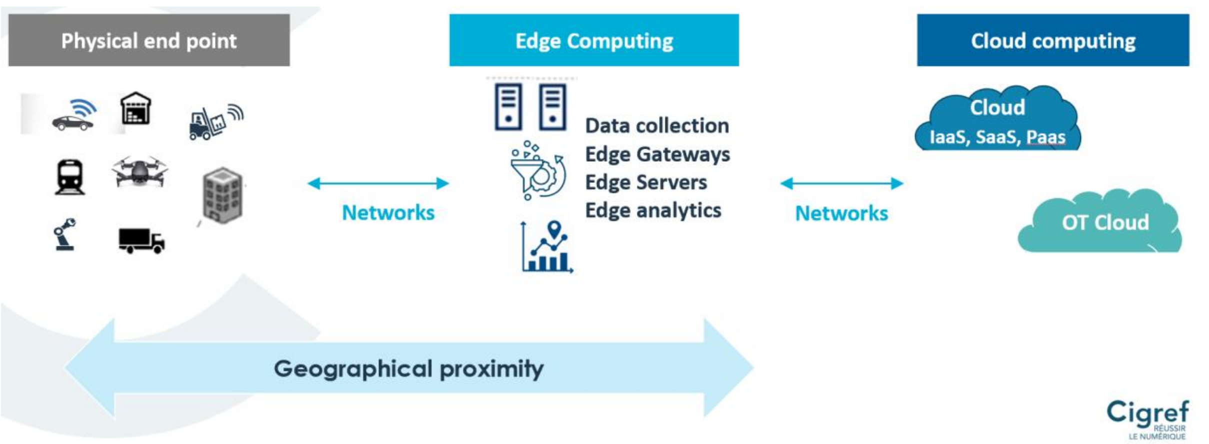

Figure 1: edge computing versus cloud computing – source: Cigref

The term “fog computing” is also used to refer to mini datacenters used for local data processing, and the network and cyber infrastructure located between edge computing and cloud computing in order to optimise the use of bandwidth and the speed at which information is processed securely.

In summary, although the cloud continues to be the heart of the network and provide storage, processing and services, we already know that not all data will transit through it. Data that does not go to the cloud will be processed closer to its source, either directly by the device itself that produces and captures the data (the car, the telephone, etc.), or close to it by base stations or small local data centres – in other words, on the edge of the local network. This is the principle on which edge computing is based.

Introduction

Companies are exploring the new opportunities offered by the digital world in response to the many forms of disruptions and the rapid rate of transformation in business models in the digital era. They are transforming to capitalise on their data, establish partnerships and reinvent business models, as already emphasised by the Cigref foundation and the working groups in their summary model of "The Digital Company in 2020"[1], published in 2015.

After **mechanisation**, during the first industrial revolution, **electrification**, with the second industrial revolution, and **robotics and IT**, during the third industrial revolution, we now come to the fourth industrial revolution, which offers **interoperability between the physical worlds and the digital world** with data processing (IoT, AI, Machine Learning, Big Data, Sensors, bots, video tech, etc.). Indeed, many sites, tools, services, etc. are equipped with sensors and smart objects or systems that are digital resources, despite the fact that some are not always perceived as such.

To promote business innovation, service customisation and process improvement, large companies and public bodies are seeking to leverage data produced in real or non-real time, internally or within their ecosystem (suppliers, customers, vendors, partners, etc.). Using this data, companies can adapt to new working practices and changing behaviours, meet new customer expectations and prepare for the challenges of tomorrow's markets. Processing such data from various sources requires specific characteristics, particularly in terms of latency[2], security and the need to manage them locally. And the cloud, despite providing agile infrastructures and technological support for these businesses, does not always meet these needs.

The media often talk about edge computing in relation to smart cars or Industry 4.0, but the potential offered by edge computing is much greater. Edge computing architecture combines several characteristics: **information** on connected objects and systems, **intelligence** with science management data, **automation** – immediate analysis, decisions and actions – and **agility** – flexibility and adaptability of teams.

The first part of this report (a summary of the Cigref working group's year-long work on "Post-cloud and edge computing perspectives") presents various typical use cases of edge computing with the benefits obtained. The second part specifies the challenges of edge computing. Finally, the participants of the working group make recommendations on its implementation. This report is intended for all employees who wish to gain a better understanding of this subject in order to be able to identify possible implementations as applied to processes, services or customer offers.

[1] https://www.cigref.fr/lentreprise-2020-a-lere-numerique-enjeux-et-defis
[2] Round-trip travel time

1. Use cases of edge computing

It is unthinkable that today (or even tomorrow) it could be possible to send all the data produced by the components or systems connected in the cloud, given the bandwidth and storage space required, the necessary response times and the desire to meet the challenges of “digital sobriety”. Hence the emergence of edge computing, which provides answers to the limits of the cloud and enables the exploitation of data generated by objects or systems connected to the periphery of the network, as close as possible to the source of the data. This chapter shows various typical use cases in which edge computing is beginning to take hold.

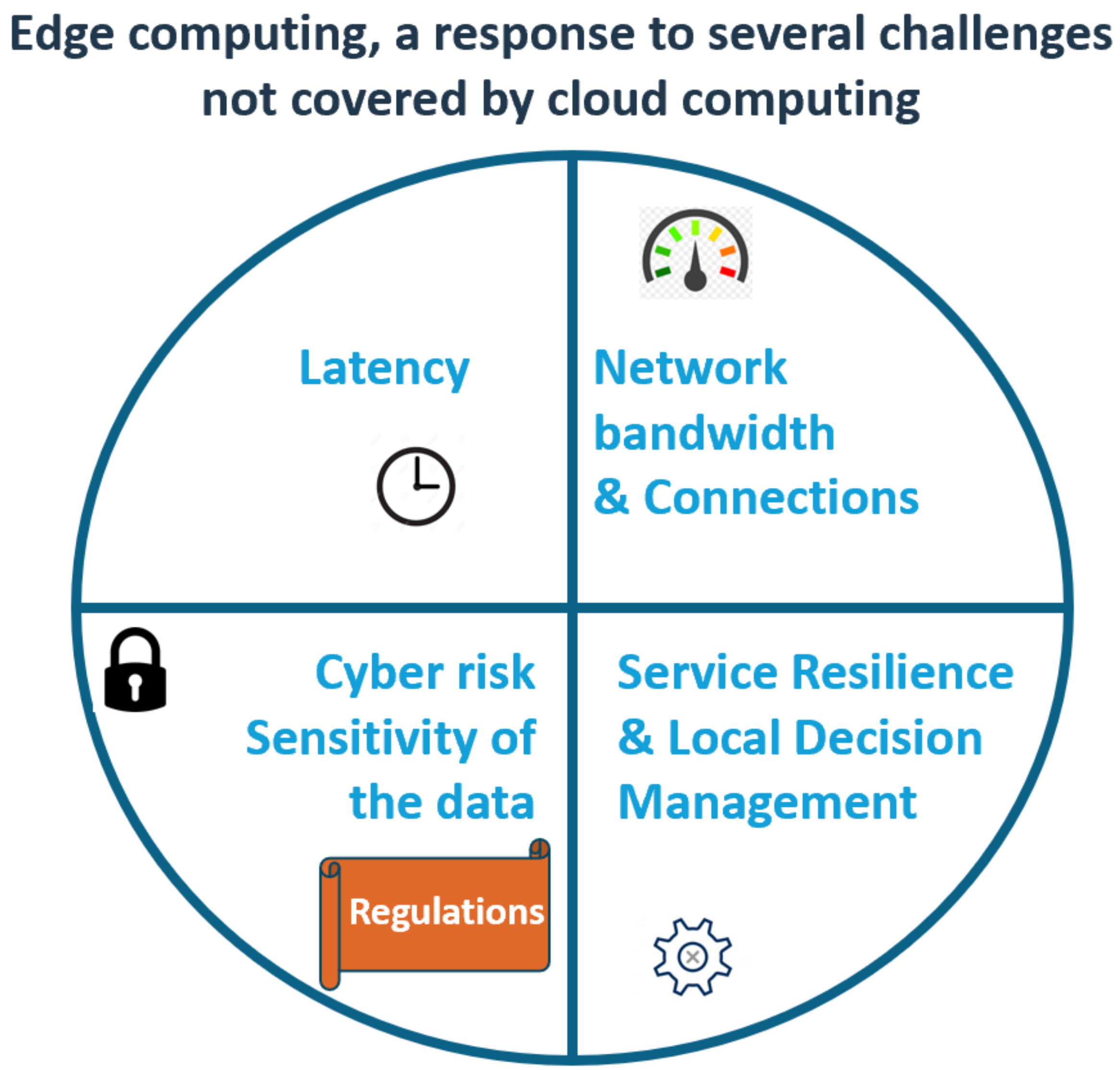

Figure 2: edge computing’s response to the challenges of cloud computing – source: Cigref

1.1. Data sensitivity management & protection against cyber threats

Edge computing reduces data traffic by processing data in the place where it is generated. Critical or sensitive data, while remaining local, is secure and/or is not subject to the same regulations as data stored in the cloud (e.g.: extraterritorial laws such as the US Cloud Act and the Cybersecurity Law).

In this way, edge computing provides a response to the growing challenge of data control, especially for European companies, as some companies do not want sensitive or personal data regulated by the GDPR to leave the company or entity. They can then choose to process or store the data internally to avoid data leaks. For example, contactless access control is an example of a rapidly-growing use case that meets GDPR regulations and has experienced a growth in demand as a result of the Covid-19 crisis. Facial recognition checks are carried out using several cameras. Companies prefer to store this personal information on site wherever possible.

Finally, edge computing fragments the risk of a failure affecting the company's cloud computing service. The **security of data and data processing** is enhanced because of the lack of central storage. With edge computing, a company operating several production sites increases its chances of guaranteeing continuity of service by distributing operations to the edge of the network.

1.2. Real-time management: latency issues

The response time of the cloud is proving insufficient for certain applications or services, and therefore poses the problem of cloud latency. In addition to the physical limitations, there are also economic limitations that result in excessive transfer, storage and processing costs. Edge computing addresses this by increasing capacity at the edge with decentralised analysis, processing and intelligence capabilities: edge processing avoids latency and allows real-time decision making. In this way, the behaviour of a machine or object can be adapted within the required timescale, and corrective measures are taken in real time in the event of a failure or danger. For example, on an industrial production line, edge computing is used to manage/supervise certain machines or equipment because it offers a computing capacity at line level that ensures real-time responses. One of the advantages of edge computing is the **speed of information processing**, especially for critical data.

Some services also require real-time exchange of information because the resulting decisions cannot be postponed. Consider, for example, a self-driving car that detects an obstacle on the road and must make the right decision in real time to avoid an accident.

Another example concerns companies implementing an accident detection solution for isolated workers with on-site processing to reduce latency time and ensure instant decision making. This choice requires the installation of local video stream calculation and analysis capabilities, and therefore calls for an edge computing solution.

1.3. Local data management: the bandwidth or network connection issue

The amount of data generated for certain services or applications sometimes increases dramatically with the use of new technological means available. Here, solutions which involve sending everything to the cloud to benefit from its computing capacities are of dubious value; it may prove to be impossible or even too expensive given the network bandwidth required. In such cases, it is necessary to relocate the computing resources locally. The local management of data processing and analysis also requires resources and skills that were previously centralised to be returned to local sites, which implies a need for strong support for the change.

> Enedis sorts data produced during drone supervision of medium-voltage overhead power lines in order to reduce the volume of data fed back to the Central IS.
>
> **Stéphanie Delaunay, Enedis**

In some cases, autonomy is imperative because the connection is simply not stable enough. This is the case, for example, on platforms out at sea, or on ships. For example, one shipping company has set up on-board systems on its container ships to control the ship's fuel consumption in response to engine data, the weather, the exhaust gas recovery turbine that produces electricity, etc.

> At Dassault Aviation, the benefits of an edge computing solution are particularly clear when considering requirements to conduct military reconnaissance missions in geographical areas with poor or zero coverage from communication networks.
>
> **Thierry Mousseaux, Dassault Aviation**

More and more companies are adopting Industry 4.0 approaches to automate certain actions such as quality control, predictive maintenance and improved measurement of their energy efficiency. Industry 4.0 must respond to many issues – latency, network bandwidth, regulation and local management of decisions – in a combination that varies according to the needs of the use cases. The sharing of a wide range of data, many of which are processed in real time, enables operations such as the validation and certification of digital twins[3] participating in the continuous improvement of

[3] A digital twin is a digital replica, i.e. a dynamic software model of an object, process or system that can be used for various purposes. Digital twins participate in the continuous improvement of processes in relation to a product's design and production line, but also its performance over time, as this digital representation is designed to track the real-time transformations of the specific object or process to which it is attached, from its design to its destruction. Digital twins work by collecting a combination of data. They incorporate artificial intelligence, machine learning and data analysis to create digital simulation models that update and change in response to changes in their physical counterparts.

processes, whether in terms of a product's design, its production line or its performance over time. A digital twin updates itself using multiple sources to represent its status, working condition or position in near real time. More specifically, this learning system integrates historical data from previous use of the machine into its digital model, which learns by itself, using data from all of the following sources:

- sensors, which transmit various aspects of its operating status;
- human experts, e.g.: engineers with in-depth and relevant knowledge of the industrial sector;
- other similar machines;
- other fleets of similar machines;
- its environment and the wider systems to which it belongs.

For strategic reasons of confidentiality, or simply because of a limited network connection in an isolated area, the task of modelling the digital twin is performed locally. This also helps to limit network congestion, ensure information security and limit the carbon footprint. This is the case for factories or warehouses located in areas in which the connection does not yet offer the required quality. Local processing with computing power and storage capacity then satisfies these aims.

During the production of woven films, breaks or tears can occur which cause the machine to stop for several hours to clean and then restart. Consequently, there are benefits to being able to anticipate them through modelling. The prototyping project consists of investigating the ability of machine learning to predict when a break is likely to occur according to different parameters. This allows the operator to act on certain parameters in order to avoid the incident and/or to schedule maintenance.

In the prototype, the data is retrieved from the AWS cloud, where it is processed using methods such as Machine Learning before being installed in a production environment, most likely on edge infrastructures. If this technology proves to be effective, the chances that it will be replicated within the group (at global, European and factory level) are high.

The business objectives are twofold: to assess the benefits obtained with this prototype (reduction of unplanned downtime, reduction of waste) and to see how the solution can be used at plant and/or company level.

- Assess the need for a single infrastructure for the whole company, or for a site or production line.
- Identify the benefits of scale at the software and/or hardware level.

Sharing an industrial company

1.4. Local management of analysis and decision making

Some industrial machines are engaged in continuous production. Any stoppage generates heavy financial losses and it can take a very long time for the machines to be restarted. In this case, local management and decision-making is necessary to anticipate and avoid stoppages as far as possible. In other cases, the company seeks above all to limit the risks of failure or disruption of its network. This is true of companies that implement monitoring and analysis solutions that ensure the security of local teams with on-site processing and decision management. Consider the example presented above of a company which ensures the safety of its isolated technicians, completely independently on-site, from a single video stream analysed locally by several algorithms running in parallel (several processing operations on a video); this video data analysis must be operational 24 hours a day and cannot be allowed to be jeopardised by a network bandwidth problem. In this particular case, this justified the choice of an edge computing solution. Yet neither does this choice prevent the use of cloud computing for handling the dataset required for the continuous improvement of the algorithms in asynchronous mode.

Other use cases satisfy the requirement for on-site management of the decision-making process: for example, the case of a sensor checking the quality of a product manufactured in a factory workshop, or the example of an intelligent floor lamp with audio sensors. The aim may be to detect a gunshot or a car accident. 99% of the time, the data transmitted by the sensors are worthless. What is important is the quick decision that results from this data. When an accident occurs, a gunshot sounds or a factory part is defective, the system must instantly alert the police or halt the production line. Decisions need to be made in the place where the sensor is, at the edge, in a fraction of a second. Putting computing and storage capacity close to the sensors enables a quick reaction.

> Edge computing will probably offer an “improved” response for AOG (Aircraft On Ground)-type interventions by our Operators and Service Stations with our Falcon civil aircraft: the data and processing capabilities are then available for support right alongside the aircraft.
>
> **Thierry Mousseaux, Dassault Aviation**

2. Challenges of edge computing

Edge computing is necessary on the one hand to address the limitations of the cloud, whether physical (latency, bandwidth), legal (data ownership and liability) or economic (transfer costs, storage, processing costs), as highlighted in the use case. But it is also essential because it adds value, whether at the business, process, system or architectural level.

Edge computing projects face a number of challenges as they seek to derive value from the various data, whether or not they are cross-referenced with each other, i.e.:

- recovering highly disparate data;
- managing data in an interoperable way;
- ensuring network connectivity;
- ensuring overall safety;
- scalability;
- managing complex systems;
- reducing the carbon footprint of digital technology.

2.1. Interoperability

Corporate architecture is diverse as a result of mergers/acquisitions, the use of IaaS, PaaS and SaaS cloud solutions, etc., often from different suppliers, with edge computing solutions now also being added to this mix. The products and solutions used internally are sometimes disparate; and in some cases, approaching obsolescence. In all industrial companies, tool and equipment pools are very varied, with old but still operational machines. It is therefore important to be able to continue to exploit this data and ensure it can be integrated (e.g. for digital twins). Then, the connected sensors, objects and systems use a large number of devices to communicate with humans or with each other – Wi-Fi, LoRa, Sigfox, 2, 3, 4G and 5G, etc. This creates a large market for the manufacturers of these devices. The multitude of databases makes it necessary to develop gateways to aggregate often disparate data models representing an ever-growing range of inconsistent standards. In order to manage and derive value from the various data, they must first of all be generated, retrieved in the available formats, processed and sometimes cross-referenced. Many devices were never designed for internet connectivity. Interoperability with smart devices using different communication protocols is a major technical challenge. The existence of a widely-used and well-known standard and protocols would remove technological and language barriers, increasing interoperability between devices.

Today, companies are shaping their IT systems architectures to ensure that they can change rapidly in response to competition, technological innovations or crisis situations requiring the continuous improvement of IT tools. They are therefore tailoring their IS architecture to meet the needs of projects such as edge computing in terms of technical requirements, security and availability, data collection and processing. Many are choosing to **build a more flexible organisation by structuring the IS as a services platform** to enable production tools and technologies to evolve rapidly. Integration into the IS must be conducted in accordance with the usual standards and good practices: deactivation of accesses, encryption, intrusion alerts, software version control, updates, maintenance, etc., and needs to adapt to the architecture constraints in hybrid and/or multi-cloud configurations imposed by the company's portfolio of applications, services and data lakes.

Most large companies orchestrate and manage **hybrid multi-cloud architectures** (private and public clouds) to address issues of business agility, different use cases and the security of critical data. These different service platforms must be managed in hybrid IT mode, i.e. the IT department will play the role of broker and service integrator through traditional IT, whether virtualised or not (on site or off site). In addition to private and public clouds, these platforms now include edge computing. These hybrid architectures involve the integration of technological silos at four different levels:

- hybrid infrastructure;
- orchestration (hybrid Cloud);
- hybrid applications / data;
- hybrid IS management with a single, unified view.

The implementation of **hybrid** and **interoperable architectures** progresses through stages of maturity, which implies **impacts on organisational structures**, **cost models**, **tools**, **governance processes** and **required skills**. To manage these hybrid multi-cloud architectures, a structured approach must be put in place:

- **Implement a Framework for assigning workloads** (applications and data) to the appropriate location (private, public or hybrid) based on business, technical, security, resilience and performance/latency criteria.
- **Focus on specific integrations** between environments rather than trying to integrate all environments at all levels.
- **Create a customer journey** through hybrid architectures for infrastructure, orchestration, application/data and management.
- **Transform the organisation now and invest in the skills and technologies** needed to integrate hybrid multi-cloud architectures with the inclusion of edge computing.

As part of its digital transformation and the rapid development of new innovative products and services, the Orange Group has launched a ***"Cloud Native*** [4] ***& Data Driven"*** transformation programme. The challenge of developing cloud-native applications is to develop and run scalable, flexible, interoperable, portable (avoiding the risk of vendor lock-in with Cloud providers) and resilient applications in any architecture, including public, private, edge or hybrid multi-cloud. Cloud-native platforms such as "Container as a Service", "Platform as a Service" and "Serveless" enable the deployment of cloud-native applications. To meet the challenges of interoperability and application/data porting in a hybrid multi-cloud environment, Container-as-a-Service solutions based on the Kubernetes orchestrator and Docker[5] containers must be used to deploy cloud-native applications. The cloud-native philosophy offers independence from infrastructure providers, whether physical/virtual or cloud, and must be **open** through being based on **open-source** technologies.

In the context of edge computing, applications must also be cloud-native and based on microservice architectures (edge applications, AI models, AI services, Edge Analytic, Edge Data). Microservices are containerised and orchestrated across the entire edge computing value chain (edge devices, edge server/gateway, hybrid edge network/micro datacenter/multi-cloud). To meet the challenges of agility, automation, standardisation, resilience and interoperability in hybrid multi-cloud architectures, companies must adopt this Cloud Native strategy based on Kubernetes and Docker technologies to orchestrate and manage containerised microservices regardless of the architecture – Private Cloud, Public Cloud, Edge, Telco Cloud or hybrid multi-cloud.

Dominique Vo, Orange

2.2. Scaling up – Industrialisation

While it is easy to implement a POC (Proof of Concept) or MVP (Minimum Viable Product) for an edge computing solution, scaling it up is quite another matter in terms of technical and operational management as well as security. Scaling requires the ability to manage massive volumes of data and to define at which level – edge/cloud – the data will be analysed. This depends on several criteria: storage and processing capacities, latency, bandwidth, connectivity, security constraints, etc. listed later in this report.

Secondly, the security of the data transmission chain must be ensured, as well as the anonymisation of the data. This is the vital role played by governance. For example, the CROUS university catering

[4] Cloud Native: cloud-native technologies enable companies to build and operate elastic applications in modern, dynamic environments such as public, private or hybrid clouds. Containers, mesh services, microservices, fixed infrastructures and declarative APIs are examples of this approach. Source: CNCF *(Cloud Native Computing Foundation*).

[5] The Cloud Native strategy built on Kubernetes orchestration and Docker container technologies (which have become market standards and widely adopted by industrialists and companies) is supported by the CNCF.

organisation in Rennes had set up a monitoring system to study the abnormally high rate of wear and tear on its furniture. The project was all ready to start when the CROUS realised that it had not brought the students, who were directly concerned, into the loop. The project was never completed because a governance system was not set up in parallel. It is in fact essential to have identified and aligned all the stakeholders – managers, IT managers, key stakeholders, etc. – before it is possible to scale up successfully. Governance determines who owns the data, where it is stored, who manages it, and who uses it.

Finally, another challenge is to be able to establish indicators of success and monitor them once the business case has been established.

2.3. Maintenance and Security

System maintenance is an important point to be considered in view of the rapid increase in the number of system components: sensors and smart objects, even if they are remote, require maintenance. Power supply is also an important point. A connected object requires a dedicated power supply – unlike a sensor, which has a very low power consumption and can therefore be powered from a battery. The example of the smartphone illustrates this point. This smart object has a relatively poor battery life which depends on its use. Edge computing solutions must be able to be powered according to their needs and maintained with updates via the cloud.

In terms of safety, IoT environments are by default permissive since the information carried by the sensor is usually not crucial. This is not necessarily the case for a smart object (e.g. if it is a camera), and even less so for smart systems. In any case, the elements that comprise edge computing – including sensors (even general public ones), devices, cameras, meters, etc. – must not introduce flaws into the information system, and must therefore be secured. Edge computing must provide a layer of security and isolation between the unified connected world and the exploitation of data.

Today, the concept of what constitutes an attack is a shifting one. It is important to consider how to make the system secure and resilient: after all, the benefits derived from the implementation of edge computing projects usually evaporate if the solution is not secure. They are not worth the risk. However, it is difficult to manage and secure edge computing projects in view of the multitude of solutions, the types of sensors and smart objects, the existing interfaces and the different networks used.

The cyber and maintenance aspects must not be underestimated and must be factored in from the design stage, as the data generated by these connected systems constitutes an asset that needs to be secured.

2.4. Management of complex systems

Edge computing involves accessing the data – during its generation, capture and analysis processing – via formats that are sometimes very different. In addition, most of the data will be increasingly generated outside the data centres and therefore scattered, which will make them even more complex to manage.

The need to cross-reference data sources with one other, taking into account only the relevant ones, and to carry out analytical processing implies the use of AI at the edge. The complexity of managing such devices requires them to be handled industrially. This is why it is strongly advisable to **include the upscaling / industrial approach upstream of the project, i.e. at the time when the project is designed and planned**, without forgetting to precisely define the organisation and governance structures.

In spite of these restrictive imperatives, companies expect near real-time data processing and analysis at a cost that must remain affordable while maintaining security levels. The physical places where the data is generated and analysed must be secure. And this remains true despite the expected explosion in the number of smart objects and devices in coming years.

Smart objects are destined to become increasingly complex, yet decision-making must continue to be fast, local and secure. The 5G networks will open up new possibilities in terms of connection, quality of service, speed, etc.

2.5. Digital sobriety

Companies and public organisations are aware of the growing impact of digital technology on greenhouse gas emissions, among other things. They are seeking to contribute to the low-carbon agenda in more meaningful ways than just their CSR (Corporate Social Responsibility) contribution.

Edge computing, in its responses to the challenges of latency, bandwidth, network connection and localised management, is a driver for reducing the environmental footprint of digital technology. However, although edge computing promises to reduce network bandwidth requirements and data traffic, it could also lead to an increase in the number of computing and storage points and thus lower datacenter efficiency.

The prerequisites for the implementation of a "digital sobriety" approach and the levers that companies can use have been identified and studied by the Cigref working group, which has just published the Cigref report "Digital Sobriety: a responsible corporate approach", as a summary of its year-long work.

3. Different players in the edge computing market

3.1. Hardware solutions offered by suppliers

Several hardware building blocks are offered in edge computing architectures: the building block that provides computing, intelligence and storage capacities is often called a "gateway": all the major historic players have a foot in this camp. Other specialised players offer components, such as Atos, which develops its own motherboards using its HPC (High Performance Computing) experts. Use cases are sometimes found in "hostile" environments and require reinforced hardware solutions. This is true of gateways installed in areas with temperatures ranging from -5 °C to +45 °C where there is no fan despite the presence of GPUs. The equipment used is an important differentiating factor in such cases, particularly in terms of computing and processing capacities. Hardware suppliers respond to this particular need for hardware development by manufacturing certain specific components.

The information filtered at smart-object level is pushed to a second-level edge gateway, which has a storage, concentration and analysis capacity greater than that of the first level, yet remains close to the data source. Proximity to the smart object and/or system eliminates the latency problem. It provides analysis using artificial intelligence and real-time data processing. This intermediate level then pushes all or part of the information to the cloud if necessary. These edge calculations therefore reduce data transfer costs, since only cleaned data that adds value is transferred to the cloud. They do, however, require the support of enterprise architects for the integration of edge computing infrastructure into information systems.

3.2. Platform providers

Some platforms allow the various Business Units to exchange and share data and to optimise production control and performance in a "smart objects" environment, such as Siemens's *Mindsphere*. This sharing of data makes it possible to validate and certify digital twins participating in the continuous improvement of processes. Operations are based on feedback via sensors, and evolve according to changes in the operating characteristics of the managed entity. This primarily affects Industry 4.0, but also other sectors. For example, at CES[6] 2019, the Mayor of Seoul confirmed the benefit of a digital twin of his city, to simulate the consequence of a political or organisational choice. Companies are seeking to rely on platforms that collect, compile and analyse data on an industrial scale. *Mindsphere* is a sort of global industrial cloud in which each player in the same ecosystem has the ability to build automation loops, manage control loops and perform preventive management or any other business

[6]Consumer Electronics Show: a show dedicated to technological innovation, held in Las Vegas in January.

application. The search for performance can take the practical form of sharing business applications within the ecosystem in question: company, suppliers, customer support, etc., with regard to supervision, visualisation, or other applications to which analytical processing is connected. The objective is to optimise ROI with the minimum investment. With this type of platform, applications – even if developed locally – can be implemented globally.

The development of big data analytical applications generally requires the involvement and interaction of several teams, some of which are not necessarily familiar with IT. Teams of stakeholders seek to develop these applications in agile mode and avoid time-consuming and often much more expensive specific developments. This is why “low-code” platforms are currently being developed, as they satisfy these requirements. The user interface is of strategic importance in this type of platform in order to be able to accommodate the various business units involved. The platform receives data from the product line, ERP, CRM or any other company asset via connectors, web services, etc., and the application interfaces are tailored to the users to whom they are addressed.

4. Edge computing: recommendations for implementation

4.1. Criteria for deciding to implement an edge project

During the working sessions, the Cigref WG participants were able to list the various criteria that provide a route towards an architecture that includes edge computing capabilities:

- **Usage value of data depending on whether it is local or in the cloud**. Given the amount of data produced, it is important to establish the location in which it is relevant to process it. This is because much data is only important at the time it is created and ceases to be of interest soon afterwards. However, using real-time information does not preclude the possibility of sending all or part of it to the cloud to increase system performance if necessary.
- **Acceptable latency time**. The use case of the self-driving car, and many others, typically requires instantaneous decision-making and is therefore intolerant of the latency associated with information communication times. 5G, once deployed, is likely to change the game in areas covered by this technology.
- **Bandwidth required for connectivity**. Maintenance by video or smart object system sometimes generates too much data to be transferred to the cloud without saturating bandwidth for an unacceptable amount of time. Networks are not necessarily sized to absorb such communications on a day-to-day basis. The edge project offers a solution in this type of case.
- **Transfer costs**. If we go back to the previous example, the cost of transferring data to the cloud can also become prohibitive for data that is too large.
- **Computing and processing capacity**. The appropriate intelligence to be sited close to the sensors depends on the reaction time required for the use case to work as expected, and the volume of data to be analysed. **Edge computing offers an AI-driven processing ability and therefore allows predictive analysis for local actions.** When edge computing is chosen, the local processing algorithm can also be trained and updated centrally and, if the systems are standardised, can take advantage of the volumes required for Machine Learning. However, the hardware and software required to process the data may be too cumbersome and too expensive to handle this task locally.
- **Security constraints**. The decentralisation offered by edge computing can be an attractive solution for limiting risks. Local data processing also avoids all forms of connection loss.
- **Data sensitivity**. Local storage and processing provide a means of complying with GDPR-style regulations.

- **Resilience**. A poor network connection can have unacceptable consequences. In some cases there is simply no choice due to lack of connection; for example, on boats, on a remote platform, or at sea. This applies to all use cases that require autonomous solutions.
- **Carbon accounting / carbon footprint**. Companies are keen to limit their ecological footprint as much as possible, and include this parameter in their use case studies.

4.2. Key steps to be considered

In Sia Partner's opinion, it is essential to **start by identifying the service or added value provided by the product**. For example, it may be to offer a library access service, a data aggregation service, etc. Next, there is a need to be able to capture data across the entire chain, hence the importance of upstream planning to locate edge servers in the right places and specify them accordingly. This becomes an ever-greater requirement as data volumes increase.

Next, **robust business cases must be built** with the objective of identifying the necessary investments, OPEX and ROI, taking indirect gains (predictive, maintenance, recycling, etc.) into account.

It is also necessary to **identify the key competencies that can exploit the value of data**. This exercise is a complex one, as several of these areas are **emerging** skills, such as data cleaning and data algorithmics. Profiles such as data analyst, data scientist or data expert, etc. can require several years of training in some cases. This explains the importance of setting up a career development or expertise path for employees.

Finally, to **support change** related to edge projects, the company must establish a communication and support system for internal stakeholders. In view of the importance of data availability and quality, it is necessary for all employees to have a "technology and data" mindset so that they can understand and organise the data in a usable way. Participating companies recommend that each entity should be responsible for producing and exploiting its data. Edge computing provides an additional incentive for companies to open up to external players and relevant ecosystems, internal or external to the company. It stimulates open innovation and the accumulation of collective intelligence, and accelerates the dynamics of innovation and growth.

4.3. Organisational support and change management

The implementation of a flexible, agile structure with an ability to learn is crucial for sustaining the digital transformation and driving the constant search for additional performance. The structure must be a distributed one, with operational contacts on different sites who pass on and share best practice. This requires efficient internal communication.

The implementation of edge computing solutions induces a form of decentralisation, shifting from a centralised cloud-type philosophy to local management at the edge. However, in certain fields such as

Industry 4.0, the path of change is reversed, as it is necessary to make business unit employees aware of the constraints of information systems, particularly when scaling up: developing certain skills and acculturating business unit employees to the standardised services and constraints linked to applications, applying standards for data formats and supplier interfaces, anticipating upstream support and maintenance requirements, monitoring and managing versions over time (patches), and providing security for projects in the form of logical and physical intrusion tests.

Finally, edge computing projects require **skills to be adapted** by means of:

- **Identifying complementary new skills:** IT architects, user interface, user experience, lawyer, etc.
- **Continuously training employees:** choose the most effective type of training: e-learning, MooC or micro-training.
- **Adapting organisational and management models** to provide greater flexibility and learn to network and collaborate better. This also requires adapting management by setting new objectives, KPIs (Key Performance Indicators), and relationship-driven management.
- **Involving all players, customers and subcontractors in the project:** information systems need to be considered as part of a more global and integrated process, beyond just the needs of a single entity or plant. This requires a dialogue with the IT department.

5. Conclusion

Companies and public organisations have understood the urgent need to enhance the value of data produced internally or within their ecosystem. To respond to this vital requirement, they are opening up their information systems and implementing the various technologies available, such as cloud computing. However, it is becoming completely impractical to send all the data produced by the company to the cloud, given the limits of bandwidth, the sizing of the networks, the response time required for certain use cases, security and regulatory constraints, the necessary system resilience, and the need to meet the challenges of digital sobriety. Edge computing provides an answer by storing, analysing and using AI tools to process data for smart objects and systems at the edge of the network, as close as possible to their source.

Edge computing promises to reduce network bandwidth requirements and data traffic, but could at the same time lead to an increase in the number of computing and storage points and thus lower datacenter efficiency within the company.

Some private, industrial or sovereign communication networks – and also the intelligent infrastructures necessary for autonomous vehicles – will in the near future require resilient network nodes; a requirement that can only be satisfied by the local processing and storage delivered by edge computing. The widespread use of edge computing will be accompanied by changes in data security practices and regulatory compliance measures, enabling it to be rolled out at corporate level. Numerous cloud players – industry, mobility infrastructure operators and equipment manufacturers – are gearing up to serve this very promising market. The hardware used represents an important differentiating factor, in terms of both hardware computing and processing capabilities and operating environments.

Edge computing is likely to experience a boom with the deployment of 5G (see Cigref report "5G: Planning and opportunities" [7]). Indeed, 5G will offer connectivity solutions that deliver the required quality of service, in turn driving new edge computing architecture deployments.

[7] https://www.cigref.fr/5g-anticipation-opportunites-influence-sur-architectures

Achieving digital success to help promote the economic growth and competitiveness of its members, who are major French corporations and public administrations, and users of digital solutions and services

Cigref is a network of major French corporations and public administrations set up in order to develop its members' ability to acquire and master digital technology. It is a unifying player in the digital society, thanks to its high-quality thinking and the extent to which it represents its members. Cigref is a not-for-profit body in accordance with the French law of 1901, created in 1970.

To achieve its mission, Cigref counts on three business units, which make it unique.

1/ Belonging:
Cigref speaks with one voice on behalf of major French corporations and public administrations on the subject of digital technology. Its members share their experiences of the use of technology in working groups in order to elicit best practices.

2/ Intelligence:
Cigref takes part in group discussions of the economic and societal issues raised by information technologies. Founded nearly 50 years ago, making it one of the oldest digital associations in France, it draws its legitimacy from both its history and its understanding of technical topics, giving it a solid platform of skills and know-how, the foundation stones of digital technology.

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