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MEC for the service of connected vehicles

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Acronyms

5G	Fifth Generation
AR	Augmented Reality
CPU	Central Processing Unit
ETSI	European Telecommunications Standards Institute
IaaS	Infrastructure as a Service
IoT	Internet of Things
ISG	Industry Specification Group
KPI	Key Performance Indicators
LTE	Long-Term Evolution
MCC	Mobile Cloud Computing
MEC	Multi-access Edge Computing
M2M	Machine-to-Machine
PaaS	Platform as a Service
RAN	Radio Access Network
SaaS	Software as a Service
V2X	Vehicle to everything
V2V	Vehicle-to-Vehicle

General Introduction

Rapid advances in computing technologies have enabled the creation of a wide range of applications generally classified as future Internet applications, such as traffic and intelligent surveillance. However, the majority of these emerging applications are compute-intensive and impose stringent time requirements.

The limited capabilities of mobile devices are augmented by leveraging the resources of cloud servers. The cloud provides virtually unlimited resources and a good range of services to enable these compute-intensive applications on resource-constrained mobile devices.

The fifth-generation standard for mobile communications, commonly referred to as 5G, was designed to meet the growing need for faster communication between people, but also with the idea of serving key economic sectors of society from the outset. In the context of 5G, Multi-access Edge Computing (MEC) enables high bandwidth for real-time applications in many areas, including augmented reality, the Internet of Things (IoT) and telemedicine.

The idea behind MEC is to intentionally push compute and storage capabilities onto the network tap to so that these workload and applications are closer to customers, improving the customer experience and enabling new services and offerings.

The objective of this project is to present the MEC platform and to review the standards implemented for MEC applications by ETSI spatially within the field of connected vehicles. We will therefore present three chapters.

The first chapter will present a theoretical study on the evolution of cloud computing and its emerging paradigms. In the second chapter, we will discuss Mobile Edge Computing and end with a case study on its application in connected vehicles.

Chapter 1

The Evolution Of Cloud Computing

1.1 Introduction

In this chapter, we will introduce a complete overview on the Cloud Computing and discuss the implementation of its emerging paradigms.

1.2 Cloud Computing

1.2.1 Cloud computing overview

Before cloud computing, there were four computing technologies, namely mainframe, personal computers, servers, and the Web. Cloud computing is characterized by Internet-based computing, which provides computers and other devices with common resources, software, and information on demand. It is currently the most notable computing medium as it uses the "Pay-as-You-Go" model and one of the largest and fastest-growing IT computing models for high-performance computing, which focuses on "on-demand" computing services and products that offer more scalability[1]. Consumers use the cloud to store personal data such as videos, backups, websites, content, and almost everything, no space is required for a server we only use cloud servers, Cloud computing is the act of accessing and storing data and programs via the Internet instead of the computer hardware. Therefore, a high-speed Internet connection is the main requirement for accessing cloud computing services, with an online connection, cloud computing can be done anywhere, anytime. The fundamental principle of cloud computing is to reduce the processing load of cloud service receivers and provide better Data security due to investments that the providers have made. [2]

1.2.2 Cloud computing technology

There are mainly three services models in Cloud Computing: Software as a Service (SaaS), Platform as a Service (PaaS), Infrastructure as a Service (IaaS)[3] (see figure 1.1).

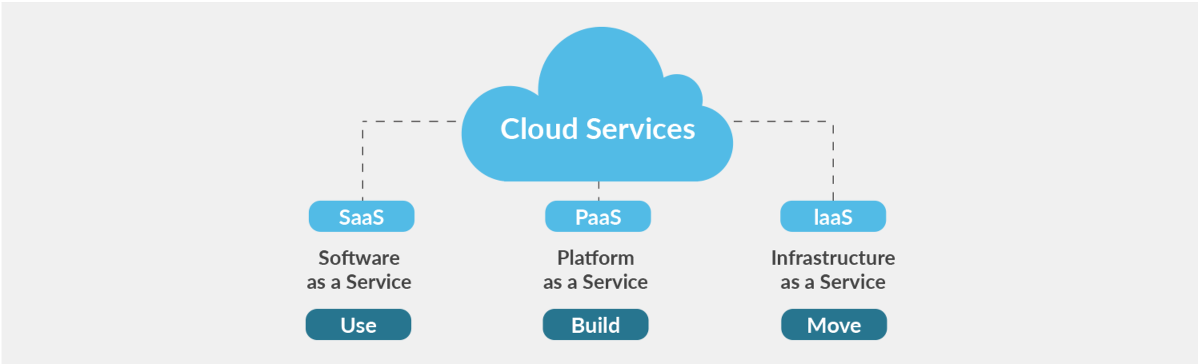

Figure 1.1: Cloud service models

IaaS
In IaaS, the cloud service provider procures a set of virtualized computing resources, such as CPU, memory, operating system and application software, etc. IaaS uses virtualization technology to convert physical resources into logical resources that can be dynamically provisioned and released by customers as required[4].

PaaS
In PaaS, a cloud service provider offers, runs, and maintains both the system software and other computing resources. Users don't have to worry about disposing of their own hardware and software resources or hiring experts to manage those resources[1].

SaaS
In SaaS, cloud service providers are responsible for running and maintaining the application software, operating system and other resources. The SaaS model appears to the customer as a web-based application interface, where the Internet is used to provide services that are accessible through a web browser. Hosted applications, such as G-mail and Google Drive, can be accessed from a variety of devices, such as smart phones and laptops, etc[1].

1.2.3 Characteristics of cloud computing

Cloud computing has many interesting characteristics that make them promising for future IT applications and services.

Service Oriented
Cloud services such as CPU time, Storage, network access, server time, web applications etc can be allocated automatically based on consumer needs without any human interaction with each service provider.

Broad Network Access
Consumers can access cloud resources on the Internet at any time and from any location using different types of devices (e.g., cell phones, laptops, tablets and desktops).

Resource Pooling
Physical and virtual computing resources are pooled in the cloud to serve multiple consumers using a multi-tenant model. These resources are location-independent, in that the customer has no control or awareness of their location.

Rapid Elasticity
Computing resources can be provisioned and released quickly and elastically depending on consumer demand. Consumers perceive these resources as unlimited and can be purchased in any quantity at any time.

Measured Services
Cloud resources and services are monitored, controlled and optimized by CSPs through a pay-per-use business model, providing transparency to both the provider and the consumer of the service being used, consumers use these services in the same way as electricity, water and gas.

Scalability
Cloud computing infrastructure is highly scalable. Cloud providers can add new nodes and servers to the cloud with minimal alteration to the cloud infrastructure and software.

Reliability
Reliability is achieved in cloud computing by using multiple redundant sites. The high reliability makes cloud computing a suitable solution for damage recovery and business critical tasks.

1.2.4 Cloud architecture

The cloud architecture defines the components and the relationships between them. In other terms, the cloud infrastructure is a building entity for the cloud.

The cloud infrastructure involves various components such as database software and hardware, network, and storage (see figure 1.2). The cloud aims to provide an environment for the user to access data and applications and move efficiently between servers and nodes in the cloud[5].

Users use different electronic devices such as mobile phones, Laptops, Personal computers and Smart devices to access different utility applications, IT development platforms, and storage over the Internet using standard protocols.

[2].

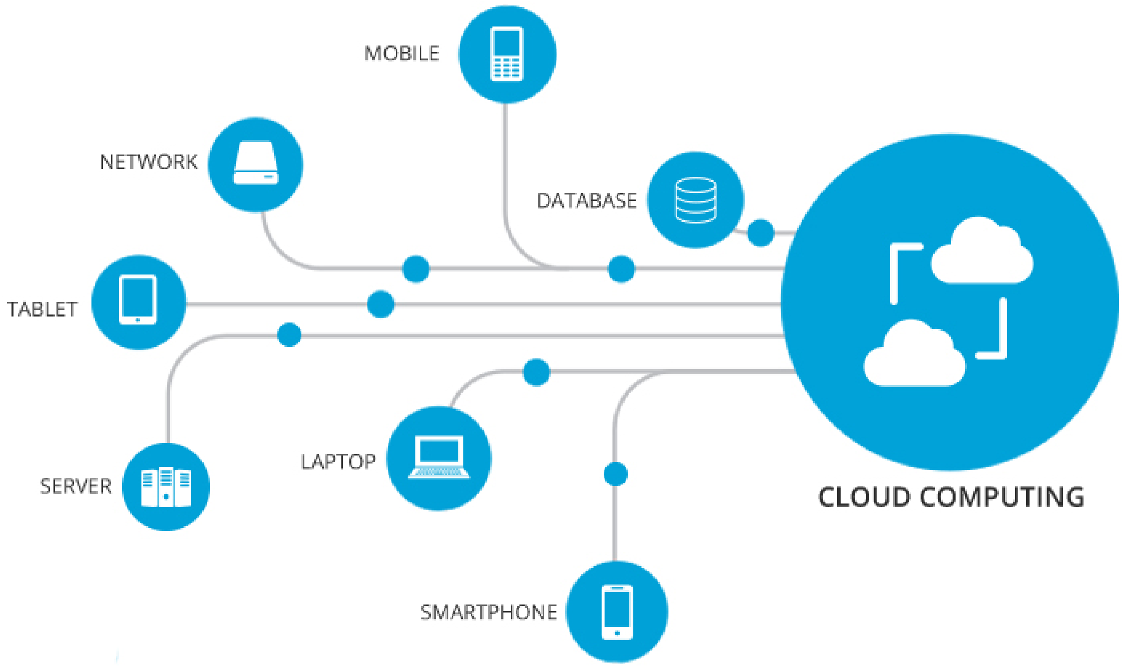

Figure 1.2: Cloud Computing Architecture

Cloud Computing uses virtual machines to increase efficiency for development, reduce the physical IT infrastructure such as RAM, Storage, the number of servers and Databases and also improve the ability of technology [5].

1.2.5 Virtualization Technology

Cloud infrastructure mainly depends on the concept of virtualization which abstracts the processes on a cloud and uses it to separate the resources from the hardware in the cloud, then the software allocates these resources in its appropriate position or use to allow more than one access of many end users at any time and place[5].

The cloud network consists of hardware like switches, routers, backup devices and servers, located in many places around the world to form the network; and then the role of virtualization takes place. It connects servers to each other, allows many users to access data, share on the cloud some resources such as applications or platforms, etc between the customer and IT companies and put a pointer to the physical resource when needed[4].

Users can also share the infrastructure using virtualization, in the cloud, virtualization is a service that separates the definition of computing functions and services from the hardware, but the software called hypervisor sits on top of the hardware and abstracts the resources of the machine, such as memory, computing power and storage(see Figure 1.3).[2].

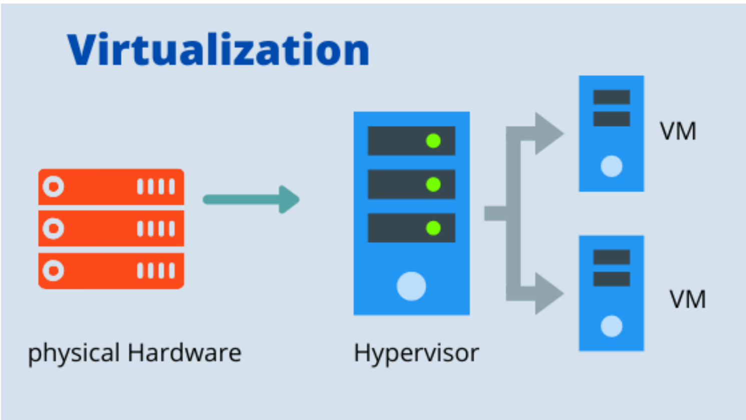

Figure 1.3: Virtualizating Technology

1.2.6 Limitation of Cloud Computing

As cloud computing comes to market with many benefits and changes the way computers are accessed, the influx of new applications and systems is pushing the traditional cloud computing paradigm to its limits such as slow response time, fault tolerance, low bandwidth utilization and security in the public cloud: since the cloud computing holds the data centrally at only one location, there is a lot of back, fourth moment during the message operations which led to rise in network bandwidth computation[2].

In fact, when it comes to managing distributed data streams and related networked applications, such as Internet of Things (IoT), Big Data applications, V2X communications, augmented reality (AR), centralized cloud paradigms struggle from a significant waste of network and storage resources as large amounts of data with little business value are embedded in the cloud[2].

1.3 Edge Computing

1.3.1 The concept of Edge computing

To address the issue of real-time data-processing and security in the public cloud a new computing model is used which is known as "EDGE COMPUTING".. Edge computing brings the centralized computing platform of the core network to the edge network.It is closely connected to equipment of IoT devices that are mostly operated by mobile users which helps in reaching the expected constraints based on the response time for the real world applications.It can help to balance network traffic, prolong the life of IoT devices and ultimately decrease the "response times for real-time IoT applications[6].

Faster networking technologies, such as 5G wireless, are allowing for edge computing systems to accelerate the creation or support of real-time applications, such as video processing and analytics, self-driving cars, artificial intelligence and robotics, to name a few.
While early goals of edge computing were to deal with the prices of bandwidth for data traveling long distances thanks to the expansion of IoT-generated data, the rise of real-time applications that require processing at the sting will drive the technology ahead.[6].

1.3.2 Edge Computing Architecture

The topmost level is that of cloud where the complete data is stored in the form of huge information without any limitation on storage. It is a central part of data and app for storage and maintenance but the edge computing implements this level as a long term storage system but not every intermediate processing[7]. The last level is the physical devices which least computing capability and very much limited resource availability. These devices are built in a single target based computation. The most common example for such end user level devices is traffic signal and atmosphere temperature measurement instruments[7].

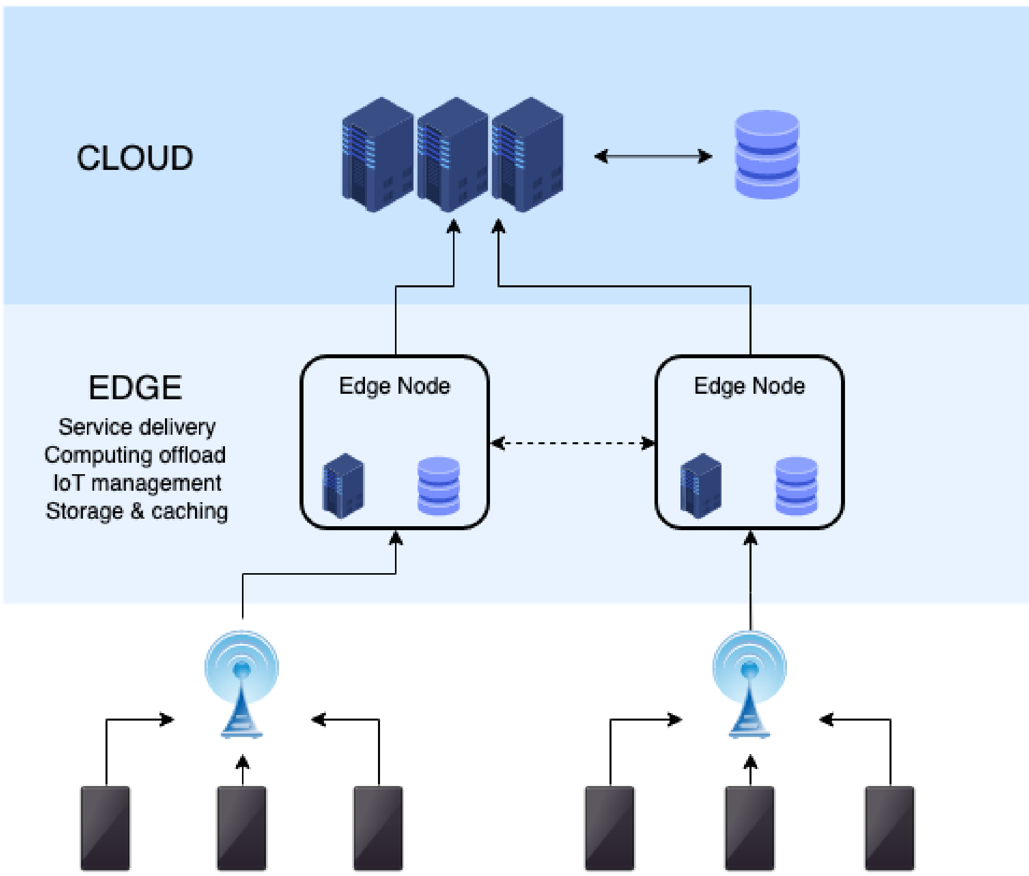

Figure 1.4: Edge Computing Architecture

1.4 Fog Computing

1.4.1 The concept of fog computing

The cloud is highly dependent on the measure of information created in the market, which depends on the capacity of the network service provider. With billions of user processes, causing and receiving information in and out of the cloud, the system becomes progressively toothy[8].

Fog computing, also known as fogging, allows gadgets to easily interface and manage their connections and missions as they see fit. The concept of fogging is the extension or lowering of cloud computing capabilities to the lowest/edge of the system to produce faster facilities for less advanced users. Consequently, it improves the quality of administration, reduces inactivity, and offers regular customer enjoyment..[8],

This paradigm supports the growing network of physical assets (vehicles, appliances, and even clothing) that are equipped with sensors to send or receive information. Fog computing can be implemented using a basic communication system, as opposed to using a large backbone network. Therefore, it is a denser coverage[8].

1.4.2 Fog Computing Architecture

As shown in Figure below, the middle layer between the end devices and the cloud consists of fog nodes. Fog nodes are computing resources deployed in a geographically distributed manner near the edge of the network. Fog computing is strong in large quantities and emphasizes quantity, where the single compute node plays a key role, whereas cloud computing emphasizes overall computing power, which is typically computed by a group of concentrated high-performance computing centers. Fog computing broadens the networked computing model of cloud computing and extends community computing from the center to the edge of the community, enabling broader use in a packet distribution[6].

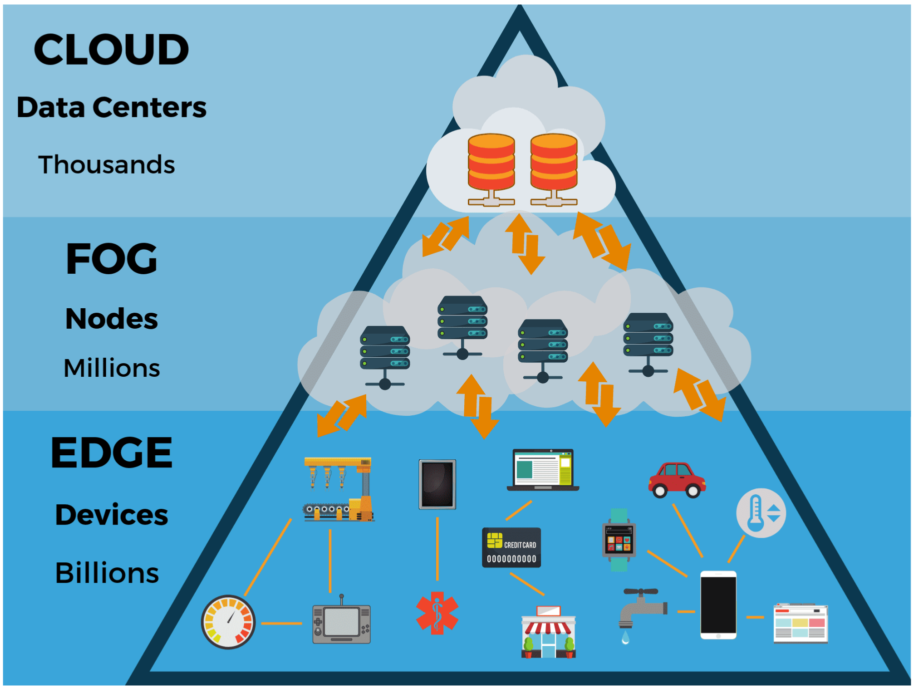

Figure 1.5: Network topology showing edge nodes and devices

1.4.3 Fog Computing Enablers

End devices can offload computational tasks to a nearby fog node, just as they would to the cloud. However, using decentralized fog nodes for offloading significantly reduces latency and mitigates the problem of the cloud becoming a bottleneck. Fog computing can take advantage of existing network equipment such as routers or base stations by providing them with additional computational capacity so that they can act as fog nodes; alternatively, fog nodes can be deployed specifically for the purpose of serving as fog nodes. In either case, fog nodes can be thought of as small data centers at the edge of the network, serving nearby end devices. Like clouds, fog nodes can use virtualization and related technologies such as containers to run applications owned by different tenants in isolation, which also facilitates application management, including application startup, auto-scaling and shutdown[6].

End device components include collaborative and autonomous decision making, micro-analysis, self-healing, sensing input, mesh computation, display output and local caching. The fog node components are: data transformation, network function virtualization, cognitive computing, local system coordination, distributed analysis, and distributed data storage.
Finally, the cloud components are: integration, orchestration, management, monitoring, automation, visualization, stateful services, long-term analysis and storage. In addition, "mediation" components are provided in each layer, as well as "messaging hub" components between layers[6].

1.5 Conclusion

In this chapter, we have highlighted the capabilities offered by cloud, edge, and fog computing in terms of delivering data and intelligence to analytics platforms located near the origin of the data. In the end, we conclude that these two technologies offer irreplaceable solutions to many IoT challenges and bring multiple benefits to the IoT, but the progress does not stop there.

Chapter 2

Mobile Edge Computing

2.1 Introduction

Living in the era where the world is overwhelmed by exponentially growing number of mobile devices (MCC) known as a combination of cloud computing and mobile computing , has succeeded to provide those devices with computation , storage and energy resources related to the centralized cloud . However, nowadays we can't deny that the explosion of mobile-connected devices' number has lead to a noticeable inefficiency of MCC which is facing several troubles , namely : high latency , low bandwidth and low storage capacity with a high energy consumption .

Such challenges are supposed to grow more serious especially by the introduction of the 5th generation . Thus ,they should be taken into consideration and solved by more efficient protocols . And that definitely remains in Mobile Edge Computing or shortly MEC with its fundamental purpose to overcome the difficulties of MCC .

2.2 MEC Overview

Mobile Edge computing was first recognized by (ETSI) the European Telecommunications Standard Institute and the Industry Specification Group (ISG). Actually , the ISG incorporates Intel Networks , Vodafone, Nokia, Huawei to mention but a few [9].

ETSI defines MEC as follows: Mobile edge computing provides an IT service environment and cloud computing capabilities at the edge of the mobile network, within the radio access network (RAN) and in close proximity to mobile subscribers.

2.3 MEC Architecture

MEC is the layer that lies in between mobile devices and the cloud .Thus, the infrastructure is known as three-layer hierarchy: mobile devices, MEC and Cloud going from the Edge to the Core network, as illustrated in fig..[10].

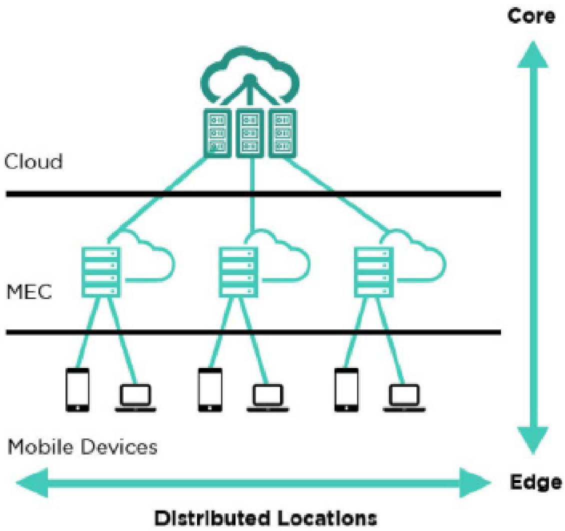

Figure 2.1: Three-layer architecture

More precisely, in every MEC architecture, different types of mobile sensors and devices -namely big data , IoT and social platforms -are connected to the core network (mobile Internet) thanks to the edge network (RAN and MEC).
This can be seen clearly through the Figure 2.2. showing how MEC brings services near to the mobile subscribers[9].

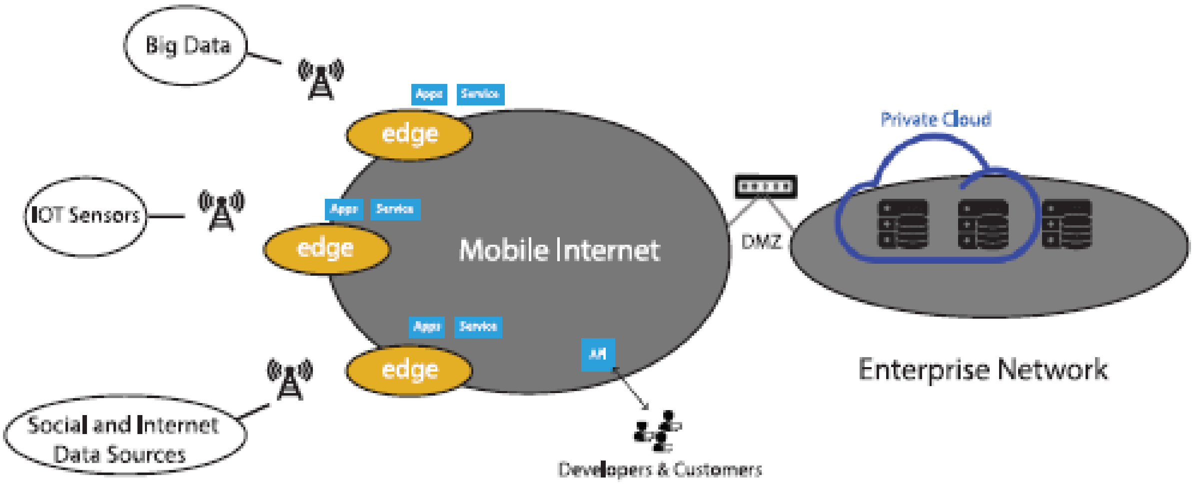

Figure 2.2: MEC architecture

2.4 MEC in 5G Networks

As the definition of MEC is tightly related to Radio Access Network (RAN) , we need to understand the general architecture of cellular network seen from a RAN perspective [9] .

2.4.1 RAN's role in cellular networks

The Radio Access Network enables the connection between the End User devices and the Operator Core Network as shown in the Figure 2.3 below that illustrates, on one side, the wireless connection between mobile terminals and the RAN which is ,in turn, wire-connected to the core network [9].

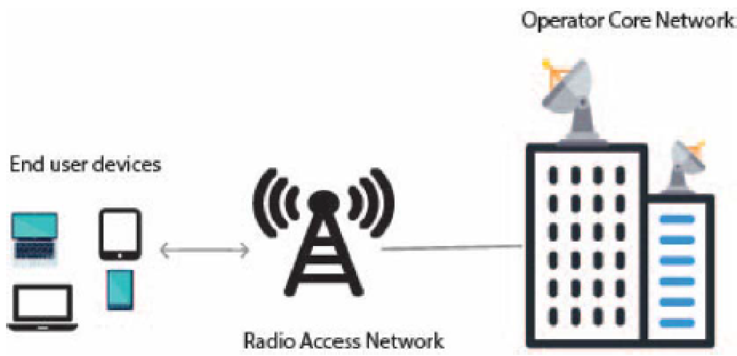

Figure 2.3: Cellular Architecture

2.4.2 5G Key Performance Indicator (KPI)

A key Performance Indicator(KPI) is a measurable value that shows how efficient a network is serving a user .In simple words, we can say that KPI shows the fitness of the network . In this project we have to apprehend the 5G KPI's which have lead us to opt for Edge computing [9].

5G KPI categories : We can say that 5G KPI is mainly based on 3 wide categories :

- Enhanced Mobile Broadband (eMBB).
- Mission Critical Control (MCC).
- Massive Internet of Things(Massive IoT). Which are deeply explained through the below given table:

Parameter	Key Performance Indicator (KPI)	Category
Peak Data Rate	DL- 20 Gbps UL -10 Gbps	eMBB
Spectral Efficiency	DL- 30 bits/Hz UL- 15bits/Hz	eMBB
Latency	C-Plane -10 ms , U-Plane 0.5ms	MCC
User Expe. Data Rate	DL-100 Mbps , UL -50 Mbps	eMBB
Area Traffic Capacity	10 Mbits/s/m2	Massive IoT
Connection Density	1 million Devices/Km2	Massive IoT
Energy Efficiency	90% Reduction in Energy usage	Massive IoT
Reliability	1 packet loss out of 100 million packets	MCC
Mobility	500Km/h	eMBB
Mobility Interruption Time	0 ms	MCC
System Bandwidth support	upto 1GHz	eMBB
Coverage	mMTC- 164 dB	Massive IoT
UE Battery Life	mMTC – 15 years	Massive IoT

Figure 2.4: FRTS requirements

Now we will discuss, in short, some of the above given categories :

1. Accessibility KPI : used to measure the success rate of users in accessing the network[9].
2. Integrality KPI : is the property that data is not unauthorized altered and service integrality is the degree to which a service is rendered without excessive loss[9].
3. Utilization KPI :describes the mean number of KPI PDU session that are successfully established in the network slice instance .It's necessary to evaluate the mean PDU session number in the work slice , it allows to indicate the system load level[9].

2.5 MEC characteristics

According to the ETSI White paper , MEC is mainly distinguished by :

1. Lower latency : MEC services are deployed at the nearest location to user devices , isolating network data movement from the core network. Hence , user experience is announced high quality with ultra-low latency and high bandwidth [11].
2. Proximity: Being deployed at the nearest location , MEC has an advantage to analyze and materialize big data . It's also beneficial for compute-hungry devices , such as Augmented Reality(AR),video analytics to name but a few [11].

3. Network context information : Applications providing network information and devices for real-time network can benefit business and events by implementing MEC in their business model .On the basis of RAN real-time information , these application are able to estimate the congestion of the radio cell and network bandwidth .This will help to make smarter decision for better delivery services to customers[11].

4. Location Awareness: Edge-distributed devices utilize low-level sig em lnaling for information sharing .MEC receives information from edge devices within the local access network to discover the location of devices[11].

5. On-Premises : The MEC property of segregation from other networks makes it less vulnerable . In fact , MEC platforms can run isolated from the rest of the network , while they have access to local resources .This is very important for machine-to-machine (M2M) scenarios[11].

The last point will lead us to discuss the V2V (vehicle-to-vehicle) scenario offered by MEC, as an example of M2M scenarios ,which will be clarified in the next chapter .

2.6 MEC Platform requirements

The implemented MEC platform was subject to two sets of requirements. The first one was the ETSI compliance requirements and the second was the French trial site requirements elaborated by the FRTS leader.

2.6.1 ETSI MEC ISG standard requirements

As already mentioned, the ETSI is an independent standaralization organization in the field of information and communication. ETSI compliance requirements can be regrouped into 4 categories .

- Generic requirements such as Application hosting [9].
- Services requirements such as the provision of MEC services to the hosted applications [9].
- Operation requirements such as the collection and the exposure of performance data [9].
- Security , regulation and charging requirements such as giving access to MEC services only to authorized applications[9].

2.6.2 FRTS requirements

The French Trial requirements were inspired from the ETSI compliance requirements which is why a similarity is noticeable between the two. FRTS requirement can be categorized into 6 categories that can be summarized through the following table 2.5 [9]:

Category	Main requirements
Framework and reference architecture	• provide a detailed architecture
Support of mobility	• Maintain connectivity between handovers
Connectivity	• Provide Inter-application (container-VM) communication • Provide Inter-MEC communication
Application deployment	• Allow deployment of VMs and containerized applications
Time synchronization	• Synchronize MEC components
Operation and management	• Provide Monitoring and alerting

Figure 2.5: FRTS requirements

2.7 Conclusion

In this chapter we had a detailed view concerning the Mobile Edge Computing Architecture that meets 5G KPIs thanks to its revolutionary characteristics .

Chapter 3

Study Case

3.1 Introduction

In this chapter we discuss the impact of MEC in the field of connected vehicles and the way Edge Computing analytics enable connected cars to send and receive data smartly.

3.2 Connected Vehicles

3.2.1 Edge Analytics

Edge Analytics enable data analysis closer to the data source rather than having to send it to and from the cloud as illustrated in the Figure 3.1. They are also known as an approach to data collection and analysis in which an automated analytical computation is performed on data at a sensor, network switch or other device instead of waiting for data to be back to a centralized data store [12].

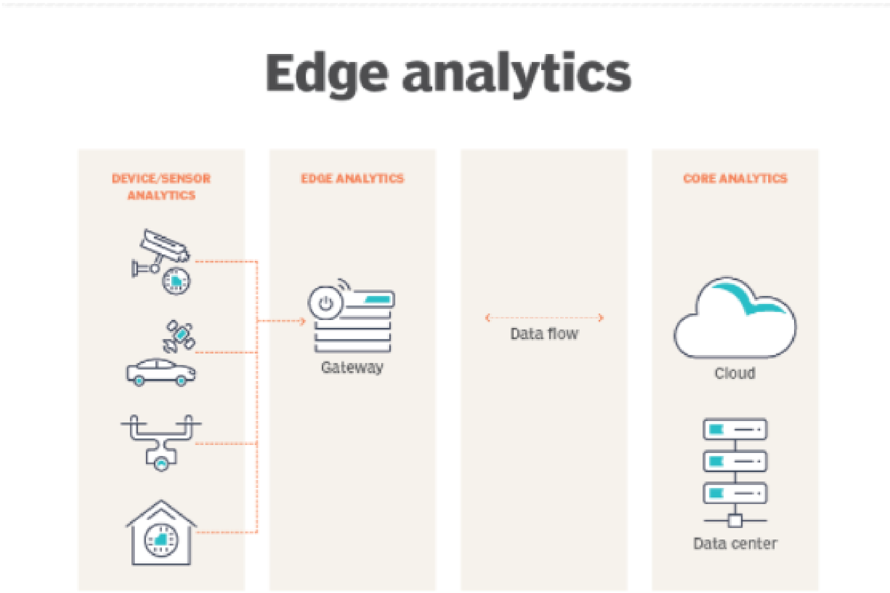

Figure 3.1: Edge Analytics

Thanks to these analysis , several benefits are guaranteed :
• Near real-time analysis of data :Since analysis take place near the data,more precisely on board the device itself, the data is more likely being analyzed in near real time [12].
• Scalability :Edge analytics is naturally scalable because each device analyzes its own data and thus the network is capable of coping and performing well under the increased workload [12].
• Possible reduction of costs [12].
• Improved security [12].

3.2.2 Vehicle to vehicle scenario

Vehicles are facilitated with Internet access that allows them to connect with other vehicles on the road. The connected scenario can either be V2V vehicle to access point or access point to access point [12].

Deploying MEC environments alongside the road can enable two-way communication between the moving vehicles. One vehicle can communicate with the other approaching vehicles and inform them with any expected risk of traffic jam , and the presence of any pedestrians and bikers . In addition , MEC server is able to make calculations and to make decisions, in order to guide vehicles accordingly provided thanks to Edge analytics [12].

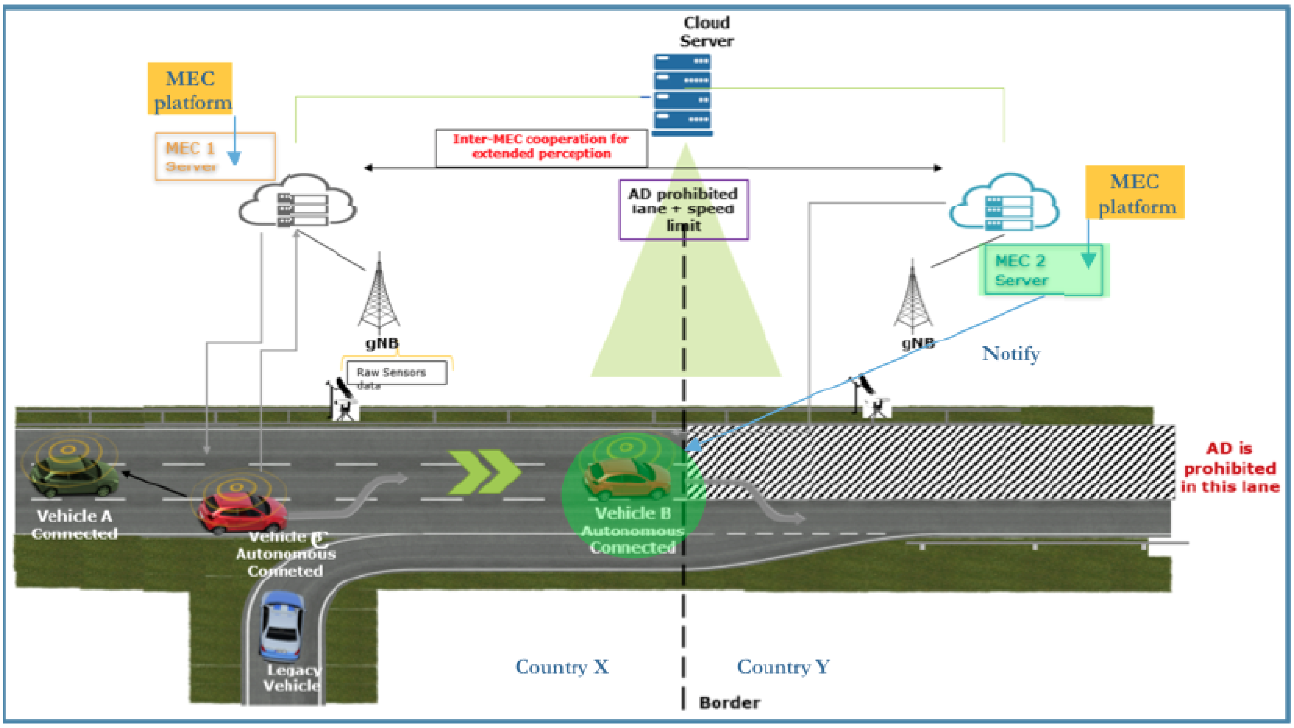

Figure 3.2: V-2-V scenarios

For instance , let's have a look at vehicle B ,shown in Figure 3.2, which is crossing the border from Country X to country Y. As a result , control of vehicle B will be Handed-over from the first MEC server to the second MEC server . And since vehicle B is entering a lane in which autonomous driving is prohibited , the second MEC server needs to send a notification to vehicle B (V2V scenario) to alert it of the situation and change its lane [12].

3.3 MEC Testbeds

5th generation Test Network :
The 5th generation test network (5GTN) architecture was developed and successfully tested at Oulu-Finland ,which is based on LTE and LTE-advanced technology. It opens an opportunity for application developers to develop their applications in a test environment before they are brought to the market .The key purpose of this testbed is to give access to the university students and visitors with high-nature 5G experience .MEC functionality is based on a Nokia provided solution that is operative in an AirFrame cloud environment and can be tested I the 5GTN architecture [10].

Industrial Tesbeds :
Nokia and China mobile successfully tested advance mobile solutions for utmost mobile data capacity and real time video. The testbed was deployed in a car race stadium where 11707 users were simultaneously connected with small cells and 6195 users with macro cells. Nokia and its partners delivered an intelligent car-to-car infrastructure communication system using operators live LTE network. Vehicles connection is facilitated by different cloudlets deployed on the Nokia MEC platform at mobile base stations as shown in fig . Vehicles changing lanes are alarmed with the critical distance between them . On the basis of distance and car velocity ,the situation is computed by the cloudlets and later signaled to vehicles with guidance of possible actions to avoid any risks [10].

3.4 Conclusion

To crown this chapter , we have to mention that Edge computing is key to fulfill the goal of V2V scenario thanks to its intelligent and highly-advanced analytics .

General Conclusion

MEC is a new technology that, in the next generation of mobile networks, will allow Content Service Providers to host use case-specific content and applications, as well as services. the MEC will be able to create new use cases and support particular scenarios such as autonomous cars operation where high data rates and low latency are expected. autonomous vehicle applications are now considered one of the most emerging applications in the field of IoT and are bound to have a positive impact on transportation systems as a whole. However, they still need the infrastructure and data networks necessary for them to become common, safe, and widely used. In the relevant literature, 5G and more specifically MEC is considered as the required key concept that could enable autonomous cars operation.

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