H2020 5G-Coral Project

Grant No. 761586

D1.2 – 5G-CORAL business perspectives

Abstract

This is the second deliverable from WP1. It targets to provide a business perspective analysis of the Edge and Fog solution envisioned in the 5G-CORAL project. In this deliverable, we have reviewed the current XaaS business models used in Cloud services and further analysed the paradigm change from Cloud to Edge with specific highlights on the views of Cloud providers and telecom operators. Further analysis of the new business ecosystem of Edge and Fog has been presented, where the possible roles that different key players may act are presented. Regarding business model analysis, the business model Canvas tool is used. In this deliverable, we presented the business model Canvases for Edge and Fog system providers, as well as for the Edge and Fog service providers of seven 5G-CORAL use cases. Furthermore, in Appendix, two new 5G-CORAL use cases are described, an updated 5G-CORAL architecture is presented, and a technical interpretation of the 5G-CORAL system-level requirements is summarized.

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List of Acronyms

Acronym	Definition
5G	Fifth Generation
5G-AA	5G Automotive Association
5G-PPP	5G Private Public Partnership
AI	Artificial Intelligence
AMOD	Automated Mobility on Demand
API	Application Program Interface
AR	Augmented Reality
AWS	Amazon Web Services
B2B	Business-to-Business
B2C	Business-to-Client
BBU	Baseband Unit
BSC	(2G) Base Station Controller
BSS	Business Support System
CAPEX	CAPital EXpenditures
CCTV	Closed Circuit Television
CD	Computing Device
CDN	Content Delivery Network
CO	Central Office
CPE	Customer Premises Equipment
C-RAN	Cloud-RAN
D2D	Device to Device
DaaS	Data-as-a-Service
DASH	Dynamic Adaptive Streaming over HTTP
DC	Data Center
DSLAM	Digital Subscriber Line Access Multiplexer
EC2	Elastic Compute Cloud
EFS	Edge and Fog computing System
EFS-VI	EFS Virtualization Infrastructure
FTTH	Fiber-To-The-Home
GCE	Google Compute Engine
HD	High Definition
HEVC	High Efficiency Video Coding
HMD	Head-Mounted Display
IaaS	Infrastructure-as-a-Service
ICT	Information and Communication Technology
IoT	Internet-of-Things
ISP	Internet Service Provider
IT	Information Technology
KPI	Key Performance Indicator
LAN	Local Area Network
M2M	Machine–to-Machine
MANO	NFV MANagement and Orchestration
MEC	Mobile/Multi-access Edge Computing
MoU	Memorandum of Understanding
MPLS	Multi-Protocol Label Switching
MQTT	Message Queuing Telemetry Transport
MS	Microsoft
MTSO	Mobile Telephone Switching Office
NFV	Network Functions Virtualization
NFVI	Network Functions Virtualization Infrastructure

OBU	On-Board Unit
OCS	Orchestration and Control System
OEM	Original Equipment Manufacturer
OLT	Optical Line Terminals
OMAF	OMnidirectional Application Format
OPEX	OPerational EXpenditures
OSS	Operations and Support System
OTT	Over the Top
PaaS	Platform-as-a-Service
POS	Point of Sale
QoE	Quality-of-Experience
QoS	Quality-of-Service
R&D	Research and Development
RAN	Radio Access Network
RAT	Radio Access Technology
RNC	(3G) Radio Network Controller
RRH	Remote Radio Head
RSU	Road Side Unit
SaaS	Software-as-a-Service
SDN	Software Defined Network
SDO	Standards Developing Organization
SD-WAN	Software Defined Wide Area Network
SME	Small Medium Enterprise
SV	Software Vendor
V2X	Vehicle-to-Everything
VIM	Virtualization Infrastructure Manager
VM	Virtual Machine
vMME	virtualized Mobility Management Entity
VNF	Virtual Network Function
VR	Virtual Reality
vRAN	virtualized RAN
WAN	Wide Area Network
XaaS	Anything-as-a-Service

Executive Summary

This is the second deliverable (Deliverable 1.2) in WP1 of the 5G-CORAL project. 5G-CORAL targets to investigate and design an integrated Edge and Fog system/solution which follows the basic frameworks laid out by ETSI NFV and ETSI MEC and extend them with new features to integrating Fog infrastructure. Deliverable 1.1 has presented the basic 5G-CORAL architecture and the use cases which are being investigated in the project. In this second deliverable, we focus on analysing the business perspectives of the 5G-CORAL concept.

Edge and Fog computing investigated in 5G-CORAL is a new paradigm, which extends Cloud computing with added computing, storage and networking at the network edges near the end-users. It can either work jointly with Cloud or work independently at the edge. There are clear benefits for Edge and Fog comparing to Cloud, as exemplified in the list below.

- Low latency communication enabling delay sensitive applications
- Traffic offload for high bandwidth applications (e.g. camera surveillance); resources are located at the Edge of the network allowing the reduction of the traffic flow between the access and the core
- Possibility to utilize user-context information; placing computation capabilities at the Edge of the network allows gathering of information from the radio network in real-time, hence it helps optimizing the service provisioning and improving user experience.

However, it is foreseen that a big investment for deploying and managing the Edge and Fog infrastructure is needed to realize these benefits. Therefore, it is key to understand whether the Edge and Fog services could be a great business or not, from a business perspective. A good business potential would help establish a thriving ecosystem delivering rich Edge and Fog services, which would push the market growth rapidly, like today's Cloud business (more than 15% growth every year according to Gartner [47]). In this deliverable, our investigations focus on analysing the new business ecosystem of Edge and Fog and discussing the views from different players, such as telecom operators, cloud providers, hardware vendors etc., who may act as different roles in the ecosystem, as well as providing business case analysis for seven 5G-CORAL use cases. One tool used for business case analysis is the business model Canvas (Strategyzer, u.d.). The business model Canvas is a tool commonly used to evaluate the business potential and opportunities for use cases. It also shows the relationships among different players acting within a specific scenario.

In the following, we provide a summary of the key contributions of this deliverable.

- Chapter 2 starts with an overview of Cloud business models, i.e. XaaS models such as IaaS, PaaS and SaaS, which have been proven as successful models for delivering Cloud services. Then, the paradigm change from Cloud to Edge is further discussed. Two different views to Edge computing from the perspectives of two key players are presented; Cloud providers and telecom operators.
    - Cloud providers take Edge as an extension of their Cloud services, especially targeting IoT applications. Unlike the Cloud case where they own data centers, Cloud providers typically don't have access to edge premises and have no intention to pay for that either. Instead, they focus on developing software stacks (e.g. AWS Greengrass and Microsoft Azure IoT edge) and let other players install the software at the Edge infrastructure. The PaaS model is used to run edge services. Such software stacks at the edge are also integrated with their Cloud services, which would help to grow their Cloud business. As an example, a detailed analysis of AWS Greengrass is provided.

- Telecom providers take Edge as an opportunity to enrich their services, not only providing connectivity services but also high-value services such as Augmented Reality (AR), Virtual Reality (VR), Connected Cars etc., which are enabled by providing the services at Edge. In addition, telecom operators can reuse their millions of base station sites and thousands of Central Office (CO) sites to provide IaaS and PaaS to host the services of other players at their edge infrastructure. All these will bring new revenue streams which may significantly contribute to operators' growth, while the revenue from connectivity services may get flattened in the future.

- Chapter 3: a new ecosystem of Edge and Fog has been analysed for a single-domain scenario. Nine roles and their relationships are presented, as summarized in FIGURE 1. In the ecosystem, the Edge and Fog system provider takes the central role of the 5G-CORAL ecosystem. It operates and invests on deploying the 5G-CORAL Edge and Fog system, mainly providing PaaS for hosting customers' software and applications. In some cases, IaaS can be provided to host VMs of customers. It is a similar role as the Cloud provider in Cloud computing, which is crucial to create the ecosystem and makes it successful.

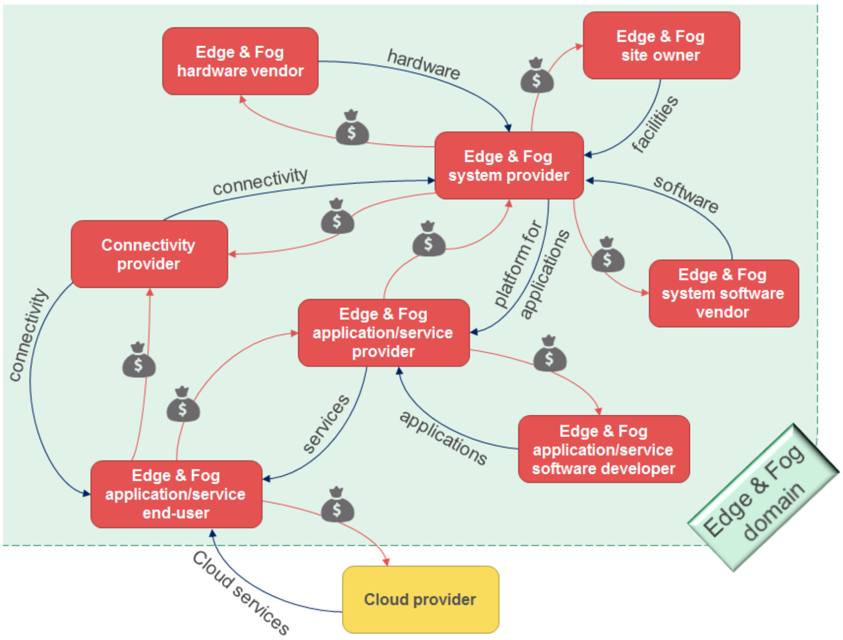

FIGURE 1 ILLUSTRATION OF 5G-CORAL ECOSYSTEM

To understand the business case for the Edge and Fog system provider, the business model Canvas was applied for the analysis, as shown in FIGURE 2. More detailed explanations refer to Section 3.2. It shows the business feasibility of the Edge and Fog system provider to run the Edge and Fog system (i.e. the 5G-CORAL system) providing PaaS (and/or IaaS). The value proposition is definitely strong with the features of low latency, traffic offload etc. where the Edge and Fog system can offer services that Cloud can't provide and enhance the existing services while keeping the advantages of PaaS and IaaS, e.g. pay for usage.

Key Partners
- Hardware vendors
- Software vendors
- Landlord (Edge and Fog site owner) providing local space for Edge and Fog equipment
- Internet service providers (telecom operator)
- Cloud providers
- Open source community

Key Activities
- Deployment of Edge and Fog infrastructure
- Development, maintenance, management and scaling of the platform
- System optimization

Key Resources
- Edge and Fog computing hardware (e.g. Edge DC, Fog CD, networking gears)
- Software supporting EFS provisioning and OCS
- Internet connectivity

Value Propositions
- EFS hosting its own and 3rd-party VNFs benefiting from low latency and/or data offloading from core network and/or central Cloud
- Provide data service (EFS services) between VNFs providing extra values for service improvement or enable new services
- Rapid self-service for VNF provisioning by OCS
- Provide advanced capability like Big Data and AI
- Automation of VNF life cycle management by OCS

Customer Relationships
- Customer conferences
- Feedback analysis
- Customer support

Channels
- Self-service
- APIs

Customer Segments
- Edge/Fog service or application providers
- The end-users for its own applications (VNFs) if any

Cost Structure
- Hardware costs for the Edge and Fog computing infrastructure
- Electricity power and Internet services (telecommunications)
- Renting space for hardware
- People for developing and managing the Edge and Fog system

Revenue Streams
- Subscription fee (e.g. monthly, annually) for hosting VNFs, can be revenue sharing with Edge and Fog service providers
- Data subscription fee for providing data services between VNFs (fixed fee or per number of services or data volume)
- Extra subscription fee for providing advanced capability such as Big Data and AI (per use or processing usage)
- Other revenue from its own applications if any

FIGURE 2 BUSINESS MODEL CANVAS FOR EDGE AND FOG SYSTEM PROVIDERS

Furthermore, the business challenges and opportunities of six key players which may play roles in the ecosystem are discussed. As a summary, Table 1 shows the roles each key player may play in the ecosystem. More detailed discussions refer to Section 3.3.

TABLE 1 MAPPING BETWEEN KEY PLAYERS AND ECOSYSTEM ROLES

Ecosystem role	Telecom operator	Software vendors	OTT service providers	Cloud providers	Hardware vendors	Vertical Companies
Edge and Fog system provider	X		X		X	
Edge and Fog site owner						X
Edge and Fog hardware vendor					X	
Edge and Fog system software vendor		X		X		
Edge and Fog application/service provider	X		X			
Edge and Fog application/service software Developer		X				
Edge and Fog application/service end-user						X
Cloud provider				X		
Connectivity provider	X					

- Chapter 4: To make the integrated Edge and Fog ecosystem successful, viable business cases are deemed as essential for the companies providing Edge and Fog infrastructure and/or services. This perspective has been clearly proven in the case of Cloud computing, where the Cloud system providers (e.g., Amazon) and the companies running their services in the Cloud (e.g. Netflix) both benefit from the business dynamics offered by the Cloud computing. Therefore, an analysis of the potential business models envisioned for seven 5G-CORAL use cases is provided. The analysis is performed from the service provider's perspective using the tool of the business model Canvas. Such analysis highlights the business feasibility of each use cases, which reflects the fact that there will be a lot of Edge and Fog services which can find their business cases, like today's cloud application and services. More detailed analysis refers to each section in Chapter 4.

- Chapter 5: Federation consideration is discussed for the multi-domain scenario. As an ongoing study, this chapter presents the current progresses made in federation studies in 5G-CORAL. It presents an overview of how federation relationships are established (static and dynamic), the level of trust they maintain (low vs. high), what resources they federate (horizontal, vertical and hybrid) and which is the payment method (subscription vs. pay-per-use). The benefits of applying federation in the 5G-CORAL system is shown through some of the use case scenarios, such as: Cloud Robotics (cleaning service scenario and robotic service scenario), VR and High-speed Train.

- Appendix: it describes two new use cases (i.e. SD-WAN and VR use cases) apart from the ones already described in D1.1 [1]. They are described following the same methodology already used in D1.1 [1] for the other use cases addressed by 5G-CORAL. An updated 5G-CORAL architecture is also presented with some changes of terminology and extended functions for interface T8, O5 and O6. Furthermore, the technical interpretation of the 5G-CORAL system-level requirements is provided by taking the work of 5G-CORAL technical work packages (i.e. WP2 and WP3) into account. Finally, a deep dive description of the telecom operator's business models for Edge computing is given.

The main conclusion of the deliverable is that Edge and Fog systems bring advantages that gives the potential to establish a new business ecosystem that can be shaped for different use cases such as multi-RAT IoT, SD-WAN, Connected cars, high-speed train, AR Navigation, VR and Cloud robotics. The Edge and Fog system provider will be one of the most important roles to foster these ecosystems. It is likely that they will use a PaaS based business model and they will have contacts with hardware vendors, site owners and connectivity providers to set up the infrastructure and with system software vendors to establish the platform for applications. They will also have a close connection to the application/service provider who utilizes the platform to get applications from application/service software developers and who can offer the application and services to the end-users.

It will be possible for different players to take on the role of a system provider. It is also possible that one player takes on several roles. Looking at the business landscape as of today the two most likely players to take on the role as a 5G-CORAL system provider is a Cloud provider or a telecom operator. The Cloud provider can leverage on their expertise of Cloud platforms and software but they lack the locations close to the customers. Therefore, it is likely that they will focus on delivering platform software and let another player run the infrastructure and local installation/maintenance. The operator on the other hand can leverage on their network that covers many sites and locations where they are close to the end-users. By extending existing sites with Edge capabilities that can host a 5G-CORAL system they have the possibility to take an important part of the business potential.

1 Introduction

The fifth-generation (5G) mobile communication network targets deployments and use cases far beyond voice and mobile broadband which are the main business areas of the preceding mobile technologies. The capabilities to support higher data rate, a vast number of connections and devices, ultra-reliability, robust security, high energy efficiency and very low latency enables the network to be used for emerging applications such as Mixed Reality, Cloud Robotics, Connected Vehicles and a variety of Internet-of-Things (IoT) use cases.

Another big trend in the communication industry is the digitalization of industries where *Cloudification* plays an important role. However, the traditional Cloud architecture is based on centralized networking, compute and storage and thus the processing is done far from the end-user which implies significant latency. Scalability is another challenge with this architecture since the centralized Data Centers (DCs) need to cope with enormous amounts of data and connections. To overcome this and to meet the requirements of the new use cases that 5G targets the networking, storage and compute capabilities must be moved closer to the end-user. This can be done by having a more distributed Cloud approach with more and smaller Edge DCs at locations that are close to the users. Such a concept has been standardized by ETSI in recent years and is referred to as Mobile Edge Computing or Multi-access Edge Computing (MEC). The 5G-CORAL project aims at also including mobile and volatile computing, networking and storage resources in what is referred to as a consolidation of Edge and Fog. The foundation of this concept with an initial system design, use cases and requirements is presented in [1].

The consolidated Edge and Fog concept is foreseen to evolve the business ecosystem of mobile networks and Cloud computing. This deliverable discusses the potential business impacts of introducing this concept and analyses different possible business models for players acting in this ecosystem. It also includes the key players views on the business challenges and opportunities that comes with the Edge and Fog. Finally, the concept of *federation* and how it could apply to different use cases is introduced.

Note that this document generally relates to the business aspects of a consolidated Edge and Fog system. However, sometimes the specific implementation of the Edge and Fog as specified in 5G-CORAL is referred to and then this is called a 5G-CORAL system.

The document is structured so that **Chapter 2** presents current business models for Cloud and Edge and lists the key players and the most important products in the area. **Chapter 3** describes a 5G-CORAL business perspective analysis including identification of the key roles and the ecosystem as well as a business model analysis for the Edge and Fog system provider who is foreseen to play a key role in this ecosystem. The key players views on the business challenges and opportunities are also presented here. **Chapter 4** include business model analysis for the 5G-CORAL use cases. **Chapter 5** introduces the concept of federation in the context of 5G-CORAL and describes how it can be applied to some use cases. Finally, the deliverable is concluded in **Chapter 6** to summarize the findings and to set the prospects for future work.

2 Cloud and Edge Business models

The Cloud computing paradigm enables access to big shared pools of computing and storage resources and services provisioned from remote DCs placed over the Internet, far away from the end-user. These remote DCs provide a huge amount of computation and storage capabilities which hardly is available locally. This paradigm is called Cloud computing because the accessed information is located in the “Cloud", not restricting a user to be placed on a specific location but allowing to access the resources remotely via an Internet connection.

Edge computing pushes some computation and storage capabilities (smaller scale than the Cloud DCs) to the Edge of the network, i.e. closer to the end-user. Getting the storage and computing power to the Edge provides some benefits which would complement the usage of Cloud:

- *Low latency communication* enabling delay sensitive applications
- *Traffic offload* for high bandwidth applications (e.g. camera surveillance); resources are located at the Edge of the network allowing the reduction of the traffic flow from the access to the core
- Possibility to utilize *user-context information*: by placing computation capabilities at the Edge of the network allows to gather information from the radio network, hence it helps optimizing the service provisioning and improving user experience.

In this Chapter, an overview of Cloud computing and the key business models based on the Anything-as-a-Service (XaaS) approach are given. Then more effort is dedicated to Edge computing, which is complementary to Cloud computing. The focus is on two relevant stakeholders of Edge computing: Cloud providers and telecom operators, who have shown great interest in running Edge computing related businesses in different ways, also focusing on different areas. Cloud providers are mainly addressing the emerging IoT area and intend to provide extensions to their Cloud services by providing Edge software stacks, while telecom operators want to reuse their base station and central office sites to host Edge Cloud services both for internal Virtual Network Functions (VNFs) and 3rd-party applications based on a Platform-as-a-Service (PaaS) model.

2.1 Cloud computing and XaaS model

The Cloud business has been growing rapidly in recent years as the *Cloudification* process has accelerated and become an important part of the digitalization trend. Big web-scale companies like Amazon, Microsoft (MS), Google, IBM and Oracle are dominating the Cloud computing market with their respective products Amazon Web Services (AWS), Microsoft Azure, Google Cloud Platform, IBM SmartCloud and Oracle Cloud. AWS holds a 35% market share for Infrastructure-as-a-Service (IaaS) and PaaS while MS, Google and IBM hold 11%, 8% and 6%, respectively. In 2017 AWS provided a revenue of around $11 billion and in early 2018 MS Azure presented an impressive quarterly growth of more than 100 % higher than the previous year [2] [3] [4]. The fast growth is foreseen to last as the Cloud providers continue to develop more features/services and add even more values to customers. MS Azure alone now provides more than 600 services and forecasts (e.g. Forrester in [6]) predict that the Cloud market will grow from $146 billion in 2017 to $236 billion in 2020.

The history of Cloud computing business traces back to 2006, when Amazon released its Elastic Compute Cloud (EC2) product as one pillar of AWS. The original idea of EC2 was to resell the spare computing power of its existing DCs (which led to the definition of IaaS), hosting the Virtual Machines (VMs) of the customers. It created a new per-use service-based business model, where companies rent VMs from Amazon and deploy their software on the rented VMs instead of owning the hardware by themselves. This is especially attractive for small companies (e.g. start-ups) as it allows to save the cost of purchasing hardware and decreases the time to initiate and scale the system. AWS also develops a Cloud platform which provides the customers not only the computing power but also other software capabilities such as database, content delivery and security functionalities through Application Program Interfaces (APIs). Such a paradigm is now called PaaS, which simplifies and strengthens the software development and deployment in the Cloud.

Software–as-a-Service (SaaS) is another mainstream Cloud computing paradigm, in which the application software is deployed in the Cloud and managed by the software vendor. Applications are accessed by the end-users via the Internet, typically through a Web interface or a simple device application, hence minimizing the hassles and tedious work of software installation, maintenance, update, backup and other operations on the premises.

A commonly used general term for the three above mentioned Cloud computing models (IaaS, PaaS and SaaS) is XaaS. Figure 3 gives an overview of the different XaaS concepts. As can be seen more and more components are managed in the Cloud by the XaaS providers when moving from IaaS to SaaS, while the customer flexibility in the system gets less and less. These characteristics determine the use cases of the different XaaS models. Here, some examples are given.

- Commonly used software that are accessed from many different platforms are good to run as SaaS, e.g. Google Apps (Gmail, Google docs, etc.), MS Office 365, Dropbox, Salesforce, Cisco WebEx, GoToMeeting and Netflix
- Highly customized software requiring customer self-development and management are suitable for PaaS such as AWS Elastic Beanstalk, Windows Azure, Google App Engine, Force.com, Apache Stratos and OpenShift.
- Migration of legacy software from the premises to Cloud is usually good to use IaaS to smoothen the migration process. Examples of IaaS systems include AWS EC2, MS Azure and Google Compute Engine (GCE).

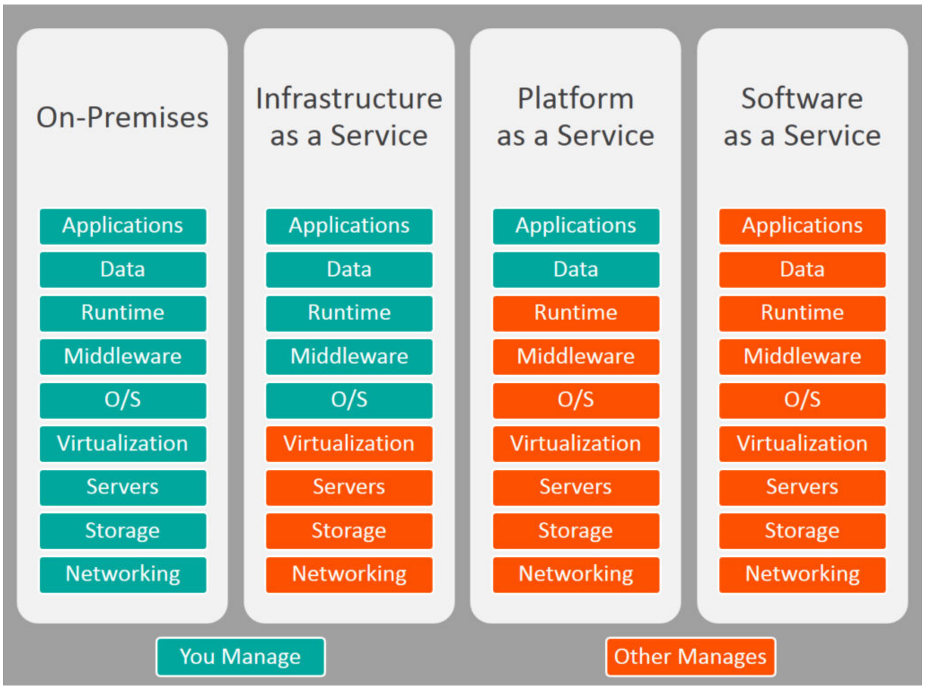

FIGURE 3: XAAS COMPARISON [5].

Cloud computing and the XaaS model are game changers which remove the need of local computing hardware and moves the software to the central Cloud. Basically, it turns CAPital EXpenditures (CAPEX) into OPerational EXpenditures (OPEX). This completely changes the ways of using, designing/developing and deploying software.

- In IaaS, the Cloud customers save the time and costs to purchase, manage, maintain, scale and support the hardware infrastructure and focus more on their own core businesses improving the productivity. Instead of paying the hardware, customers pay for the run time of the VMs on a usage basis, with significant CAPEX savings.
- In PaaS, in addition to the IaaS benefits, the Cloud customers benefit from simplified software development (focusing on the key features relevant to the applications) and getting support of the latest software technologies through proper APIs, reducing the barrier of adopting advanced technologies such as Artificial Intelligence (AI), Big Data, etc. In this case, the PaaS provider becomes a key partner of the customers in terms of software development, as the platform APIs and services are integrated in the software. Customers pay subscriptions (flat and/or usage-based) to the PaaS provider.
- In SaaS, the Cloud customers greatly reduce the time and costs to install, manage, upgrade software and let the Information Technology (IT) staff focus more on other more important matters and issues. Instead of paying licenses for the locally installed software, customers pay subscriptions (flat and/or usage-based) to the SaaS provider.

2.2 Moving from Cloud to Edge

As previously described, having some computing capability and intelligence at the Edge of the network would benefit the applications which require running close to the end-users, e.g. for low latency, traffic offload and security reasons. It clearly complements the Cloud computing business as it enables new use cases. For example, some 5G use cases with significant business potential, e.g. AR/VR, camera surveillance, Cloud Robotics and connected vehicles would be unfeasible without having Edge computing in place.

As an extension to Cloud computing, the XaaS-based models fit to Edge computing as well, where the Edge providers develop IaaS and PaaS to host customers' Edge applications/software, while the SaaS providers implement software from the Edge (together with Cloud) to the end-users. However, when moving computation capabilities closer to the end-users and into more diverse locations the business ecosystem becomes more complex and this gives an opportunity for different players to take part of the business. An example is the telecom operators who can leverage from their networks and their existing equipment sites. With their site presence they have the opportunity to add Edge computing hardware and add Edge capabilities that they can bundle with their network offerings.

The Cloud providers on the other hand typically would not have access to end-user-close locations. They could then possibly focus more on the software side of the Cloud business and let other players handle the site and the hardware. The following subsections will describe the Edge business considerations for the Cloud providers and the telecom operators in more detail.

2.2.1 Cloud provider

Cloud providers such as Amazon and MS target IoT as their key business area for Edge computing. They have recently showcased innovative Edge solutions such as AWS Greengrass and MS Azure IoT Edge. This is due to the fact that previous Cloud-based services are not entirely suitable for the IoT use cases. More specifically, the main limitations can be listed as follows:

- *Limitation on latency-sensitive service*: in AWS or MS Azure, a client can only consume a service from a Cloud server, which is usually located far from the client itself, and hence the quality of a latency-sensitive service would be hard to be fulfilled.
- *Always requiring Internet connection*: an IoT device, usually power constrained, cannot consume a service without Internet connection towards AWS or MS Azure Cloud server, resulting in wasting its energy in order to maintain an always-on connection, even though data traffic is intermittent.
- *High consumption of network resources*: in AWS or MS Azure, huge network resource utilization is required for delivering a certain amount of data between a high number of IoT devices and the Cloud server.

Both AWS Greengrass and MS Azure IoT Edge run the PaaS model at the Edge of the network, as an extension to their Cloud offering. They provide a software stack which can be self-installed on the Edge nodes by the customers. This is because the key asset of Cloud providers is their software capability: they don't own any Edge premises and it is unfeasible for them to acquire such infrastructure. On the IoT device side, they also provide the device software stack to interoperate with their Edge software stack. Customers pay subscriptions for the Edge services based on the number of devices connected, which may vary depending on the region [2]. Also, AWS Greengrass offers two pricing options for customers using a number of Greengrass core devices ranging from 3 up to 10000 units: pay-as-you-go with a fixed monthly fee for each employed device, and a 1-year subscription per each device, which entails a 22% savings with respect to the first option. Cloud APIs are also provided to help integrate their Cloud services.

An overview of the AWS Greengrass architecture is shown in Figure 4.

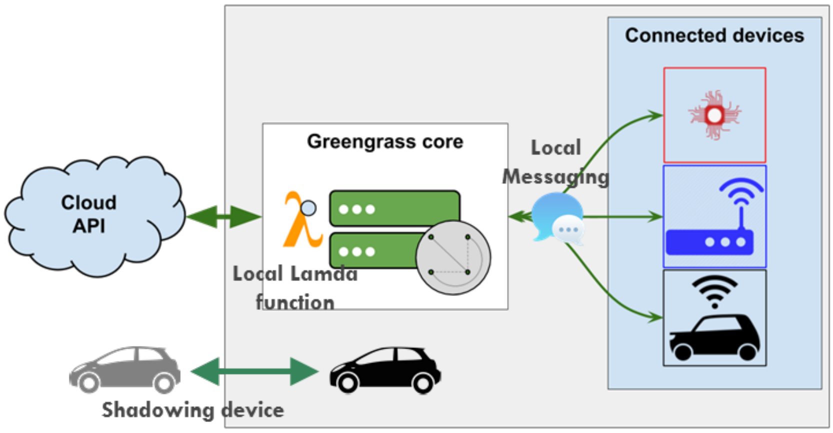

FIGURE 4: AWS GREENGRASS ARCHITECTURE.

It consists of three key components, namely Greengrass core, Greengrass JDK, and Cloud API [7]. Greengrass core carries out Edge computing for Greengrass group and interoperates with AWS Cloud. The Local Lambda function within Greengrass core can elaborate local data received from IoT devices belonging to the Greengrass group. Greengrass core uses Message Queuing Telemetry Transport (MQTT) as messaging protocol to communicate with IoT devices within the group and can receive multiple sensors' data as well as control connected devices through commands generated from Local Lambda function. The Greengrass JDK should be installed into an IoT device in order to interact with Greengrass core: such IoT device can be then authorized as a Greengrass group member and can communicate with Greengrass core via local messaging.

In AWS Greengrass most of the data is locally processed and executed by the Greengrass core. However, the computing resources of the Greengrass core and local data are limited such that various functions available in the Cloud platform cannot be afforded, thus leading to a degradation of the execution accuracy. For this reason, the Greengrass core includes Cloud APIs to interoperate with the AWS Cloud platform. It can utilize many functionalities of the AWS Cloud platform which are imported to the Local Lambda function via the Cloud API. Also, the Greengrass core can report metadata to the AWS Cloud platform, which are generated from local sensors' data received from IoT devices and filtered by the Greengrass core. The metadata can feed the AWS Cloud platform to conduct proper inference and update the AWS Local Lambda functions for the specific service. Furthermore, the AWS Cloud API can be used in the Cloud platform to shadow the IoT device, i.e. a virtual representation of the device that acts as a communication layer between the mobile/Cloud application and the physical device connected to AWS. The Cloud platform monitors the metadata of IoT devices and updates their status. A client can then remotely monitor the status of IoT devices and control them via a web application.

In summary, AWS Greengrass features the following benefits:

- *Respond to local events in near real-time*: AWS Greengrass devices are able to locally modify the data they generate and then quickly react to local events, while still using the Cloud for management, analytics and durable storage.
- *Simplified device programming with AWS Lambda*: AWS Greengrass employs the same AWS Lambda programming model available in the Cloud, meaning that code developed in the Cloud can be seamlessly deployed within the devices.
- *Operate offline*: AWS Greengrass allows connected devices to operate even in case of intermittent connectivity with the Cloud. As soon as the device reconnects, Greengrass takes care of synchronizing the data on the device with AWS IoT, thus delivering seamless functionality regardless of connectivity.
- *Reduce the cost of running IoT applications*: with AWS Greengrass a device can be programmed to filter data locally and only upload to the Cloud what is necessary for the applications to properly run.
- *Secure communications*: AWS Greengrass authenticates and encrypts device data for both local and Cloud communications. As a result, data are never exchanged between devices and the Cloud without proven identity.

In the following, use case examples adopting AWS Greengrass are introduced.

2.2.1.1 Elevator monitoring

An elevator manufacturer could adopt AWS Greengrass as a service platform to enhance the management. As shown in Figure 5, an elevator is typically equipped with various sensors, e.g. temperature, cameras. etc. that would report sensing data to the AWS Greengrass core. The latter can determine an action according to the reported data and, if it can be handled locally, AWS Greengrass core can find an appropriate Local Lambda function for elaboration. If required by the action, the Greengrass core reports the event and data to AWS Cloud platform via Cloud API. AWS Cloud platform relies on several functions, e.g. Amazon Machine Learning, AWS IOT, AWS Lambda etc., in order to improve management actions. The metadata could be also reported to a building owner (or operator), which can enable visualization management for the building owner itself.

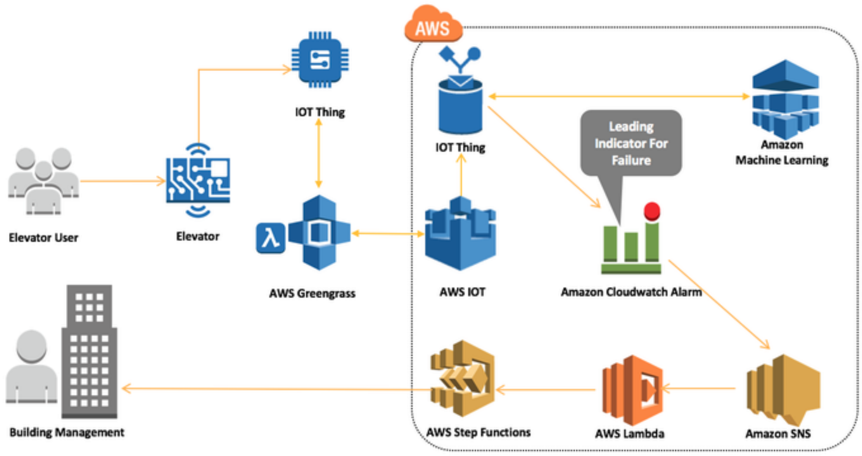

FIGURE 5: ELEVATOR MONITORING BY AWS GREENGRASS [4].

2.2.1.2 Automated Vehicle

Aptiv (a subsidiary of Delphi) and Denso (one of the world's largest suppliers of auto components and software) adopted AWG Greengrass and microservices for the Automated Mobility On Demand (AMOD) platform, shown in Figure 6, to drive the onboard user experience, along with Edge processing, monitoring and control of automated vehicle. A user can obtain fast reaction for some events detected by Kinetic sensors installed in the car by means of the AWS Greengrass core's Local Lambda function. Also, anomaly events could be learned and reported to the AWS Cloud platform. Trip data with location information can be filtered by the AWS Greengrass core and fed into the AWS Cloud platform, which can then be stored within the Amazon DynamoDB to improve user-specific travel experience. In addition, it could be used to update the assistance AWS Greengrass core's Local Lambda function and enhance the driver's safety. An overview of the overall architecture is illustrated in Figure 7.

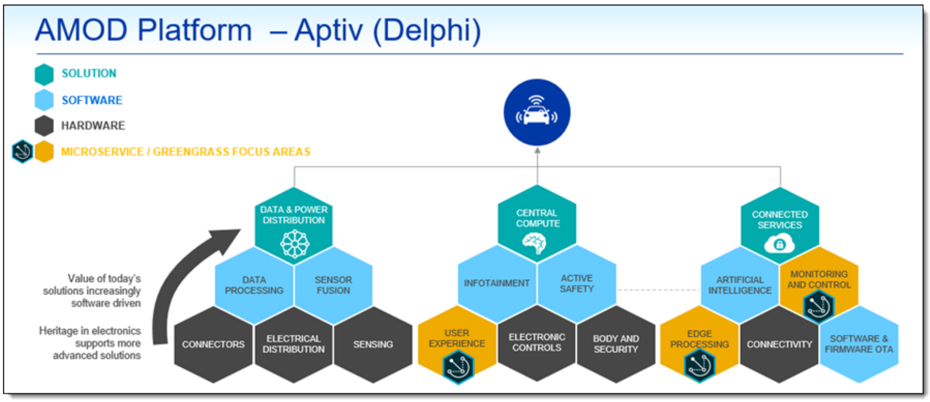

FIGURE 6: AMOD PLATFORM [8].

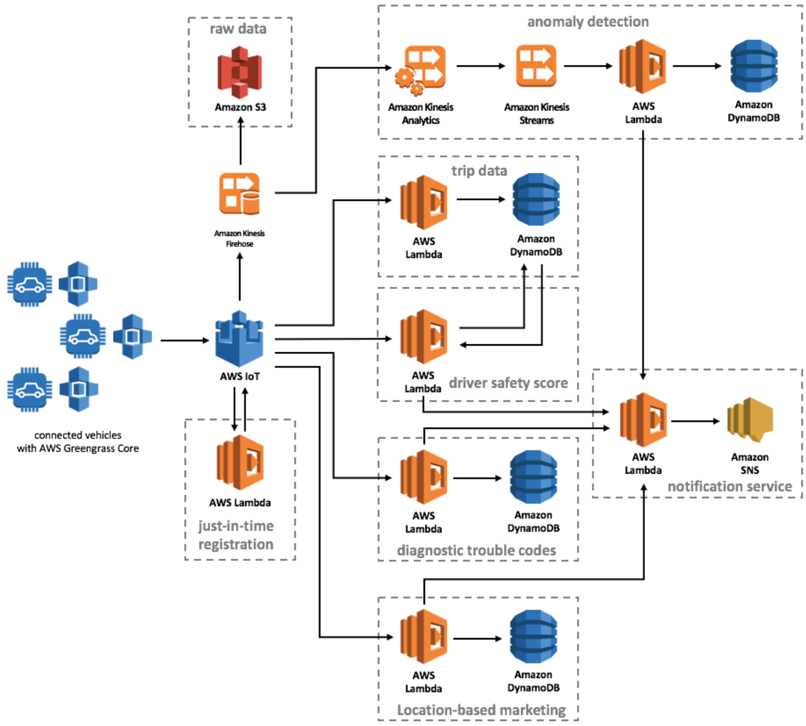

FIGURE 7: CONNECTED VEHICLES BY AWS GREENGRASS [8].

2.2.1.3 MEC for private LTE network

Nokia presented a MEC solution integrated with AWS Greengrass during the AWS workshop in June 2017 [9]. As shown in Figure 8, Nokia's MEC hosts AWS Greengrass in the Edge, which enables a number of IoT applications over a private LTE network. This collaboration aims to support new 5G use cases and to develop disruptive IoT applications for large enterprise customers as well as to enhance user experience for Nuage Networks Software Defined Wide Area Network (SD-WAN) customers who employ AWS.

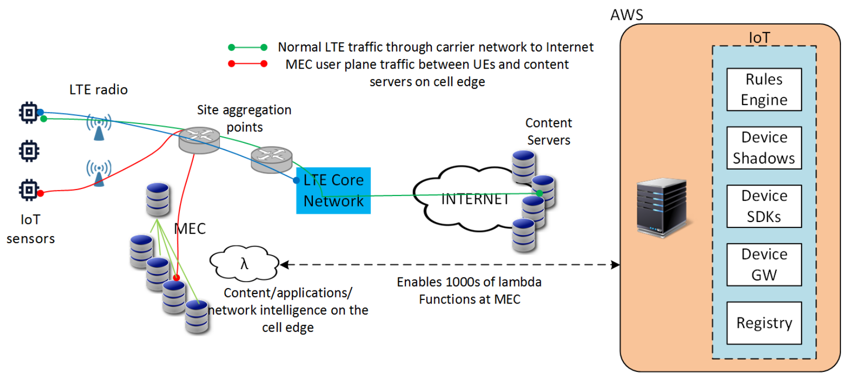

FIGURE 8: AWS GREENGRASS INTEGRATED WITH NOKIA'S MEC PLATFORM [7].

2.2.2 Telecom operators

Telecom operators are currently facing the problem of providing a platform being able to support requirements for new innovations such as Augmented Reality (AR), Virtual Reality (VR), Connected Cars and so on. In this context the Edge computing can be considered as part of the future operator's network since the existing mobile network has a lot of limits making it unable to support new innovative services. To start with, the current network capacity and latency are critical factors, as can be observed, for instance, when performing high-quality video streaming over 4G networks.

New innovative services, however, demand much more than video in terms of requirements (e.g. capacity, latency etc.) from the mobile network, therefore if mobile operators would be able to replicate what Cloud providers can provide but closer to the Edge of network, with lower latency and possibly improved scalability, then there is obvious opportunity to charge premium pricing for new, closer-to-the-Edge services. This forces the operators to stop being just connectivity sellers, hence becoming an important player in providing higher-value services. The logic behind this is that telecom operators can reuse their millions of base station sites and thousands of Central Office (CO) sites to offer Edge services. This makes it possible for operators to provide Edge services in their own Edge computing infrastructure leveraging their own premises to host, in the same way as Cloud providers do with their Cloud services via their own DCs. This is a key difference and advantage comparing to Cloud providers since they can run IaaS reselling the Edge computing power hosting VMs and run PaaS selling the telecom platform capabilities.

Edge Cloud, however, should not be seen as an alternative to Cloud computing but they have to be considered complimentary for each other: in fact, depending on the use case to be served, it might be better to instantiate the VNFs needed to execute a specific network procedure within an Edge node while others in a Cloud server.

Edge computing involves the establishment of small Clouds at strategic nodes of the network, with an architecture which recalls the Content Delivery Network (CDN) concept. For operators this means adding Cloud-style computing resources to mobile base stations or network aggregation points, hence allowing next generation network solutions being able to perform bandwidth-heavy and latency-dependent operations as required by, e.g., AR and VR, which represent two of this decade's biggest emerging markets. As reported in [10], in fact, the AR market – valued at 4.21 billion $ in 2017 – is expected to grow at a CAGR of 40.29% during the forecast period from 2018 to 2023, reaching 60.55 billion $ by 2023. Similarly, the VR market – valued at 5.12 billion $ in 2017 – is expected to grow at a CAGR of 33.95% during the forecast period, reaching 34.08 billion $ by 2023.

Current trends in operators' environment that might help building a foundation for Edge computing are the following [11]:

- *Need to reduce costs and increase revenues*, which drives most of the initiatives around operator's Cloud deployment. Cloud, together with virtualization, allows to turn network CAPEX into OPEX (by shifting from proprietary and dedicated equipment to standardised servers) as well as to increase "programmability" of the network to host new applications and services, which can be deployed/updated/scaled rapidly.
- *Need to address new services which are inherently Edge-oriented*: IoT, vertical enterprise applications as well as new consumer services (e.g. IPTV) also fit well into the necessity of having both distributed capabilities and virtualization. For instance, industrial IoT may need real-time control functions of robots, conveyors and so on, housed extremely close by for millisecond (or less) latency. Same as for connected vehicles, which need roadside infrastructure. Furthermore, enterprises might demand on-premise data storage, even for Cloud-delivered services, for security reasons.
- *Possibility to exploit the Edge context data*: some applications are not just latency-sensitive in terms of response between end-user and server, but also need other local, rapidly changing data (e.g. cell congestion or radio interference metrics) to work properly. The use of these data within a platform in a remote location (e.g. in the core network) may be possible only after a certain time period (i.e. the time to reach the

platform) which may be longer than it takes the data to change. This means that the contextual data may be outdated, leading to a wrong action taken by the application. Data originated and used at the Edge could be more useful.

- *Hosting all virtual network functions centrally might be unfeasible*, i.e. only certain functions can be centralised – billing systems, gateways between the core network and a packet data network (Internet), for instance – but others make more sense to be distributed. As an example, CDN caches need to be closer to the network Edge in order to avoid the transport of millions of separate video streams to homes, all the way down from one central facility. This requires some DCs to be located either at aggregation points, central offices or final delivery nodes (base stations, street cabinets, etc.).
- *Growing interest of operators towards Virtual Radio Access Network* (VRAN): the concept of Cloud-RAN (C-RAN) has taken hold recently, based on which traditional base stations are split into baseband units (BBUs) and the actual radio transmit/receive components, also referred to as Remote Radio Head (RRH). A number of BBUs can be clustered together at one physical location, with a fronthaul connecting the RRHs (fibre or other mean, based on the split option). This improves not only efficiency of both power and space utilization, but also allows the BBUs to be combined and virtualized, not precluding the possibility to add further compute functions.
- *Exploitation of physical locations' property*: operators have often sold or rented physical space in their facilities, e.g. colocation of equipment racks of other mobile operators. In turn, they also rely on renting space for their own infrastructure, especially for siting antenna equipment on roofs or walls. Both activities continue today and Edge computing can also be seen as a way to sell "virtual" space in distributed compute facilities.

Operators' business case for deploying Edge computing in their networks will be driven by a variety of new use cases: content/video delivery is probably the most mature use case – and the closest to Telecom operators' existing business – but applications/services addressing the needs of a multitude of verticals (including tourism, retail, healthcare and facilities maintenance) make Edge computing the perfect technology enabler, especially in mobile scenarios. IoT and Machine-to-Machine (M2M) also represent a possible source of revenues, coming from industrial automation, autonomous driving up to remote/robotic surgery, which are completely unthinkable with today's networks. To sum up, the business case for Edge computing is quite simple: if an operator does not deploy it, it will not be able to achieve the 5G objectives in terms of latency reduction for high performance or mission critical services.

However, whether operators adopting Edge computing will achieve opportunities to significantly grow their revenues requires further investigations [12]; recently there have been several Edge computing investments and service announcements among the most significant operators worldwide. As an example, AT&T plans to start deploying MEC in 2018 [13]; Deutsche Telekom signed partnerships with a MEC specialist whose technology it seems likely to install in its own network [14]; Reliance Jio is deploying MEC to create a mobile CDN [20]; and Telstra is selling off half its central offices aiming at converting the remaining ones to Edge DCs [21]. This demonstrates that if operators aim to be or remain market leaders, they have to think at Edge computing in order to deliver the products and services for which 5G is the promised platform, in a timely manner.

However, the market that mobile operators are trying to enter is already being targeted by other players, e.g. enterprise service providers, IoT specialists, Cloud computing and IT vendors, and even their own network equipment providers. Operators have some advantages – e.g. access to location and service quality data, as well as the ability to integrate the Edge computing with the mobile access network - but they will compete for revenues that can often be cannibalized by others using unlicensed and alternative wireless technologies. In addition, it is also hard to envisage whether Edge computing capability will deliver premium revenues, since the most dominant players in Edge computing market will try to protect their share as much as possible. Potential revenues for the operator can only be achieved when the operator will be able to properly provide "Edge computing enabled" services packaged within other high-value services, hence introducing valuable differentiated services at premium prices.

Some simple existing business models for operators can be listed below [17]:

- *Free model*, where applications are distributed within the operator's network free of charge, and the charge is applied to the final consumer.
- *Retail model*, with the operator acting as capacity seller to application developers and managing these client relationships directly.
- *Wholesale model*, in which the operator sells capacity to a Cloud service provider, who then resells that capacity to its own base of application developers.

The above-listed business models strongly rely on the operator's core business, which is the connectivity provisioning. However, connectivity is now heavily commoditized therefore there is the need to identify other factors than, e.g. Quality of Service (QoS), which can contribute in defining the operator's business model. Basically, the operator has to understand whether it is beneficial to move since the beginning towards new Edge-computing based business models or to wait for a strong market demand of Edge computing before changing the way it makes revenues. There might be the risk that Cloud providers will start offering services themselves which, on the other side, represents an obstacle for the operator in building new attractive offerings (i.e. renovate its own network) to new players, being this the best way to create demand for Edge computing.

3 5G-CORAL business perspective analysis

5G-CORAL goes beyond the Cloud and Edge concepts by taking into account mobile and volatile computing, networking and storage resources, i.e. a consolidation of Edge and Fog. The baseline architecture of 5G-CORAL is described in [1] and an updated version of the architecture taking the outcome of the work conducted in technical WPs of the 5G-CORAL project (i.e. WP2 and WP3) into account, is described in the Appendix 0. In short, the 5G-CORAL architecture is based on the ETSI NFV and ETSI MEC frameworks, where a mix of physical and virtualised resources available in the Edge and Fog tiers is considered. The architecture is based on two main building blocks:

- *Edge and Fog computing System (EFS)*: a logical system subsuming Edge and Fog resources that belong to a single administrative domain. An EFS provides a service platform, functions and applications on top of available resources. EFS applications, functions, and service platform are also referred to as EFS entities. An EFS may interact with other EFS domains.
- *Orchestration and Control System (OCS)*: a logical system in charge of composing, controlling, managing, orchestrating, and federating one or more EFS(s). An OCS comprises Virtualisation Infrastructure Managers (VIMs), EFS managers and EFS orchestrators. An OCS may interact with other OCS domains.

With the 5G-CORAL concept it is foreseen that the business ecosystem will evolve further from the Cloud and Edge ecosystems described in Chapter 2. To understand the new business scenario is important to consider the key roles that can play a part of this ecosystem. This section will list and describe these foreseen key roles and their relationships. Then a possible business model for the 5G-CORAL system provider is analysed by using a business model Canvas approach. Finally, Section 3.3 will present the key players' views on the business challenges and opportunities and discuss how they can take on different roles in the ecosystem.

3.1 Role analysis and ecosystem

The key roles of the 5G-CORAL ecosystem are described in the following.

- **Edge and Fog system provider**

The Edge and Fog system provider takes the central role of the 5G-CORAL ecosystem. It operates and invests on deploying the 5G-CORAL Edge and Fog system, mainly providing PaaS for hosting customers' software and applications. In some cases, IaaS can be provided to host VMs of customers. It is a similar role as the Cloud provider in Cloud computing, which is crucial to create the ecosystem and makes it successful.

- **Edge and Fog site owner**

Different from the Cloud business where Cloud providers own the DC sites, in Edge and Fog computing the Edge and Fog nodes (i.e. Edge DCs and Fog Computing Devices, Fog CDs) are highly distributed so that it is difficult (even unfeasible) for the Edge and Fog system providers to own the sites for hosting these nodes, especially for Fog nodes. Even for telecom operators, they need to rent the space for the base station sites from the local facility owners. Therefore, the Edge and Fog site owners are important to allow massive deployment of the Edge and Fog system: in the context of the 5G-CORAL project the innovative concept of *federation* is widely used since Fog resources – which may belong to multiple owners – need to be federated in order to create a single infrastructure. This is one key difference from Cloud business, where the DC are built and owned by Cloud providers. A detailed analysis from the business point of view can be found in Chapter 5, along with some exemplary scenarios where federation is applied.

- **Edge and Fog hardware vendor**

Edge and Fog hardware vendor designs and produces the hardware products such as Edge DCs, Fog CDs and network gears required to run the overall system. It is the hardware supplier to the Edge and Fog system provider.

- **Edge and Fog system software vendor**

Edge and Fog system software vendor develops the Edge and Fog system software (e.g. 5G-CORAL platform compatible software). It is the software supplier to the Edge and Fog system provider. Like for Cloud providers, Edge and Fog system providers can develop the Edge and Fog system software by themselves. However, it may purchase software components from other vendors (i.e. the Edge and Fog system software vendors).

- **Edge and Fog application/service provider**

Edge and Fog application/service provider is the customer of the Edge and Fog system provider. It deploys applications on the Edge and Fog system and provides the Edge and Fog services like AR, VR etc. to their end-users. This role is important as it contributes to the revenues of the Edge and Fog system provider. If the businesses of Edge and Fog application/service provider are healthy and profitable, this would make the whole Edge and Fog business ecosystem sustainable and profitable. Similar to Cloud service providers, Edge and Fog application/service providers typically use SaaS model for charging their end-users.

- **Edge and Fog application/service software developer**

Edge and Fog application/service software developer develops the Edge and Fog applications. It is the software supplier to the Edge and Fog application/service provider. For a big application provider, it can develop the application software by itself. However, it may purchase software components from other vendors (i.e. the Edge and Fog application/service software developers).

- **Edge and Fog application/service end-user**

Edge and Fog application/service end-user consumes and pays for the Edge and Fog services provided by the Edge and Fog application/service providers. End-users can be consumers, enterprises, Government etc. similar to Cloud service end-users. Charging can be done directly by means of subscriptions following the SaaS model otherwise it can be done indirectly through advertisements or in other similar ways. For example, services can be provided for free but advertisements are pushed to the users. In this case, the Edge and Fog application/service provider earns money based on advertisements distribution service which is paid by advertisers. This approach is very common among consumer end-users.

- **Cloud provider**

As described before, the Edge and Fog services can be seen as an extension of Cloud services. Cloud providers will provide their Cloud services, which can be integrated as an end-to-end service crossing user-Edge/Fog-Cloud to serve the end-users better. It should be noted that, in some cases, Edge and Fog can work in a standalone mode, i.e. without interactions with Cloud. However, partnerships with Cloud providers would be beneficial to Edge and Fog businesses.

- **Connectivity provider**

The connectivity provider makes fixed and/or mobile Internet connectivity available to the Edge and Fog system providers and to the Edge and Fog application/service end-users. It is crucial that the connectivity is robust and reliable with sufficient speed, latency and other characteristics as required by the Edge and Fog services.

The roles described above and their relationships are summarized in Figure 9.

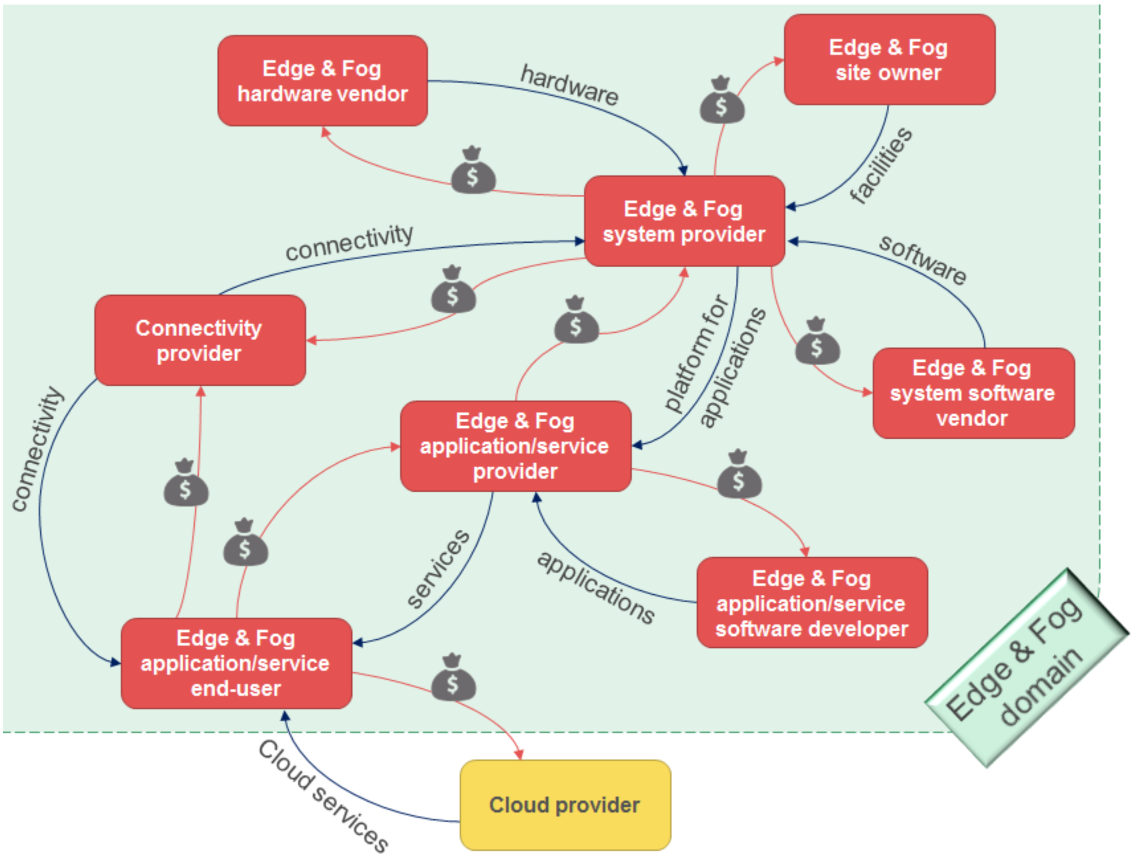

FIGURE 9: 5G-CORAL ROLES AND THEIR RELATIONSHIPS.

3.2 Business model analysis for Edge and Fog system provider

As described in the previous subsection, the Edge and Fog system provider plays the central role in 5G-CORAL ecosystem. To achieve the full benefit of the 5G-CORAL platform, the Edge and Fog system provider should run PaaS model providing the Edge and Fog platform to the Edge/Fog application/service provider, hosting their software and applications in the form of VNFs. To analyse the business perspectives in the context of the use cases addressed by 5G-CORAL project the business model Canvas has been taken as a reference [18]. The business model Canvas is a tool commonly used to evaluate the business potential and opportunities for use cases. It also shows the relationships among different players acting within a specific scenario. The business model Canvas for the Edge and Fog system provider is shown in Figure 10, followed by further explanations for each Canvas segment. Note that several players can act as Edge and Fog system provider, for example telecom operators, Over-The-Top (OTT) service providers, network equipment vendors, start-up companies etc. In the business model Canvas there are several common aspects to Cloud services, as well as some key differences.

<table>
<tr>
<td rowspan="2">Key Partners
• Hardware vendors
• Software vendors
• Landlord (Edge and Fog site owner) providing local space for Edge and Fog equipment
• Internet service providers (telecom operator)
• Cloud providers
• Open source community</td>
<td>Key Activities
• Deployment of Edge and Fog infrastructure
• Development, maintenance, management and scaling of the platform
• System optimization</td>
<td rowspan="2">Value Propositions
• EFS hosting its own and 3rd-party VNFs benefiting from low latency and/or data offloading from core network and/or central Cloud
• Provide data service (EFS services) between VNFs providing extra values for service improvement or enable new services
• Rapid self-service for VNF provisioning by OCS
• Provide advanced capability like Big Data and AI
• Automation of VNF life cycle management by OCS</td>
<td>Customer Relationships
• Customer conferences
• Feedback analysis
• Customer support</td>
<td rowspan="2">Customer Segments
• Edge/Fog service or application providers
• The end-users for its own applications (VNFs) if any</td>
</tr>
<tr>
<td>Key Resources
• Edge and Fog computing hardware (e.g. Edge DC, Fog CD, networking gears)
• Software supporting EFS provisioning and OCS
• Internet connectivity</td>
<td>Channels
• Self-service
• APIs</td>
</tr>
<tr>
<td colspan="3">Cost Structure
• Hardware costs for the Edge and Fog computing infrastructure
• Electricity power and Internet services (telecommunications)
• Renting space for hardware
• People for developing and managing the Edge and Fog system</td>
<td colspan="2">Revenue Streams
• Subscription fee (e.g. monthly, annually) for hosting VNFs, can be revenue sharing with Edge and Fog service providers
• Data subscription fee for providing data services between VNFs (fixed fee or per number of services or data volume)
• Extra subscription fee for providing advanced capability such as Big Data and AI (per use or processing usage)
• Other revenue from its own applications if any</td>
</tr>
</table>

FIGURE 10: BUSINESS MODEL CANVAS FOR EDGE AND FOG SYSTEM PROVIDER.

Customer Segments (CS)

The main customers of Edge and Fog system provider are the Edge and Fog application/service providers who want to host their applications and services on the Edge and Fog system which serves their end-users. If the Edge and Fog system provider also makes Edge and Fog services available to end-users, they also act as Edge and Fog service/application providers. This is similar to Cloud business, where big Cloud providers such as Amazon and MS originally use their spare computing resources to run Cloud business. It is taken as an advantage for Cloud providers having their own workload, which would help Cloud providers to optimize their Cloud system and services based on experiences obtained from their own services. Such scenario may also apply for Edge business.

Value Propositions (VP)

The value propositions indicate what values are created for the targeted customers, e.g. solve customers' problems, help them save costs, improve products quality and create new products etc., which would eventually make the customers willing to pay for the services provided.

The provided key values are the following:

- EFS hosting its own and 3rd-party VNFs (or applications) benefiting from low latency and/or data offloading from core network and/or central Cloud. These are the core value differentiated from Cloud, which would help the Edge and Fog service providers improve their existing services (e.g. improving video streaming services by caching at Edge) and create new profitable services such as AR/VR.
- Provide data service (EFS services) among VNFs providing extra values to for service improvement or enable new services.

- Rapid self-service for VNF provisioning and automation of VNF life cycle management by OCS. These features are similar to Cloud services, which are proven meeting the customers' needs and freeing customers from such tedious management tasks.
- Provide advanced capability such as Big Data, AI, etc. This feature is also similar to Cloud services, which make the application easier to add advanced features.

Channels (CH)

Channels indicates how products or services are distributed and delivered to the customers. Similar to Cloud, the service should be accessed by self-service portals (web interface) and through APIs. This helps customers to rapidly roll out their own services or products.

Customer Relationships (CR)

Customer relationships show how the link with the customer is established and maintained. This is also similar to Cloud: developer/customer conferences, online customer support and feedback analytics to keep customers informed with new technologies and services are typical means. It is quite common today that big Cloud providers have annual conferences for software developers and their customers to announce new features and technologies, hence serving the ecosystem better. Normally, customer's request and feedback are easier to be supported online as the data which can be used to accelerate the cycles to handle requests and rolling out new features are stored in the Edge.

Revenue Streams (RS)

Revenue streams are the results of the values created for the customers. For IaaS and PaaS models, the main revenue sources are the Edge and Fog service subscriptions, primarily achieved from the Edge and Fog service providers. These revenues are recurring, typically paid monthly, quarterly or annually. Some examples are reported:

- Subscription fee (e.g. monthly, annually) for hosting VNFs. It can also take the revenue sharing model with Edge and Fog service providers into account. This will make it easier for customers to initiate their services since it is a simple contract with low start-up cost.
- Data subscription fee for providing data services among VNFs (fixed fee, per number of services or data volume, etc.). This is one key feature in 5G-CORAL system since the data provided can help improving service quality (e.g. better localization using data from multiple Radio Access Technologies, RATs) and even enable new services which were previously unfeasible.
- Extra subscription fee for providing advanced capability such as Big Data, AI, etc. (per use or processing usage). This is similar to Cloud services.
- Other revenue from the end-users of its own Edge and Fog applications if any. As discussed before in the context of the Cloud business, it is highly beneficial for the Edge and Fog system provider to also run Edge and Fog services by itself. This would help to improve the platform's features and performance based on the experiences in running its own Edge and Fog business.

Key Resources (KR)

Key resources are the assets which are required to provide the Edge and Fog services. As for the Cloud services, both hardware and software - together with Internet connectivity - are required to run the Edge and Fog business. One difference with respect to the approaches of AWS Greengrass and MS Azure IoT Edge is that hardware is preferably owned by the Edge and Fog system providers, e.g. in case this role is performed by the telecom operator.

Key Activities (KA)

Key activities are the most important tasks to run the business. To build up an Edge and Fog system, the first step is to deploy the hardware to the Edge of the network. Then, it is daily work to maintain, manage and scale both hardware and software of the system. System optimization is also important to continuously improve the system efficiency.

Key Partnerships (KP)

The following partners are important for the Edge and Fog system provider to run its business.

- Hardware vendors: they represent the hardware supplier providing the Edge and Fog computing components (e.g. Edge DCs, Fog CDs, networking gears). The hardware is typically general-purpose, which is not difficult to develop and produce. For example, Edge DCs can be standard servers or workstations, while Fog CDs can be mini PCs such as Raspberry pi.
- Software vendors (Edge and Fog system software vendors): they are the software supplier developing the Edge and Fog system software (e.g. 5G-CORAL platform compatible software).
- Landlord (Edge and Fog site owner) providing local space for Edge and Fog equipment.
- Internet service providers (telecom operators): providing wired and/or wireless connectivity.
- Cloud providers: for applications and services which require interactions with the Cloud, a partnership with Cloud providers will help to on-board customers from the existing customer base of Cloud. It can also create customer values to provide interfaces to Cloud by APIs.
- Open source community: open source software has been increasingly used in Cloud systems. Open source is a key paradigm which would help developing complex systems, which are typically difficult to develop totally by one vendor from the scratch. Open source has advantages in flexibility, agility, speed, lower costs, security, etc. Open source model has been well adopted today for some key software components used in the context of web and Cloud industries. This trend can also be applicable to Edge and Fog systems.

Cost Structure (CS)

Basically, the cost structure captures the costs which are spent on the key resources, key activities and key partnerships. This defines the bottom line of the business, while the revenue streams define the top line. The following summarize the main cost sources.

- Hardware costs for the Edge and Fog computing infrastructure.
- Electricity power and Internet services (telecommunications).
- Renting space for hardware.
- Workforce for developing and managing the Edge and Fog system.

Summary and discussions

The business model Canvas presented above shows the business feasibility of the Edge and Fog system provider to run the Edge and Fog system (i.e. the 5G-CORAL system) providing PaaS (and/or IaaS). The value proposition is strong with the features of low latency, traffic offload, etc., where the Edge and Fog system can offer services that Cloud can't provide and enhance the existing services while keeping the advantages of PaaS and IaaS, e.g. pay for usage. The key business challenge is to deploy the Edge and Fog systems massively. It can be expected that it would require a lot of investments for dense deployment and reusing the existing premises can significantly reduce the associated costs. Some players such as telecom operators do have such opportunity to reuse their infrastructure sites, therefore having significant advantages. This is a similar advantage which Amazon, MS and Google have in their Cloud business. New players such as OTT service providers (e.g. Facebook) can also enter this business, for instance by deploying Edge and Fog system within public venues like shopping malls, airports and so on. In this case, the premise should be leased from the landlord. Nevertheless, different players will have different views and can play different roles in the 5G-CORAL ecosystem. This will be discussed in more details in the following section.

3.3 Key players' views on business challenges and opportunities

Now when the business perspectives of 5G-CORAL have been introduced and the business ecosystem has been identified with the key roles, it is interesting to understand how different players look at the business challenges and opportunity. This section presents the views of different players have on the 5G-CORAL business ecosystem and discusses which roles are most applicable to them, which is summarized in Table 2.

TABLE 2 MAPPING BETWEEN KEY PLAYERS AND ECOSYSTEM ROLES

Ecosystem role	Telecom operator	Software vendors	OTT service providers	Cloud providers	Hardware vendors	Vertical Companies
Edge and Fog system provider	X		X		X	
Edge and Fog site owner						X
Edge and Fog hardware vendor					X	
Edge and Fog system software vendor		X		X		
Edge and Fog application/service provider	X		X			
Edge and Fog application/service software Developer		X				
Edge and Fog application/service end-user						X
Cloud provider				X		
Connectivity provider	X					

3.3.1 Telecom operator

Nowadays it is crucial for a telecom operator to improve the quality of experience for its end customers. Not only, the operator also strives at deploying products and services in a faster way than today, hence finding new opportunities for monetizing its network by provisioning value added services instead of simply being a connectivity provider.

Operators are also quite cautious in avoiding to base their business on hardware and software platforms which have too many years in terms of life cycle: there is the need to have agile and open architectures and software, which both create true value to the end-user as a consequence of the operator being able to quickly deliver a service.

From a business viewpoint, both Edge and Fog approaches can help the telecom operators, depending on the application(s)/service(s) they want to provide. To this end, what 5G-CORAL proposes, i.e. a virtualised and integrated Edge and Fog environment exploiting multiple RATs, might be very beneficial for the telecom operator, which can exploit its planned investments in network virtualization for expanding its own service portfolio to also include those services requiring very challenging network performance, e.g. latency-sensitive applications. From the technical perspective, the operator considers both Edge and Fog computing to be fundamentally the same: conceptually they are all about pushing processing and storage capabilities closer to the end-user (e.g. within its own devices) but at different granularity. The economics of Edge and Fog computing trade off additional cost of distributed compute and storage at the Edge of the network for backhaul cost reduction and performance improvement: in other words, Edge and Fog enable improved response of the applications (i.e. latency) and reduced cost of transporting data to the Cloud [19].

The addressable use cases in an Edge and Fog context also depend on whether the telecom operator acts either in a *single* or in a *multi-operator* scenario. Both (i.e. single and multi-operator) include hosting 3rd-party applications and the distinction between the two scenarios is mainly based on the number of telecom operators considered in each scenario: one or a multitude, respectively. The first scenario is likely to be feasible even today, as shown by the great interest of operators in testing and verifying Edge/Fog computing's features and capabilities, such as Deutsche Telekom with the MobiledgeX incubator program [20], Telefonica in the context of the OnLife Networks initiative [21], AT&T which is developing OS software stack supporting services optimized for Edge Computing [22] and TIM in the context of the TIP Edge Computing Working Group [23].

Use cases implemented in a multi-operator scenario, instead, might require more time to be practically implemented since current technical solutions lack interoperability, which is deemed as necessary. Interoperability of Edge deployments was initially considered in ETSI ISG MEC in the context of *Mobile* Edge Computing by focusing on RAN features only, then starting to also encompass fixed-network Edge computing (hence, *Multi-access* Edge Computing).

Multi-access was also addressed in the RAN, e.g. traffic offloading from LTE to other RATs [24]. Offloading traffic towards Wi-Fi looked particularly interesting because Wi-Fi can provide significant data capacity (wide available carrier bandwidths in unlicensed spectrum), it is low power and uses cheap equipment, hence resulting in easy deployment of numerous cells. However, Wi-Fi offload presents some challenges when delivering a seamless experience for the end-user based on the service continuity between Wi-Fi and LTE. 5G-CORAL architecture can be useful to solve this kind of problem by leveraging the federation mechanism which allows the seamless service migration functionality. Details about this feature can be found in Section 5.3.3 for one of the 5G-CORAL uses cases, i.e. High-Speed Train.

In order to further realize interoperability, ETSI signed a Memorandum of Understanding (MoU) with the OpenFog Consortium, a vendors-driven organization where the similar approach of Fog computing has been developed [25]. This will allow to accelerate the release of standardized APIs, with the possibility for the developers to write applications being able to run on both OpenFog and ETSI MEC architectures exploiting a unified management strategy [11]. And since one of the most important innovation in 5G-CORAL is the mobility of Fog nodes, it might be also interesting to consider pricing models where the UE accesses the Edge services from a roaming network node. This pricing model should be dynamic and based on network parameters of the RAT the UE is using in that specific moment, e.g. latency, session re-establishment delay, jitter, bandwidth availability and required security level [26].

There is also another approach in implementing use cases exploiting Edge and Fog solutions, which is based on a unified "management & operation" of Edge/Fog and Cloud tiers, resulting in CAPEX and OPEX optimizations. This can be achieved when 5G will be available, where AI and cognitive capabilities at various level of Operations Support System/Business Support System

(OSS/BSS) will become a reality. However, by extending the Cloud capabilities to the Edge and Fog tiers might reinforce Cloud providers' role with respect to telecom operators in the emerging Edge and Fog market, since Cloud providers would be able to provide services based on Edge and Fog without the need to rely on operator's distributed computing, storage and networking capabilities [11]. While telecom operators are coordinating their efforts with vendors in order to realize common standards and interoperable frameworks for integrated Edge and Fog computing solutions, it is important that operators do not wait for these to be mature enough before starting to leverage the commercial opportunities offered by Edge and Fog computing.

To this end, in [11] five operator-centric business models have been reported addressing Edge computing (see Figure 11) and being able to support a variety of use cases. These business models describe the role of the operator being either an *enabler* of Edge services *for other players* in the value chain or an entity which is able to *operate in an end-to-end manner*, in both cases exploiting Edge computing for revenue generation [27]:

- *Dedicated Edge hosting*: the operator deploys and manages Edge resources to be used by its customers to run their applications.
- *Edge IaaS/PaaS/NaaS*: the operator provides its customers not only Edge resources but also a platform for developing applications.
- *Systems integration*: the operator acts as the "orchestrator" of an ecosystem of different players for providing tailored and reliable specific Edge-enabled solutions for Verticals.
- *B2B2x solutions*: the operator creates business solutions which typically are general purpose (i.e. less tailored) for both customer's internal purposes or for contributing to an end-customer offering (B2B2X).
- *End-to-end consumer retail applications*: the operator acts as a digital service provider for consumer applications.

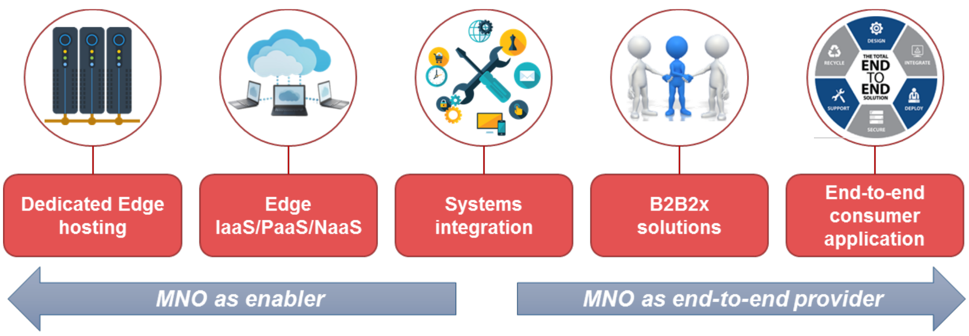

FIGURE 11: TELECOM OPERATOR'S BUSINESS MODELS FOR EDGE CLOUD.

A detailed description of the above-mentioned telecom-oriented business models is reported in the Appendix.

Among them, in [27] it is stated that the *Edge IaaS/PaaS/NaaS hosting* business model is the only one which provides a clear value for the operators to cooperate and avoid market fragmentation: by decoupling Edge IaaS from Edge PaaS, in fact, new partnerships among operators can be achieved, hence realizing a global multi-operator ecosystem where greater economies of scale and larger abilities to monetize can be possible. By considering the 5G-CORAL ecosystem's roles previously identified, it can be stated that the operator can act as an *Edge and Fog system provider*: basically, the operator provides Edge IaaS services (e.g. connectivity and network services) whilst Edge PaaS services (software platform services such as service chaining) can be provided by also 3rd-parties, e.g. Edge and Fog features' providers as for Deutsche Telekom with its MobiledgeX program, other than by the operator itself being a service enabler for other operators in case of a multi-operator scenario.

This can be done, however, only if a standardized interface between IaaS and PaaS will be defined and, especially in multi-operator scenarios, interfaces among operators will be available at both connectivity and software platform level. This would enable the development of global open ecosystems for the various Verticals (e.g. Vehicle-to-Everything (V2X), multimedia interactive gaming, AR/VR, Industry 4.0, etc.) as it will create the conditions for fuelling new forms of partnerships among operators and between operators and Information and Communication Technology (ICT) providers. In particular, the standardization of the IaaS-PaaS interface, which is the key enabler for new related business models, could be a joint task of ETSI (MEC, NFV) and GSMA as recommended in [28].

In the context of 5G-CORAL, in order for the operator to fully play the Edge and Fog system provider role, it is necessary to enhance the "Edge IaaS/PaaS/NaaS hosting" business model taking Fog computing into account. To this end, some business models for the operator acting as a Fog provider can be derived by considering what has already been adopted in similar contexts, e.g. in either Cloud computing, IoT, M2M or mobile applications:

- *"Extended connectivity"* model: the Fog provider offers its customers a set of services as an add-on with respect to the basic connectivity service in order to "improve" terminals' performance.
- *"aaS"* model: services provided via a Fog infrastructure are sold based on a "as a Service" model to application providers or, in turn, to SaaS services providers which might require their customers to pay for the related costs.
- *"Wholesale"* model: the Fog provider offers basic capacity of its own Fog infrastructure (i.e. without "aaS" services) to Cloud computing providers or enterprises, then establishing a payment model which can be, e.g., direct, revenue sharing, etc.
- *"Application store"* model: the Fog provider creates a marketplace gathering all the applications deployed over its own infrastructure and establishes a revenue sharing model together with the application provider. Developers, in facts, might exploit the operator's pervasiveness to monetize their applications that connect to millions, even billions of devices. The operator, in turn, is able to secure revenues from developers and from end-users of those devices. Within the marketplace, developers would share services and technologies with other developers and leverage APIs and connectivity to create even stronger and more profitable Edge-based applications [29].
- *"Join Fog computing with private local Cloud at the Edge"* model: this basically represents a way for the operator to accelerate the deployment of Fog computing by federating with local private Clouds (with spare computation and storage capacity) deployed at the Edge of the network. Therefore, it might be possible to lease spare computation and storage to the Fog provider (i.e. the operator) then paying the private Cloud owner to use its resources only when actually needed, avoiding CAPEX and reducing OPEX.

The above-listed business models, except the last one, are basically based on the "*build it and developers will come*" approach: this, however, requires the operator to have the correct frameworks in place to integrate at least automation and orchestration with end-to-end visibility in order to maximize the service quality. Furthermore, the resulting architecture of the ecosystem needs to be robust and reactive enough so that developers can migrate easily with very little effort [29]. All these aspects are properly addressed by the 5G-CORAL system which has been designed having the extremely heterogeneous scenario where it operates in mind.

Finally, the possibility to dynamically allocate and monitor (at different granularity) the Edge and Fog system resources of the 5G-CORAL solution belonging to several stakeholders enables dynamic charging policies allowing to set the price of the different resources and to determine which fraction of the payment goes to each player of the overall ecosystem, hence maximizing the revenues.

3.3.2 Software vendors

Pushing the computing and storage capabilities to the Edge of the network opens different business models for the software vendors. Figure 12 shows the three potential business models for Edge/Fog environments from the point of view of the software vendor (SV), each of the business model can support a diversity of use cases. From a general point of view the software vendor can act as an end-to-end provider or as an enabler; as an enabler the software vendor performs the role of the Edge and Fog application/service software developer or the Edge and Fog system software vendor.

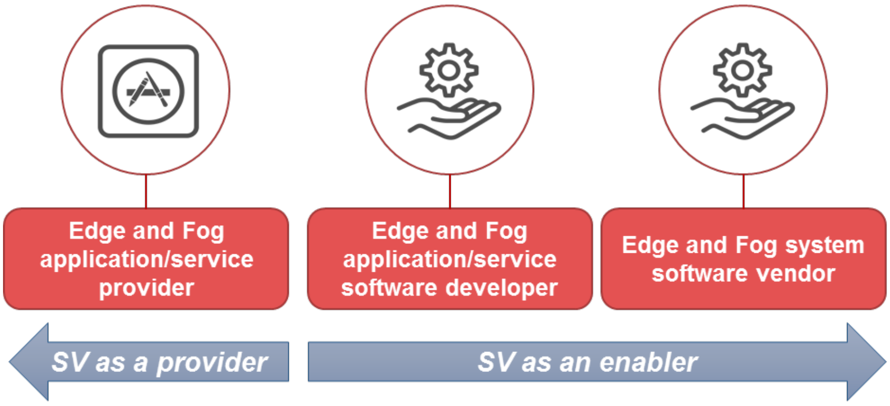

FIGURE 12: SOFTWARE VENDORS BUSINESS MODELS.

3.3.2.1 Edge and Fog application/service provider

In this business model the software vendor acts as an end-to-end provider fitting into a Business to Consumer (B2C) model; it deploys applications on the Edge and Fog system and provides the Edge and Fog services. The commercial opportunity resides on the main benefits of the Edge and Fog computing platform (low latency, high bandwidth, real time access to user's context information, etc.).

Some examples of applications and services that can be provided are:

- AR/VR applications residing at the Edge thanks to the low latency and high bandwidth capabilities of the Edge/Fog platform.
- IoT gateway to offer connectivity to IoT devices.
- Higher quality content distribution powered by the lower latency and higher bandwidth.
- Cloud Robotics, as the Edge/Fog platform capabilities allow moving the robots' intelligence to the network.
- Gathering specific context information: location, network information, users' information, etc.
- Data computation, analytics and statistics: Big Data.

3.3.2.2 Edge and Fog application/service software developer

In this business model the software vendor acts as an enabler, fitting into a Business to Business (B2B) model, creating Edge and Fog applications and services for other software developers and for the Edge and Fog application/service provider (SaaS). Some 3rd-party developers can consume the offered services to provide applications to the end-users.

Some examples of applications and services that can be developed were previously mentioned in Section 3.3.2.1.

3.3.2.3 Edge and Fog system software vendor

In this business model the software vendor acts again as an enabler and fits into a B2B model developing the Edge and Fog system software (PaaS). The developers will create services and applications to run on top of the offered system software. These applications and services will be consumed by the end-users or by other software developers.

Some examples of use cases applicable to this business model are:

- Integration of MEC infrastructures: different operators or vendors own different MEC platforms with different capabilities and APIs; the software developers can create a platform to integrate the different MEC infrastructures into a unified platform which is transparent to the 3rd-party developers.
- Integration of MEC infrastructure with Cloud: the software vendors can create a software system to integrate 3rd-party Cloud platforms with operators MEC platforms in a unified framework.
- Dynamic placing: the software developers can create a software system to run the applications; this software system can monitor the different MEC platforms to find the cheapest one where to place the application.

3.3.3 OTT service providers

OTT providers are expected to offer their services over the Internet network, decoupled from telecommunications providers. How these providers might see and exploit the 5G-CORAL solution is covered in this section. They can act as Edge and Fog application/service providers and/or Edge and Fog system providers.

As service providers, they are characterized by generating value to its customers. In this case, 5G-CORAL enhances both capabilities and features of the network. Thus, while the utility of the service will be kept the same, how the service is delivered can be enhanced. OTT providers will generate video, audio, voice and application traffic that can leverage 5G-CORAL features.

Due to Edge and Fog computing, core network offloading will become a reality, whit the possibility to locate the content closer to end-users. For services requiring high throughput, e.g. the streaming service, the Edge and Fog computing technology will allocate content closer to users while avoiding the core network to process the content itself.

A second characteristic aimed to be implemented in 5G-CORAL is multi-RAT. The range of devices that the user can use to access the services is broaden, which might be a business case for device manufacturers since not only mobile devices are in the scope of this providers. Latency is also expected to be significantly reduced and the capacity will be increased. Both allow the end-user to experience a better quality of service, minimizing communication losses.

OTT services present a great opportunity for the Cloud provider as well as the Edge and Fog system provider. They can provide a perfect environment to deploy OTT services which will be paid by the OTT service providers for its use.

These services will be deployed on the 5G-CORAL platform (hosting both specific hardware and software) which will be placed in a location near to the end-user. This represents a market niche for the Edge and Fog site owner, the hardware vendor and the system software vendor which, along with the software developer and the end-user, all achieve benefits from considering the OTT provider within the 5G-CORAL paradigm.

3.3.4 Cloud providers

As described in Section 2.2.1, Cloud providers deliver Cloud services to customers through different roles, including provisioning of virtualized hardware, management of Cloud infrastructures, provisioning of development and testing platform, aggregation of different modular services into a package, and so on. As introduced in Section 2.2.1, Cloud providers also represent a key role in the 5G-CORAL ecosystem, as Cloud services will be integrated crossing the Edge/Fog layers to more efficiently serve the end-users. In this context, the 5G-CORAL platform can help Cloud providers deliver Cloud services by more efficiently offering, processing and maintaining Cloud software that customers can use online. This can be achieved by leveraging on the 5G-CORAL EFS platform, hosting essential services located closer to the end-users, i.e. in the Edge and Fog layer. This will also facilitate the aggregation of multiple services and the creation of packages that can be offered to the customers. Furthermore, 5G-CORAL also represents an opportunity for Cloud providers to run PaaS and solely supply the software stack, rather than investing money in deploying Edge and Fog infrastructure. This way, Cloud providers can avoid spending resources in running, managing and maintaining dedicated data centres, and fully focus on developing software running on the Edge and Fog layers.

Another benefit consists in enhancing the mediation process between other Cloud providers and customers and the establishment of a market place with supporting services such as a billing service, thus playing the role of a broker. This also opens the door to a novel paradigm called Cloud Federation, where services supplied by different entities are aggregated in a single pool supporting basic interoperability functions, including resource migration and resource redundancy [30]. Multiple Cloud providers can cooperate in developing and maintaining a service by relying on the 5G-CORAL EFS platform, which can play the role of aggregator of services and applications deployed by different providers. This way, Cloud providers can provide more sophisticated services, whereas customers can achieve better performance at lower running costs.

Finally, seamless and flexible service delivery can be obtained through the multi-RAT support, which provides a number of radio access technologies with different benefits, ranging from ad-hoc connectivity and localization, to high throughput and low latency data delivery. This provides Cloud providers with more flexibility and enhanced ability to handle QoS requirements of each specific service.

3.3.5 Hardware vendors

Traditionally, the core business of hardware vendors is selling hardware, e.g. network equipment, computing devices such as servers and workstations. Big hardware vendors, especially the ones with the end-to-end capability, also provide solutions and system integration service to climb up the value chain. Managed services managing customer's hardware (e.g. maintenance and support) are also quite common today to get recurring revenue regularly. In managed services, it is often that the hardware is leased to the customer for the contracted period.

Regarding the new opportunity brought by Edge and Fog, the need for the new infrastructure drives up demands for deploying more hardware and adding more computing, storage and networking capability at the Edge. This will increase the market size of the hardware vendors. A new opportunity also arises that the hardware vendors can take the role of the Edge and Fog system provider. In the leasing model, e.g. with managed services, the hardware devices are still owned by the hardware vendors. It is possible that the hardware vendors sell the spare resources of the Edge and Fog system. It can be a good opportunity for the network equipment vendors which can reuse the network nodes and enhance them with more computing capability to serve more Edge and Fog services. This would create new revenue streams and further drive the growth. Of course, network equipment vendors can also partner with telecom operators to build up the Edge and Fog system and jointly provide services, e.g. taking revenue sharing model.

Another impact to hardware vendors is that the trend for hardware virtualization will accelerate the transformation of hardware vendors into the software domain. This would increase their software competence and make it more possible to enter the Edge and Fog system business.

3.3.6 Vertical companies

5G-CORAL has new opportunities for all the vertical companies, especially for enterprises and facility owners. For instance, an enterprise acting as an Edge and Fog system provider will be able to integrate 3rd-party resources - provided by both the facility owner being an Edge and Fog site owner and the hardware vendor - as part of its network in order to have an end-to-end service by leveraging and integrating the already deployed corporate DCs and IT environment. Alternatively, Edge and Fog site owners, e.g. shopping mall owner, high-speed train company, and field of connected cars) could be business providers to connectivity providers by sharing/lending their facilities which would be used to extend the network coverage and capacity if needed. Moreover, Cloud providers, Edge and Fog system software vendors and application/service providers will also be able to offer their services and applications with the low-latency required for, e.g. Ultra-Reliable and Low Latency Communications (ULLRC) applications in the shared/lent environment. To sum up, the ecosystem provided by 5G-CORAL fits well with the requirements in 5G systems and opens up the new market for enterprises and facility owners.

4 Business model analysis of 5G-CORAL use cases

In this Chapter, the business model canvas is used as a tool to analyse and evaluate the 5G-CORAL business opportunities for each of the 5G-CORAL use cases from the perspective of *Edge and Fog service provider*, who runs SaaS on top of the Edge and Fog platform provided by the Edge and Fog system provider. Basically, the Edge and Fog service provider deploys its applications (i.e. EFS application) and/or VNFs (i.e. EFS functions) on top of the Edge and Fog system and serves its end-users in different use cases to make their business feasible.

To make the integrated Edge and Fog ecosystem successful, viable business cases are deemed as essential for the companies providing Edge and Fog infrastructure and/or services. This perspective has been clearly proven in the case of Cloud computing, where the Cloud system providers (e.g., AWS) and the companies running their services in the Cloud (e.g. Netflix) both benefit from the business dynamics offered by the Cloud computing, as discussed in Section 2.2.1. Therefore, in this chapter, an analysis of the potential business models envisioned in the seven 5G-CORAL use cases is provided. Among all seven use cases, 5 use cases (i.e. Multi-RAT IoT, Cloud Robotics, Connected Cars, High-Speed Train and AR Navigation) are documented in D1.1 [1], while the latest two use cases, i.e. SD-WAN and VR, have been added in Appendix A1 and A2 of this document, respectively, following the same approach which has been used for describing the other uses cases in [1]. The business case analysis of all these use cases is performed from the service provider's perspective with the support of the business model Canvas. Such analysis will highlight the benefits from a business perspective that could be potentially enabled by having a 5G-CORAL environment in place.

For convenience, a list of 5G-CORAL use cases is briefly described below:

- Multi-RAT IoT: the main idea of this use case is to investigate the possibility to have one radio network infrastructure (instead of parallel network deployments) to serve multiple IoT RATs. The IoT baseband functions are centralized and cloudified to an Edge Cloud environment. The main benefits are increasing network flexibility, reducing network cost and increasing scalability.
- Cloud Robotics: the Cloud Robotics use case comprises two different scenarios. The first scenario envisions the robots cleaning the common areas of the shopping mall. This cleaning task is automatically triggered when deemed necessary, based on the video recorded by the shopping mall cameras and processed and analysed by the Cloud Robotics application. The second scenario, instead, envisions the delivery of goods by a group of robots working synchronously. Robots are coordinated and synchronized to deliver goods from the shopping mall warehouse to the shops. Thanks to the low latency provided, Edge and Fog computing allow the deployment of the intelligence of the robots to the Edge of the network enabling remote multi-robot collaboration, coordination and synchronization.
- Connected Cars: in 5G-CORAL, by leveraging the deployment of Fog CDs located nearby and even inside the vehicles (e.g. Road Side Unit (RSU), On-Board Unit (OBU)), information can be exchanged in a more quick and distributed way, resulting in valuable safety improvements and improving the network response time. Moreover, during a traffic-jam, innovative techniques like local caching in Content Delivery Networks (CDNs), leveraging the computational and storage capacity of 5G-CORAL Fog CDs (located within vehicles) and the available multiple RATs, could be useful to cope with increasing both capacity demand and volume of signalling messages.
- High-Speed Train: in high-speed train use case, various services utilized by passengers on board require a seamless connection. This is very challenging due to the frequent handover which occurs every 26 seconds while the train is moving at the speed of

300km/hr. Moreover, the massive signalling from frequent handovers is expected due to a large number of passengers on-board the train. Therefore, the 5G-CORAL's edge and fog infrastructure aim to achieve seamless connection in the high-speed train by breakout mobility functions on the fog/edge that could potentially mitigate the burden of passenger's mobility signalling on the backhaul. Also, it reduces the signalling amount to the backhaul. Consequently, local virtual MMEs will be deployed on the Fog CDs as part of the EFS to cope with the huge amount of signalling envisioned at such a high-speed. The CDs are deployed on-board and can also be used to host some specific core functions, such as local breakouts, to enable the storage and consumption of content locally without the need of going through the train's backhaul connection or with minimum signalling. Besides, the on-board Fog CDs can migrate content and context information to on land Fog CDs in advance when passengers are approaching the train station.

- AR Navigation: augmented Reality (AR) Use case provides the continuous Augmented live navigation experience for the users while leverages the 5G-CORAL's edge infrastructure. AR live navigation brings seamless navigation and shopping experience to the user, which allows to identify filmed objects and place an arrow for directions in the right spot on the screen. In order to localize the current position of the users. The user captures the video and sends to the nearby deployed Image Recognition server running on top of fog node for the localization purpose. IBeacons deployed nearby also sense the user's presence and aids in the precise localization.
- SD-WAN: the SD-WAN Use Case in 5G-CORAL is located in a shopping mall. The main objective is to provide WAN connectivity to businesses inside the mall by leveraging SD-WAN functions, to provide total connectivity to all of their company services. Thus, we can define three applications of the use case. First, WAN connectivity to shops and organizations located inside the mall with WAN networks. Second, to provide POS terminals with a connection to the bank avoiding a direct VPN connection. Finally, occasionally to connect remote employees with its organization network.
- VR: the Virtual Reality use case consists of a 360° video live streaming service delivered by a number of 360° cameras installed in specific points of interest inside a shopping mall. The aim is to offer an ultimate experience to users attending a live event, e.g., celebrity appearances, contests and sporting events, as well as handle overcrowded situations that can occur when a high number of people gather in a limited space. The 360° video live cast will offer the opportunity for everyone inside a shopping mall to watch the live event panoramically and reduce the crowd management cost. In addition, fog and edge devices will be deployed in order to showcase the main benefits of the related technology, such as throughput increase and latency reduction.

4.1 Multi-RAT IoT

In this use case, as an example, the telecom operator running SaaS as an Edge and Fog service provider, providing Multi-RAT IoT VNF services on top of the EFS managed by the Edge and Fog system provider. Figure 13 shows the business model Canvas corresponding to the Multi-RAT IoT use case. The following paragraphs describe more in detail the different sections of the Canvas.

<table>
<tr>
<td rowspan="2">Key Partners
• Edge and Fog system provider
• Software vendors for virtualized IoT gateways
• HW vendors for radio heads
• System integrator</td>
<td>Key Activities
• Deployment, maintenance of the radio heads
• Software test and verification
• Network management of IoT gateways
• Network system optimization</td>
<td rowspan="2">Value Propositions
• Cost saving with one radio infrastructure to provide multi-RAT IoT services
• Virtualized IoT gateways supporting Multi-RAT providing long term legacy support and future proofness
• OPEX instead of CAPEX following SaaS model
• Easy network scaling and management
• Automatic traffic management
• IoT device management
• IoT data management and analytics</td>
<td>Customer Relationship
• Customer support (online and offline)
• Feedback analysis</td>
<td rowspan="2">Customer Segments
• Enterprise customers, such as smart building, smart factory, smart grid, …
• Government segment, e.g. for smart city</td>
</tr>
<tr>
<td>Key Resources
• Radio head hardware
• Software for virtualized IoT gateways</td>
<td>Channels
• Self-service
• APIs
• Regular operator stores
• Customer services (telephone, online)</td>
</tr>
<tr>
<td colspan="2">Cost Structure
• Hardware costs of radio head infrastructure
• Software costs of virtualized IoT gateways
• Subscription fee for using the Edge and Fog platform
• Cost for system integration
• Electricity power
• Workforce for network operation and maintenance</td>
<td colspan="3">Revenue Streams
• Subscription fee of the Multi-RAT IoT service (per gateway instances, as well as considering number of devices)
• Subscription fee for IoT device management (per number of IoT devices)
• Extra subscription fee for providing IoT data management and analytics</td>
</tr>
</table>

FIGURE 13: BUSINESS MODEL CANVAS FOR THE MULTI-RAT IOT USE CASE.

Customer Segments (CS)

IoT has become a hot topic on the agenda of industries and societies to realize digital transformation. The Multi-RAT IoT service targets those customers which will deploy the IoT networks for smart building, smart factory, smart grid or smart city. One customer segment is the enterprise, ranging from medium size to the large size, such as various manufacturing companies (factories), airports, shopping malls, etc. Another example of big customers is the Government, especially in the smart city area. It is foreseen that the market drive of IoT in these two customer segments will be very high [48].

Value Propositions (VP)

Multi-RAT IoT services softwarize and centralize the IoT gateway functions in the Edge Cloud while deploying a single radio infrastructure at the premises of the IoT service. This approach fits especially the massive IoT type of applications, e.g. massive monitoring, which are more latency tolerant. It addresses the main pain points of both enterprises and the Government customers regarding the high cost of deploying parallel IoT networks, the long-term legacy technology support, the technology future proofness (software upgrades for supporting a new technology) and the management hassles of IoT devices, network and data. Furthermore, with the Edge Cloud technology, the network can be automatically scaled up when more and more IoT devices get online. SaaS business model benefits the customers with the charge per usage model, e.g. per number of IoT gateway instances.

Channels (CH)

Regarding the communication, distribution and sales channels for the Multi-RAT IoT services, the telecom operators first could benefit from its own existing channels interfacing with enterprises and the Government customers, e.g. through customer services and telecom operator stores. Furthermore, self-service provisioning provides a fast deployment of services and a better visibility of the deployed services. Through APIs, it allows to get the multi-RAT IoT services integrated with other Edge and/or Cloud services, e.g. the existing IT system within an enterprise.

Customer Relationships (CR)

As in a Cloud solution, the management data are stored in the Edge Cloud, which can be easily accessed by the telecom operator. This would help early detection of service problems and it would also improve the software quality. Data access would also help to process the customer feedback, provide quick support and improve the service quality. In general, this would help to maintain the relationship with customers.

Revenue Streams (RS)

The key revenue sources are from three main services being provided: Multi-RAT IoT service, IoT device management service as well as IoT data management and analytics service. All these services can be charged with SaaS per usage model, i.e. subscription (e.g. monthly, annually) according to the usage of the services. In the following some examples are reported:

- Multi-RAT IoT service: subscription can be charged according to both the number of activated IoT gateway instances and the number of devices.
- IoT device management service: subscription can be charged per number of IoT devices.
- IoT data management and analytics service: subscription can be charged per number of calls to the advanced data analytics features.

Key Resources (KR)

In addition to the software for IoT services deployed in the Edge Cloud, the telecom operator needs to provide also the radio head infrastructure which is connected to the Edge Cloud via Ethernet. This is the key difference from a pure Edge SaaS provider which, typically, does not need to provide any infrastructure.

Key Activities (KA)

Before providing the services, radio head infrastructure needs to be deployed and connected to the Edge Cloud via Ethernet (IT network). Such a radio network needs to be maintained during the operations. The IoT gateway software needs to be tested and verified before the service rollout. After service rollout, the IoT network and platform need to be maintained, managed and optimized.

Key Partnerships (KP)

There are several partners of the telecom operator working together in order to provide Multi-RAT IoT services. They are the suppliers providing software, hardware and services to the telecom operator.

- Edge and Fog system provider: provides the Edge and Fog system to host the software of the Multi-Rat IoT services. Note that telecom operators can take this role as well to provide the Edge and Fog platform.
- Software vendors: provide the software of the IoT gateways, as well as other IoT Edge software.
- Hardware vendors: provide the radio head hardware.
- System integrator: integrates both hardware and software within the Edge platform.

Cost Structure (CS)

The main costs are the payments to the suppliers previously listed as key partners, as well as the investments for network operation and maintenance as listed below:

- Hardware costs for purchasing radio heads.
- Software costs for purchasing IoT gateway software and other IoT Edge software.
- Subscription fee for using the Edge and Fog platform
- Cost related to the system integration
- Workforce for network operation and maintenance

Summary and discussions

From the analysis of the business Canvas, the feasibility of the business case of providing multi-RAT IoT Edge services from the telecom operator perspective was shown. It solves some key pain points in IoT deployments and meets the demand of its customers, i.e. enterprises and Governments. Multi-RAT IoT service is one type of telecom services and it is easy to understand that the telecom operator can run this business as a new revenue source, leveraging its experience and resources for network operation, sales and customer relationships.

Note that such Multi-RAT IoT services can also be provided by new players, e.g. IoT network vendors (or network equipment vendors) and the new IoT network operators (other than big telecom operators) such as start-up companies. This will be promising if local spectrum licensing model is approved by the regulation, based on which Verticals can rent spectrum for local usage. Otherwise, only unlicensed spectrum can be used, which would limit the market size and the guaranteed level of QoS. Nevertheless, the business model Canvas for other players in this case would be similar to the Canvas shown above and related to the telecom operator. The only difference is that the IoT network vendors are capable of developing the Multi-RAT IoT software by themselves. It is likely that 3rd-party software companies might be still needed as one company can't develop and support all the available standards.

4.2 Cloud Robotics

The Cloud Robotics use case comprises two different scenarios. The first scenario envisions the robots cleaning the common areas of the shopping mall. This cleaning task is automatically triggered when deemed necessary, based on the video recorded by the shopping mall cameras and processed and analysed by the Cloud Robotics application. The second scenario, instead, envisions the delivery of goods by a group of robots working synchronously. Robots are coordinated and synchronized to deliver goods from the shopping mall warehouse to the shops. Thanks to the low latency provided, Edge and Fog computing allow the deployment of the intelligence of the robots to the Edge of the network enabling remote multi-robot collaboration, coordination and synchronization.

The business model Canvas in Figure 14 below gives an overview of the two scenarios of Cloud Robotics, where the robot manufacturer provides both the robot hardware and the software that will be instantiated on the Edge and Fog infrastructure:

<table>
<tr><td rowspan="2">Key Partners
• Application developers
• Edge/Fog providers
• Internet service providers</td><td>Key Activities
• Maintenance of hardware
• Maintenance of software
• Customer relations
• Interacting application developers</td><td rowspan="2">Value Propositions
• A robotic service
• A software development framework to develop 5G-CORAL applications</td><td>Customer Relationships
• Direct relation with the customers
• Relation with software developers</td><td rowspan="2">Customer Segments
• Retail shops
• Shopping malls
• Cleaning companies
• Application developers</td></tr>
<tr><td>Key Resources
• Robots
• Robot development framework</td><td>Channels
• Direct feedback from the customers
• Software-based feedback</td></tr>
<tr><td colspan="2">Cost Structure
• Robot building cost
• Software development cost
• Maintenance cost of hardware
• Maintenance cost of software</td><td colspan="3">Revenue Streams
• Sell robot hardware
• Subscription or pay-once software services</td></tr>
</table>

FIGURE 14: BUSINESS MODEL CANVAS FOR THE CLOUD ROBOTICS USE CASE.

Customer Segments (CS)

Cloud Robotics endows capabilities to the robots via the usage of Cloud technologies, such as Cloud computing and storage. The proved benefits of such approach can be hence extended to the Edge and Fog infrastructure which provides a common host for deploying time-sensitive services for robotics. The Cloud Robotics service allows customers that would deploy their robotics services relying on deployed Edge and Fog infrastructure in a given area (e.g. shopping mall, airport). For both Cloud Robotics scenarios, the cleaning and the delivery of goods, the customers segments include the medium enterprises such as cleaning service companies or shopping malls, airports, fares, public areas, etc.

Value Propositions (VP)

The Cloud Robotics service is composed of two scenarios that compared to the traditional approach improve:

- Automation of tasks: the cleaning tasks can be triggered automatically optimizing the cleaning procedures. The automated delivery of goods, instead, will accelerate the delivery process within the shopping mall.
- Better shopping experience: the cleaning tasks will be triggered depending on the density of visitors minimizing the disturbance to the customers providing better shopping experience. The faster delivery of goods to the shops will help to provide a better service to the customers.

The Cloud Robotics service aims to put a robotic service and a software development framework to develop 5G-CORAL applications within the customers' service.

Channels (CH)

Two types of communication channels for the Cloud Robotics services can be envisaged. On one hand, there is a direct feedback from the customers according to the satisfaction on the cleanness of the shopping mall and whether the robot is disturbing in crowded areas when considering the cleaning service. For the delivery of goods, instead, the direct feedback is about the speed in the delivery of goods when required. And on the other hand, a feedback is gathered from the software that is running in the robots. Through this channel we track and guide the behaviour of the robots to give a good service.

Customer Relationships (CR)

As a Cloud solution, the management data are stored in the Edge Cloud in most of the cases since the robot intelligence is limited, which can be easily accessed by the service provider and the software developers. This would help early detection of the service problems and improve the software quality. Data access would also help process the customer feedback, provide quick support and improve the service quality. In general, this would help maintain the relationship with customers and developers.

Revenue Streams (RS)

The key revenue sources are from two main services provided: either sell robot hardware and subscription or pay-once software services. The second service is a SaaS per usage model, i.e. subscription (e.g. monthly, annually) according to the usage of the services.

Key Resources (KR)

Key resources of this service are the robots as a pure hardware and the robot applications as the service to give the orders to the hardware.

Key Activities (KA)

The service given implies several important issues to properly work and guarantee some quality of service to the customers. In the first place, the service provider has to maintain and update the software and hardware when needed based on the feedback received. This implies maintaining relations with the customers and the interaction with the computing/networking infrastructure provider during all the process.

Key Partnerships (KP)

For this service the suppliers provide software, hardware and services to the customers.

- Edge and Fog system provider: provides the Edge and Fog system to host the software of the service.
- ISPs: provide the infrastructure to be used by the service.
- Application developers: if external applications are tested over the hardware of the robot.

Cost Structure (CS)

The main costs are the payments to the suppliers as well as the costs for network operation and maintenance. Thus, costs can be divided in robot building costs, maintenance cost of hardware and software, and software development costs.

Summary and discussions

From the analysis of the business Canvas related to the services of the Cloud Robotics use case, the feasibility of the business case of providing hardware and software applications to then derive a service to allow users to develop and test their own applications has been proven. It solves some key main points in the shopping mall deployments and meets the demands of its customers.

Note that this use case includes two robotics services, even if they are similar (both include the robot as a hardware), one of them includes the software in the service thus each of them involves different types of relations and partners.

4.3 Connected Cars

The connected vehicle market is one of the main growth areas in the 5G scenario, with a potential revenue of $USD 253 billion by 2025 [31]. Connected cars are changing the automotive industry, as modern vehicles progressively look like more computing nodes on wheels. Car Original Equipment Manufacturers (OEMs) are emerging with new business models for improving vehicle safety, maintenance, and, in addition, providing drivers and passengers with navigation and entertainment services.

To get a better understanding of the business environment related to the Connected Cars' scenario, an example of a possible business model is illustrated in Figure 15, which has been realized from the car OEM perspective where it mainly acts both as an Edge and Fog system provider (when it offers its own platform to 3rd-parties for allowing them to install their applications, i.e. PaaS) and as an Edge and Fog application/service provider (when it offers Data-as-a-Service, DaaS).

In this example a car OEM owes a car platform (Fog CDs, sensors, cameras, modems, on-board storage capabilities). The car OEM then focuses on offering the possibility of using the car platform and the vehicle data collected from the platform towards 3rd-parties (e.g. OTT players such as insurance companies) and end-users with the goal of improving the safety of drivers and passengers and also for their entertainment. PaaS, DaaS and classic subscription models are possible here, at different levels and for different costs.

In both cases some of the key partners of the car OEM in offering such services will be the communication providers and road infrastructure operators that offer the connectivity, the Edge DCs and the roadside Fog CDs (Road Side Units, RSUs). The 5G-CORAL solution is the technology enabler for the interactions among the above-mentioned players.

Key Partners	Key Activities	Value Propositions	Customer Relationship	Customer Segments
• OBU platforms vendors • Communication Providers • Road Infrastructure Operators • Edge/Cloud Providers • Drivers and passengers	• Maintenance of the vehicle platform • Interacting with customer segments • Interacting with communication provider, road infrastructure operator and Cloud provider	• Car platform integrating virtualized OBUs and multi-RAT support enabling low latency communications, almost real-time application execution, vehicle data collection and local caching capabilities, all available as a service • Enhanced car safety services	• Automatized relation with OTT players • Direct relation with drivers and passengers	• OTT player (e.g. insurance companies, on-demand video providers) • Transportation companies • Drivers, passengers
	Key Resources • Car platform • Customer relations		**Channels** • B2B • B2C	
Cost Structure • Cost of car infrastructure (OBUs, radio equipment, software platforms) • Connectivity cost		**Revenue Streams** • Paas/DaaS towards OTT players • Subscription based services towards drivers		

FIGURE 15: BUSINESS MODEL CANVAS FOR THE CONNECTED CARS USE CASE.

Customer Segments (CS)

A multimedia content provider can exploit innovative techniques such as local caching in CDNs, leveraging the computational and storage capacity of 5G-CORAL Fog CDs (located within vehicles and installed by the car OEM) and the available multiple RATs. This could be useful to cope with increasing both capacity demand and volume of signalling messages. Vehicular insurances can redefine the car insurance mechanism subscribing the vehicular metadata service, without installing themselves any appliances on the vehicles (Pay as you drive in [32]). In addition, transportation companies and municipalities can leverage on the data collected from the vehicles, aggregated or not, to develop innovative services related to fleet management, traffic management, air pollution mitigation, monitoring car accidents and so on. Car OEMs can also directly provide V2X services to their customer, such as predictive maintenance as reported in [32] (e.g. gathering diagnostic data to detect and correct problems more quickly). Moreover, they could provide a set of services linked directly to safety and autonomous driving.

Value Propositions (VP)

The Car OEM can provide a car platform integrating virtualized On-Board Units (OBUs) and multi-RAT support enabling:

- Low latency and reliable communications.
- Almost real-time application execution.
- In-vehicle local caching capabilities of multimedia contents.
- Vehicle data collection available as a service to the OTT players.

The OTT players can enrich their offered services to drivers and passengers without installing any new hardware on the vehicles, reducing CAPEX and time-to-market in delivering new services (e.g. currently insurances companies require the driver to install black boxes on their cars). Regarding the direct offering of enhanced safety services to the drivers, the value proposition consists in the valuable social benefit of protecting life of drivers and passengers.

Channels (CH)

Car OEMs deliver PaaS and DaaS through APIs. They may also provide a web user interface to those APIs. Offering safety services to end-users, car OEMs can leverage both on vehicular applications and on the integration with users' smartphones and wearable devices.

Customer Relationships (CR)

Car OEMs can maintain relationships in a number of ways according to their customer segments. They can offer personal support to OTT players (B2B) through the sales and product lifecycle, but most of the interactions will be handled through dedicated online tools. Drivers and passengers can be reached through online and physical service support and marketing activities (B2C).

Revenue Streams (RS)

Car OEM may charge OTT players and transportation companies at different levels and for different costs depending on the service required (PaaS and/or DaaS). Subscription-based services, instead, can be provided to drivers and passengers.

Key Resources (KR)

Car OEMs own the on-board platform (hardware and software). A vehicle has a lifetime of at least 8 to 10 years, and then its hardware needs to be resistant and stable. In addition, they can leverage on Edge/Cloud resources for the completeness of the infrastructure.

Key Activities (KA)

Car OEMs are in charge of the maintenance of the vehicle platform that has to comply with road safety regulations and product safety standards. Moreover, Car OEMs interact with communication provider and road infrastructure operator, exploiting their connectivity services and their Edge DCs and Fog CDs for achieving low latency communications and a higher reliability. Communication providers and road infrastructure operators are also interested in accessing to the data collected from the vehicles, then a number of business interactions are available here.

Key Partnerships (KP)

Car OEMs can buy in-vehicle platform components from silicon companies and integrate them into their products, using a lot of software (proprietary but also open source solutions). The connectivity with an end-to-end low latency and high level of reliability, but also the capability of offloading the application processing near the vehicles, are among the most important requirements for the considered use case. For this reason, Car OEMs have also strong relationships with communication providers and road infrastructure operators. The communication provider leases all necessary resources, both physical and virtual, from one or many 5G infrastructure providers to run an end-to-end slice which will leverage on central and Edge DCs. OBUs can be run from car OEMs, RSUs can be run from the road infrastructure operators or communication providers, while Edge DCs can be run from communication providers or Edge Cloud providers. The driver/passenger can be also a key partner of car OEMs: acting as prosumers, in facts, they can provide data to the infrastructure and/or to other vehicles getting rewards or discounts.

Cost Structure (CS)

The main costs are the payments to the suppliers previously specified as key partners (mainly connectivity costs and Edge/Cloud services' fees), as well as the other costs listed below:

- Hardware costs of purchasing vehicle platform components (OBUs, modem, etc.).
- Costs for developing the vehicle platform's software.
- Cost for system integration of the vehicle platform components.

Summary and discussions

The Connected Cars business can be improved by enabling new use cases, as shown in the proposed business model Canvas, and by leveraging the unprecedented possibilities of having Fog CDs on vehicles and RSUs. Vehicles data can be used for data analytics, for enabling new services and improving existing ones such as localization, traffic management and safety. It can be offered as DaaS, included in the Edge and offered as PaaS. Some services can be provided directly to end-users (i.e. passengers and drivers) through dedicated solutions.

Many different players can run some part of the infrastructure (both Cloud and Edge/Fog): communication providers, car OEMs, OTT players (e.g. Netflix, etc.) and Cloud providers (Amazon, Google, etc.). In general, collaboration between 5G industry and automotive industry is needed to design a 5G V2X technology that meets their needs: both need to interact with Standards Developing Organizations (SDOs) and policy regulation makers. 5G Private Public Partnership (5G-PPP) and 5G Automotive Association (5G-AA), for example, are now studying and developing solutions for upcoming transportation and mobility services [33], [34]. As illustrated through the analysis of the business Canvas, the technology solution proposed by 5G-CORAL efficiently meets the technological and business demands of the identified stakeholders.

4.4 High-Speed Train

In the High-Speed Train use case various services can be targeted when adopting Fog CDs. Here Fog CDs are needed to support traffic breakout and mobility. In theory either the high-speed train company or the telecom operator can own the Fog CDs but, in real deployments, Fog CDs are most likely to be owned by the high-speed train company. In case the telecom operator can place Fog CDs on board the high-speed train or within the train stations along the railway, this will help to provide services (SaaS as an example) such as visitor information, station map, weather broadcast and others to the passengers as part of the Internet connectivity contract. In other words, the telecom operator will charge passengers to provide them new services while utilizing the high-speed train facilities, hence representing a source of revenue for the telecom operator. Another approach to adopt SaaS in High-Speed Train use case is the one where the high-speed train company offers or rents its platform to OTT providers or application developers. These can use the Edge Cloud capabilities as well as the communication metadata to develop new applications and services on top of Fog CDs, such as AR/VR, fitting the application/service demands of high-speed train passengers. The OTT provider or application developer are not required to pay for renting the platform but they need to sign an agreement with the high-speed train company to share a percentage of the revenues from their developed applications/services which are supposed to be purchased by passengers. In addition, the high-speed train company and/or telecom operator can provide an integration service for OTT players by setting up Fog CDs to be interconnected among each other as well as connected to the Edge Cloud. In particular, OTT service provider design requirements of setting up Fog CDs can allow to meet the QoS for passengers since it cooperates actively with the platform owner (either the high-speed train company or the telecom operator). Last but not least, the new applications/services can host advertisement from interested parties such as a shopping mall co-located with a train station, representing another source of revenue. The corresponding business model Canvas is given in Figure 16 from the viewpoint of the telecom operator.

<table>
<tr>
<td rowspan="2">Key Partners
• Edge and Fog system provider
• Software vendors or OTT provider for AR/VR
• Telecom Operator
• Equipment vendors (small cells, CPEs)
• High-speed train Company</td>
<td>Key Activities
• Deployment, maintenance of the small cells, CPEs
• Software test and verification
• Network management of vMME and Fog CD
• Network system optimization</td>
<td rowspan="2">Value Propositions
• Provide platforms enabling more advanced functions and new services to the passengers
• Traffic breakout and mobility support
• Virtualized MME to overcome the signal storming and reduce core network overhead
• Automatic traffic management</td>
<td>Customer Relationships
• Customer support (online and offline)
• Feedback analysis</td>
<td rowspan="2">Customer Segments
• Passengers
• Shopping mall located at the train station</td>
</tr>
<tr>
<td>Key Resources
• Fog CD
• Software running on top of the Fog CD</td>
<td>Channels
• Self-service
• APIs
• Regular operator stores
• Customer services (telephone, online)</td>
</tr>
<tr>
<td colspan="3">Cost Structure
• Hardware costs of Fog CD
• Software costs of virtualized MME
• Subscription fee for using the Edge and Fog platform
• Cost for system integration
• Electricity power and internet connectivity
• People for network operation and maintenance
• Renting of space for hardware at train or train station</td>
<td colspan="2">Revenue Streams
• Subscription fee of services
• Subscription based services towards agent with costs related to the service level agreed
• Percentage of OTT/app developer's revenue
• Advertisement run on top of the services</td>
</tr>
</table>

FIGURE 16: BUSINESS MODEL CANVAS FOR THE HIGH-SPEED TRAIN USE CASE.

Customer Segments (CS)

In the High-Speed Train use case, the telecom operator will provide both software and hardware infrastructure for the services provided on-board the trains based on agreements with the high-speed train company. Also, the virtualized communication stacks adopting Fog CDs on top of the infrastructure will allow new services to be provided and several business opportunities involving different players in real deployment scenarios. For instance, by promoting the travelling with the high-speed train (which is usually costly) with reliable AR services. Another example: Fog CDs can host several applications such as video streaming, VR, etc. Furthermore, the shopping mall located at the train station can provide various advertisement on top of the aforementioned services. Consequently, two main customer segments can be identified in this use case: passengers and shopping mall owner. This scenario is also detailed in 5.3.3 as an example of the federation mechanism – being one of the 5G-CORAL innovations – involving the high-speed train company, the telecom operator and the shopping mall owner.

Value Propositions (VP)

For the High-Speed Train, the telecom operator adopting the Edge and Fog system will create new values compared to traditional approaches, which are as follow:

- Traffic breakout: by deploying a virtual MME (vMME) at the Edge of the network, multiple benefits in terms of Quality of Experience (QoE), flexibility and cost can be achieved. For example, end-users on board the train could have a better QoE while travelling on board as well as when approaching the train station, hence the service interruption due to high mobility experienced during e.g. video streaming can be minimized by adopting traffic split solutions. This improvement is very flexible to be used and with a very little increase in cost with respect to the original network.
- Virtualisation: by addition/modification/delete of functions to support service migration and handover between Fog CDs. In this way new reliable services could be provided for end-users on board the train which were not possible without the integration of Fog CD with virtualized components (e.g. vMME), hence opening the door for new revenue opportunities. For example, on-board gaming will be possible without service interruption during the trip.
- Mobility support: by reducing the signalling storm towards the Core Network due to the frequent handover of hundreds of passengers, also triggering mobility functionalities ahead of time.
- Increased scaling and automation possibilities: in the High-Speed Train use case the Fog CD is typically cheap and with low power consumption, while the virtualized communication stack running in the Edge Cloud can dynamically scale with the load of the communication network.

Channels (CH)

The virtualized communication stacks adopting Fog CDs will bring new services and several business opportunities for e.g. the high-speed train company: in fact, promoting the travelling with the high-speed train – which is usually costly – can be done by also providing passengers with reliable AR services. To this end, AR windshield displays can be used for providing real-time information such as scheduling and route changes and other customer needs. As an example, image-augmented physical maps of the train station can be provided to passengers so that they can visually and or audibly access the portion of the station that they are actually using or they need.

Customer Relationships (CR)

Passengers could be subject to a self-service when downloading the application on their phones. The relationship with the OTT provider or the telecom operator is based on contracts or charged when downloading and using the service. Also, if the service also includes some advertisements, than the owner of advertisement will pay the telecom operator or the high-speed train company for hosting these advertisements. An advertisement owner could be the owner of the shopping mall located at high-speed train station.

Revenue Streams (RS)

The main source of income is perceived to come from the advertisements of the shopping mall and from charged VIP services (i.e. customised top class assistance) to passenger provided by OTT or the telecom operator itself, which can both develop applications/services enriching the passengers' travelling experience.

Key Resources (KR)

For this use case one of the main aspect is the fact that some of the LTE core network entities are brought near to the end-users (passengers), within a virtualized environment. In particular, the vMME deployed on board the train, on top of the Fog CD will avoid the signalling storm and provide better QoS, simultaneously.

Key Activities (KA)

As part of the agreement with the high-speed train company, the telecom operator has to monitor the Fog infrastructure for dynamic response to the traffic/service demand. This scaling activity may require building a relationship with software providers (OTT providers) and/or hardware vendors. In this way, new services on top of the Fog CDs can outreach to the passengers.

Key Partners (KP)

The telecom operators have to partner with the following players in order to provide services tailored for the High-Speed Train use case:

- Edge and Fog system provider.
- Software vendors for e.g. AR/VR services.
- Hardware vendors for e.g. small cells, Customer Premises Equipment (CPE).
- High-speed train company.

Cost Structure (CS)

The cost structure for running the system is quite complex and involves several key partners. The summary of costs is reported in the following:

- Hardware costs, for buying Fog CDs.
- Software costs for the vMMEs.
- Subscription fees for using the Edge and Fog platform (in case this is not provided by the telecom operator).
- Costs for system integration.
- Electricity power and network infrastructure for Internet connectivity provisioning.
- Telecom operator's employees for network operation and maintenance.
- Renting of space for hardware on board the train or within the train station.

Summary and discussions

From the analysis of the business Canvas, the feasibility of the business case of providing Edge services based on vMMEs deployed on top of Edge/Fog units was shown. In particular, the vMME overcomes the intensive (but needed) signalling going back and forth from/to the core network and opens the door for new services which require certain QoS for passengers. The telecom operator can adopt this business model by signing an agreement with the high-speed train company, achieving new revenues from advertisements of interested parties. In addition, for the OTT providers, the High-Speed Train use case can be a source of revenues because of passengers purchasing their services. Last but not least, the business model for the High-Speed Train use case involves many players based on the agreements among the high-speed train company and the different stakeholders.

4.5 AR Navigation

The AR Navigation system can be seen as SaaS provided by the Fog solution provider and running on the EFS managed by the Fog system provider. This use case relies on a mesh network of computing devices for which Fog seems to be more suitable than Edge. The role of the Fog solution provider can be played by companies providing Fog systems (Fog equipment vendors), infrastructure (local network operators, Internet Service Providers (ISPs), telecom operators) or software solutions (software companies, OTT).

In the Canvas provided below the focus is on the telecom operator as a Fog solution provider. It would provide the shopping mall with the combined Fog-based AR Navigation solution. Therefore, it needs to integrate and maintain the software (AR Navigation), the system (Fog system) and the infrastructure (Fog CDs and networking). In order to do so, it might need to partner with hardware vendors and software solution providers.

The business model Canvas in Figure 17 gives an overview of the telecom operator's business model for the AR Navigation use case.

<table>
<tr>
<td rowspan="2">Key Partners
• Fog equipment vendors
• Networking equipment vendor
• Shopping mall operator/owner
• Software vendor for AR Navigation and Fog platform</td>
<td>Key Activities
• Deployment, maintenance and scaling of the Fog infrastructure
• Customer and partner relations</td>
<td rowspan="2">Value Propositions
• AR Navigation application for the mall clients
• AR Navigation based advertisement for the retail stores</td>
<td>Customer Relationships
• Direct relation/ automated service with retail stores
• Self-service with the mall clients</td>
<td rowspan="2">Customer Segments
• Mall clients
• Retail stores</td>
</tr>
<tr>
<td>Key Resources
• Fog infrastructure
• Fog system
• Fog solution (AR Navigation)</td>
<td>Channels
• Retail stores: through the shopping mall operator
• Clients: advertisement and/or Wi-Fi starting page</td>
</tr>
<tr>
<td colspan="2">Cost Structure
• Fog infrastructure
• Fog system
• AR Navigation application
• Space rental in the shopping mall</td>
<td colspan="3">Revenue Streams
• From the mall client for the use of the navigation in the form of pay-as-you-use, subscription or paid application
• Charge retail stores for showing their ads to the mall clients</td>
</tr>
</table>

FIGURE 17: BUSINESS MODEL CANVAS FOR THE AR NAVIGATION USE CASE.

Customer Segments (CS)

The telecom operator will provide both software and hardware infrastructure to the shopping mall premises to provide AR Navigation solution and later other Fog-enabled applications. While the AR Navigation solution is directly targeted towards mall clients willing to find a particular location in the shopping mall, the same system can be used for advertisements of the mall's retail stores. As a result, two customer segments can be devised for this business model: mall clients and retail stores.

Value Propositions (VP)

For the mall clients, the telecom operator will provide an AR Navigation solution which will allow mall clients to freely navigate within the shopping mall. On the other hand, retail stores will be given a platform to push advertisements and coupons into the AR Navigation application.

Channels (CH)

Mall clients will use the AR Navigation system through the UE application they will download while entering the mall. The information about the indoor navigation service will be passed to them via the shop's sign advertisements at the mall door via the login page when accessing mall's Wi-Fi system. Retail stores, on the other hand, can be contacted directly via the shopping mall operator.

Customer Relationships (CR)

Mall clients will be subject to a self-service when downloading the application on their phones. The relationship with the retail stores will be maintained directly by visiting/calling stores or in automated manner via the advertisements' platform (similar to the Google AdWord system).

Revenue Streams (RS)

Although the main source of income is perceived to come from the advertisements of the retail stores it is also possible that mall clients might pay for the use of the navigation application (e.g. in pay-as-you-use manner or for premium content).

Key Resources (KR)

The assets that the telecom operator will integrate to provide the service include the AR Navigation solution, the Fog system and the Fog infrastructure.

Key Activities (KA)

The telecom operator will have to monitor the Fog infrastructure for dynamic response to the demand. This scaling activity will require to maintain relationship with key partners responsible for delivery of the solution components (e.g. the Fog solution provider). At the same time, tight relation maintenance with the mall operator will be required to reach coordinate the outreach to the end customers.

Key Partners (KP)

Since the telecom operator might not have the whole know-how in AR Navigation, Fog systems and Fog infrastructure fields it might establish a partnership with appropriate entities. These include: Fog equipment vendors, networking equipment vendors, software vendors for AR Navigation and Fog platform. In addition, a collaboration with the shopping mall operator/owner will be key to rent space for setting up the system and interact with target customers.

Cost Structure (CS)

The cost of running the system is related to the key partnership described earlier. Assembling an entire system would require purchasing hardware and software components from vendors, developing own solutions (e.g. AR Navigation phone application) as well as renting space in the shopping mall to deploy the system.

Summary and discussions

AR Navigation solution is undoubtedly a new business opportunity for many players related to Fog computing technology. It would involve combining several elements which can be provided by many players. The end product provider, which in the example described above is a telecom operator, would have to collaborate with key players or combine their roles within its competency. It is important to note that the proposed dynamic of Fog software and hardware infrastructure can be reused for other applications and solutions providing a more diverse service set to the end customers. It would increase the revenue flow and pay the investments and operating costs (CAPEX and OPEX, respectively) faster. It is important to highlight that the AR Navigation use case business dynamics might be accomplished also via the traditional Cloud computing; however, the main reason for using the Fog approach is the very stringent latency requirement to be fulfilled for the AR application to properly work. Therefore, the above-descripted business aspects will be feasible only when the Edge and Fog will become pervasive.

4.6 SD-WAN

Software Defined Wide Area Network (SD-WAN) technology is the new generation of Wide Area Networks (WANs) which leverages Software Defined Network (SDN) in the scope of WNAs. This use case integrates Edge and Fog infrastructure to virtualize network functions in order to provide a low latency and distributed network service that permits the deployment of an organization's WAN interconnecting the headquarters, branches and Cloud. The envisaged scenario is the shopping mall, where branch shops can use this service to establish a local network and to connect it to the company WAN. Also, a Point of Sale (POS) application is defined, where banks can establish a Virtual Private Network (VPN) connection with the shopping mall. Those shops that use the payment service will connect to the WAN access point with their POSs and process the payment. Isolation features make this scenario feasible to become a multi-tenancy environment, while resilience, fault-tolerance and flexibility are features that also enhance the use case. A detailed description of the use case can be found in Appendix A1.

The following business model Canvas in Figure 18 is focused on the SD-WAN service operator, which basically can act as a

- WAN connectivity provider to shops and organizations within the shopping mall
- POS terminal provider for connecting shops to the bank avoiding a direct VPN connection
- Provider of Internet connection allowing for remote employees to connect to the organization's network.

The SD-WAN service operator provides the above services without owning any infrastructure.

Key Partners
- Communication Infrastructure providers
- Edge/Fog Infrastructure providers

Key Activities
- Gathering context information by the underlying resources to choose the best RAT option
- Design, development and deployment of the software into the Fog hardware
- Continual technological improvement of the service
- Customer and software support for the clients
- Status and security monitoring

Key Resources
- Edge/Fog infrastructure
- SD-WAN software
- Communication Infrastructure

Value Propositions
- Headquarters, branches and enterprise Cloud services connection
- Centralized management of Cloud and networking
- Modularity - development of new features as requested
- Flexibility - perform changes in the network services on the fly
- Zero-touch deployment - easy to deploy, no technical expertise needed on premises
- OPEX cost reduction – reduce private MPLS connections
- Balancing between different multi-RAT technologies
- Deployment on top of Edge and Fog resources owned by 3rd-parties

Customer Relationship
- Sales and Support departments

Channels
- B2B
- Banks
- Shopping Mall

Customer Segments
- Shops belonging to a company with branches in different locations. The user are employees of the company working in the shops, e.g. shop assistant using IT services like a product management program
- Temporal visitors requesting WAN connection
- Banks requesting a Point of Sale service for shops in the mall, grouping the connections

Cost Structure
- Software development and maintenance
- Infrastructure renting

Revenue Streams
- Service subscription fee
- Usage fee

FIGURE 18: BUSINESS MODEL CANVAS FOR THE SD-WAN USE CASE.

Customer Segments (CS)

This use case targets services used for WANs operation. A group of customers comprises shops located in the shopping mall whose company utilizes a WAN to connect its shops. These shops can become a branch of that network. Also, banks which provide POSs to shops represent another set of customers. This payment service typically utilizes a VPN to connect with the bank servers but can also be realized by means of a SD-WAN. Finally, sporadic events or users that need a connection to their private networks could utilize the SD-WAN service as well.

Value Propositions (VP)

Some benefits based on SD-WAN approach being applicable to shops and banks can be determined: first, connectivity of branches, headquarters and Cloud infrastructure, which is the main objective of this service. This network can be centrically managed, changing configuration parameters on the fly. Also, modularity and flexibility are key values, since new functionalities can be developed due to the software supporting the network. In addition, the hardware is decoupled from the software, being easier to deploy. This hardware can be owned by a 3rd-party and leverages Edge and Fog resources. Finally, multi-RAT support is also considered, since POSs with Wi-Fi connection can be used as an alternative to POSs using the conventional cellular connection.

Channels (CH)

Channels for communicating, distributing and selling the SD-WAN service follow the common Business-to-Business (B2B) approach directly with the company requesting the service. However, it also shopping mall and bank channels can be considered, which can act as intermediaries to contract the service. For instance, if the bank acquires it, all shops that are clients of the bank could be feasible users of the SD-WAN service.

Customer Relationships (CR)

A sales and support department is considered by the service provider to keep the relationships with customers. The sales department will be in charge of SLA, legal and business aspects, while support will be a point of contact with the SD-WAN service itself to notify incidents, request features, and so on.

Revenue Streams (RS)

As a service, two revenue streams can be defined: a usage fee depending on the user's consumption of the service and a subscription fee based on time. Another revenue stream is due to the support and maintenance of the software developed in the shopping mall which hosts the POS service.

Key Resources (KR)

Three types of resources are identified. First, the Edge and Fog devices, serving as hardware for the service. Then, the software needed to instantiate the SD-WAN and to manage it. Finally, network infrastructure to connect the components, for instance Ethernet cables or wireless access points.

Key Activities (KA)

Based on service management's good practices, the activities to take into account are gathering context information by the underlying resources to choose the best RAT option to align with customer needs. Then design, development and deployment of the software into the Fog hardware will be performed. Finally, it needs a cyclical process where the software continually improves in order to keep enhancing the service. This can be achieved by status and security monitoring and software support.

Key Partnerships (KP)

Since the service is not considering the underlying hardware layer, an Edge and Fog system provider is a key partner, e.g. the shopping mall owner (which, in this case, is also the site owner). The same applies for both the network infrastructure and the Internet connection. Thus, the service can run its own software solution on top of the provided infrastructure.

Cost Structure (CS)

Basically, the costs are for the software development and maintenance, and for the infrastructure renting.

Summary and discussions

After analysing the business Canvas for the SD-WAN, the service can be considered feasible especially for POS payments and WAN connections in concrete venues. It could be less viable for temporal events requesting WAN access, since it is less usual. While shops requesting WAN connectivity would be just linked to multi-national companies, POS payments are widely adopted and can comprise mostly all the shops and services of the venue.

In addition, this adds value to current WAN solutions, which are always interesting in terms of business opportunities, while considering the trend of Edge and Fog technology expansion.

4.7 VR

The VR use case represents a new SaaS relying on multiple computing layers, i.e., Cloud, Edge and Fog. Several market players can invest in such technology, ranging from Cloud providers to event organizing agencies keen to provide enhanced services to the end-user. In the following, the focus will be on the event organizer and the related business model will be discussed. The corresponding business model Canvas is given in Figure 19.

<table>
<tr>
<td rowspan="2">Key Partners
• Shopping mall owner
• Infrastructure owner
• Advertisers</td>
<td>Key Activities
• Hardware/ software deployment
• Testing and verification
• Public engagement/ ads</td>
<td rowspan="2">Value Propositions
• Immersive event participation without attending the event in person
• Analytics</td>
<td>Customer Relationships
• Direct relation with shopping mall and/or event organizer</td>
<td rowspan="2">Customer Segments
• End-users
• Advertisers</td>
</tr>
<tr>
<td>Key Resources
• 360-degree camera
• VR-capable devices
• Fog/Edge/Cloud computing substrates</td>
<td>Channels
• Contract and agreement among shopping mall, advertiser and event-organizer</td>
</tr>
<tr>
<td colspan="2">Cost Structure
• Cost of infrastructure deployment, rental, and maintenance</td>
<td colspan="3">Revenue Streams
• From the end-user for the use of VR in the form of pay-as-you-go or membership-based payment
• Charge advertisers for using VR for advertisement exposure</td>
</tr>
</table>

FIGURE 19: BUSINESS MODEL CANVAS FOR THE VR USE CASE.

Customer Segments (CS)

Profitable customers envisioned in this use case are the end-users, who are willing to pay a fee in order to watch the live event through the VR service. In addition, significant revenues will be expected to be obtained from advertisers to show advertisements during the course of the live event.

Value Propositions (VP)

The key benefit of this use case consists of providing a novel immersive way to virtually attend a live event as if the spectator was standing in the frontline. VR technology in conjunction with Ultra High-Definition 360-degree cameras deployed in the shopping mall can make this happen and is extremely appealing to an event organiser who wishes to promote the event and get customers engaged.

Channels (CH)

In this context, typical sales channels are established through contracts and agreements among the different players, such as the shopping mall owner, advertisers and event organisers. Customer channels will be created online via websites, or through adverts showed in the premises, or through direct interaction with the shopping mall customers, e.g. via flyers distribution.

Customer Relationships (CR)

Relationships with the customers will be maintained by relying on the direct relation with the shopping mall and the 3rd-parties. Also, human interactions will be needed to help the customers get most of the VR experience and to demonstrate how to use it.

Revenue Streams (RS)

As with many similar entertainment services, such as cinema, theatre and so on, customers can be charged either on a pay-as-you-go basis or by subscribing to a membership. Furthermore, profits can be made by charging advertisers for employing VR to show adverts.

Key Resources (KR)

Essential resources for the VR use case are the 360-degree camera capturing and streaming the live event, the VR-capable end-user devices, including goggles and smartphones, and hardware/software to run Fog, Edge and Cloud computing substrates.

Key Activities (KA)

Key tasks include software installation and hardware deployment, such as camera and end-user devices installation as well as service testing and verification. Another key activity consists in public engagement and advertising.

Key Partners (KP)

The shopping mall owner will play a fundamental role in this business model, being the VR service hosted in his/her premises. Next, the infrastructure owner will supply connectivity and power, while the advertisers will be able to show adverts and monetise through the VR service.

Cost Structure (CS)

Costs comprise the infrastructure deployment and maintenance as well as equipment leasing, such as the cost of hardware equipment, wireless broadband connectivity, Internet leased lines and power consumption.

Summary and discussions

Given the business model analysis provided above, it is worth pointing out that the adoption of the VR technology together with the support of Fog and Edge computing solutions can enable novel business models as the one described earlier. In our scenario, an event organiser entity can deploy a VR-enhanced live streaming service capturing an event occurring in the shopping mall and make profits by charging customers interested in the immersive VR experience and advertisers keen to show adverts through the VR service.

A similar business model Canvas can be adopted for different players, e.g. the shopping mall owner or advertisers. Furthermore, the VR use case can be attractive for the music and TV industry as well as the major multimedia streaming companies, such as Netflix, Amazon and Spotify, which may introduce premium subscriptions in order to allow customers to benefit from the VR service.

5 Federation considerations in 5G-CORAL

5.1 Motivation

Section 3.1 explains the view of the key players regarding benefits and business models that Edge and Fog systems bring. Each described use case comprises several components that belong to different business actors or different *administrative domains*. Each of the components, provided by the business actors, needs to interoperate with each other perfectly in order to deliver the end-to-end service to the end-customer. The Edge and Fog system is the common component in most of the use cases whilst the other ones are mostly use case specific. In an effort to dynamically re-use and combine as many 5G-CORAL system components as possible – each belonging to different players within the ecosystem – for providing a plethora of services via full exploitation of the 5G-CORAL Edge and Fog platform, the concept of *federation* among different administrative domains needs to be introduced.

As reported in [35], an administrative domain is defined as a collection of resources operated by a single organization and it is viewed as a cohesive entity whose internal structure is unimportant from the outside. Federation is the mechanism allowing to integrate multiple administrative domains - at different granularity – into a unified open platform where the federated resources can trust each other at a certain degree, which is determined based on the service-/business-level agreement or partnership among the organizations. By enabling the resources' federation, the business actors can expand their footprint, introduce new service spectrum, increase their competitiveness and keep track with increasing customer expectations. The idea is to allow business actors, from different or same area of interest, to create business relationships that would allow them to extend or create new end-to-end services for their end-customers by importing external features or resources (being used for other services) from already deployed Edge and Fog systems, without the need of deploying dedicated infrastructure or building new complex architectures. In the following sections, the federation concept is explained more in depth, focusing on several use cases as well.

5.2 Federation background

The federation approach in 5G-CORAL has been extensively investigated in [35]: in the following, only the concepts needed for providing federation considerations for a subset of the use cases addressed by 5G-CORAL are considered.

Two types of federation have been considered in 5G-CORAL: *static* (off-line) and *dynamic* (on-demand) federation. The former consists of a pre-established agreement among interested administrative domains. This federation relationship is established prior to any EFS operation. The initial information exchange and settlement of agreements (e.g. which resources would be shared) happen during business meetings, with agreements including all the pricing and sharing policies in the form of Service Level Agreements (SLAs). The pre-established federation is finished with the agreed parties exchanging their connection points. Each administrative domain can establish different levels of federation; the level of federation is basically the level of trust between two administrative domains: when considering two administrative domains, namely A and B, a high level of federation means that the administrative domain A allows more control over the range of resources belonging to administrative domain B which will subject to the federation, but regardless of the resource capacity. Low levels of federation share limited resource capacity as well as limited information regarding the shared resources. High level of federation relationships, instead, might include high resource capacity and high degree of information regarding the federated resources. The pricing model – i.e. how to charge the federated resources being used - is not tightly coupled with the type of establishing a federation and is determined during the establishment process (either dynamic or static). As mentioned in [35], the pricing for federating EFS resources can be fixed for limited subscription (monthly or yearly based) or dynamic based on a pay-per-use mechanism (referred to as posted-price scheme in [35]). Only the latter pricing model allows administrative domains to change the price per federated EFS resource at certain limited period of time, without changing the participants in the federation. This allows the pre-established federated domains to utilize the OCS as an auctioneer entity while the involved administrative domains bid for the available EFS resources.

The dynamic approach establishes federation relationships while the system is working on-line, i.e. EFS operations are running. Since the connections among different administrative domains are dynamically changing, this can be termed as *open federation*. The dynamicity of the open federation requires high degrees of trust, security and control and can be either *centralized* or *distributed*. In the centralized open federation both the control and trust burden are in the hands of a single entity. This single entity can be either a server or even an organization that takes care of establishing the relationship, connections, exchange of information and resources among all the federated administrative domains. The central entity takes the role of auctioneer providing a common point where different administrative domains can be federated and bid for the available EFS resources. The central entity also implements secure communication protocols and it oversees monitoring and maintenance of agreed federation terms. The cost of maintaining the central entity is not negligible and can be borne through cooperative contribution of the involved administrative domains (equal share) or through different levelled subscriptions fees.

The dynamicity of the federation relationships imposes pricing to be applied on per transaction or per usage of the EFS resources – the fixed (i.e. subscription-based) pricing model is more complex to be defined than the pay-per-use. As described in [35], *cooperative* and *non-cooperative* pricing model can be applied. The cooperative model is more inclusive and maximizes the utilization of federation since more administrative domains are willing to participate, whilst the non-cooperative model introduces competition among involved partners for maximum revenue.

The distributed open federation is a dynamic federation where the trust burden is distributed at each administrative domain, allowing all participants to form peer-to-peer networks for exchanging EFS resources. In this case, the clustering of the participating domains is mainly driven by the geolocation proximity. Recent advances in trust enabling technologies, such as Blockchain (Ethereum, IOTA) [36] [37], allow rapid, highly secure and fast setup of a distributed federation network. Leveraging consensus mechanisms implemented in the Blockchain network, the participating administrative domains are able to engage and rapidly establish federation relationship. Furthermore, the usage of Smart Contracts [39] can allow dynamic pricing with adjustable price per transaction, following the market supply and demand. The usage of the federated EFS resources is automatically monitored and the relationships can be automatically formed or broken down satisfying custom rules or metrics. The concept of joint Blockchain and Smart Contracts is a hot technology topic with high applicability potential, but suffers of high scalability issues in the current state. Future advances should bring high security and openness for administrative domains with either low or high EFS resource capacity to equally leverage the federation concept, removing the need of 3rd-party mediators.

In any type of federation (pre-established or open) the incentive for participating is maximizing the revenue from leveraging unused EFS resources or extending the service footprint by consuming external EFS resource capacity which, however, comes at a higher cost. The pre-established federation has a simple setup procedure, while the open federation suits the inherent dynamicity of the 5G-CORAL system.

In terms of administrative domains or types of business actors involved, the federation can be distinguished into *horizontal*, *vertical* and *hybrid* federation. This categorization in the context of Cloud technology is explained in [35]. The horizontal federation is on a peer-to-peer basis, where administrative domains share components at the same level (e.g. resource-level components such as radio heads, antennas, cameras, etc.). Vertical federation is when federated administrative domains form a hierarchy of federated components; this could refer to the federation between Edge and Fog layers, between central Cloud and Edge layer, or between central Cloud and Fog layer. Exemplary scenarios are either a public EFS system federated with a private Cloud or a central Cloud entity which is federated with a remote EFS system. Finally, hybrid federation is when there is a combination of both vertical and horizontal federation.

5.3 Examples of federation considerations for some 5G-CORAL use cases

5.3.1 Cloud Robotics federation

As described in [1] the Cloud Robotics use case leverages and integrates Edge computing, storage and other Internet technologies for industrial and commercial applications. Edge computing and its low latency benefits allow the migration of the robots' intelligence to the Edge of the network for multi-robot collaboration, coordination and scheduling from the network.

The Cloud Robotics use case comprises two different scenarios; the first one is the cleaning scenario where robots are used for cleaning the less populated zones of the shopping mall. The second scenario is the delivery of goods performed by robots which coordinate and synchronize themselves to deliver goods from the shopping mall warehouse to the interested shops.

In both scenarios, federation of resources or services can be applied to either produce the end-to-end service or to extend/complement already existing services. Furthermore, in both scenarios, the stakeholders are different players with different roles.

5.3.1.1 Cleaning service scenario

The deployment of the cleaning service, from a high-level perspective, has two steps: 1) the shopping mall owner buys the robots with pre-installed software for performing the above-descripted task; 2) integration into the already existing Wi-Fi network of the shopping mall. Once the service is up and running, the shopping mall actually consumes the service.

The requirements for the cleaning service scenario are the robots interconnected to each other via a Wi-Fi infrastructure (hardware) along with application (software) that would coordinate the cleaning task. The robots and the cleaning application (i.e. hardware and software) are provided by the robotic manufacturer, while the Wi-Fi infrastructure is the already installed Wi-Fi connectivity of the shopping mall. In this case the cleaning service does not consume any federated service or resource. However, the cleaning service can be provider of federated resources: the robots, in fact, are equipped with different hardware components (e.g. cameras, lidar sensors, motors) which can be used for creating new services or to extend/complement existing ones. For instance, the security surveillance service can be improved by using the cameras on-board the robots. During the times in which the robots are in idle mode (i.e. not performing the cleaning task) in a given corner of the shopping mall, the surveillance service can leverage the cameras on-board the robots for a better overview of the shopping area. This could be seen as a form of horizontal open federation (i.e. dynamic federation established between peer administrative domains) where the result is an extension of the existing security system achieved by consuming and managing available resources (e.g. cameras) which were initially intended for other services (e.g. the cleaning service), see Figure 20. However, depending on business policy, the federation of resources can also be established following the static approach.

All the players, i.e. the shopping mall owner, the security company and the robot manufacturer, benefit from the federation scenario. For the robot manufacturer, the possibility to benefit from the federation depends on whether the shopping mall owner buys or rents the robots used for providing the cleaning service. Only for the latter case, the robot manufacturer is responsible for the robots, their maintenance and has incentive to re-use them for other purposes, without violating the cleaning service agreed terms. This also applies to the delivery of goods scenario, described in the following subsection.

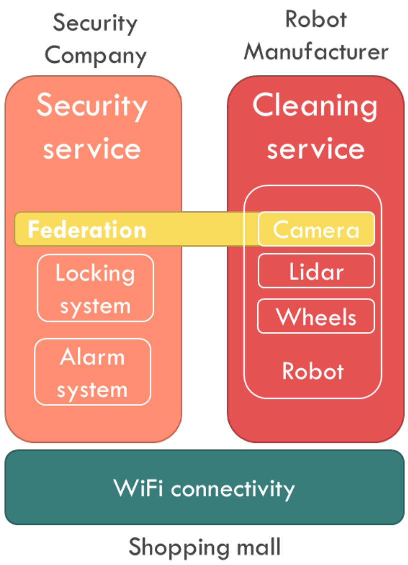

FIGURE 20: FEDERATION SCENARIO IN CLOUD ROBOTICS: CLEANING SERVICE.

5.3.1.2 Robot delivery service scenario

A logistics company may offer to the shops in the shopping mall (end-customers) a robot delivery service. This basically aims at transport required goods, products or any physical objects from the shopping mall storage area to the shops by using multiple synchronized robots.

The minimal requirements for establishing the end-to-end service would be:

1. software application connected to a Cloud or Edge DC (computation and storage), provided by the communication company.
2. Wi-Fi infrastructure already deployed in the shopping mall.
3. Robots – only the hardware of the robots without any pre-installed intelligence (i.e. software), provided by the robot manufacturer.

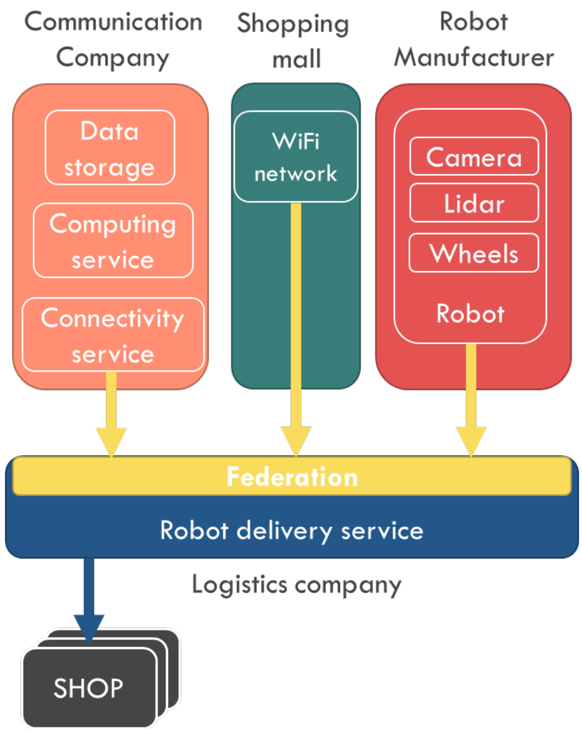

FIGURE 21: FEDERATION SCENARIO IN CLOUD ROBOTICS: ROBOT DELIVERY SERVICE.

Each of the minimum required components are not administrated by the logistics company. The robot delivery service requires hybrid open federation of each of the components that are not primarily dedicated for this service, as illustrated in Figure 21: the communication company, in fact, would provide the connectivity to the Cloud services that are already consumed by the logistics company as well as additional storage and computational power for the robotic application. The shopping mall would provide the Wi-Fi infrastructure that is already deployed for the shopping mall customers and finally the robot manufacturer can provide any of the deployed robots (e.g. the ones intended for the cleaning service) to be used for delivering goods while in idle mode.

All connected or stitched components, as an end-to-end service, are transparent to the end-user, while beneficial for all the players involved.

5.3.2 VR federation

The VR use case can significantly benefit from the adoption of federation strategies among different players in the shopping mall. This is motivated by the fact that the VR live streaming service can be typically set up by a multimedia or TV operator, who usually owns all the equipment necessary to manage the live cast. However, local and remote connectivity is generally supplied by other entities based on SLAs.

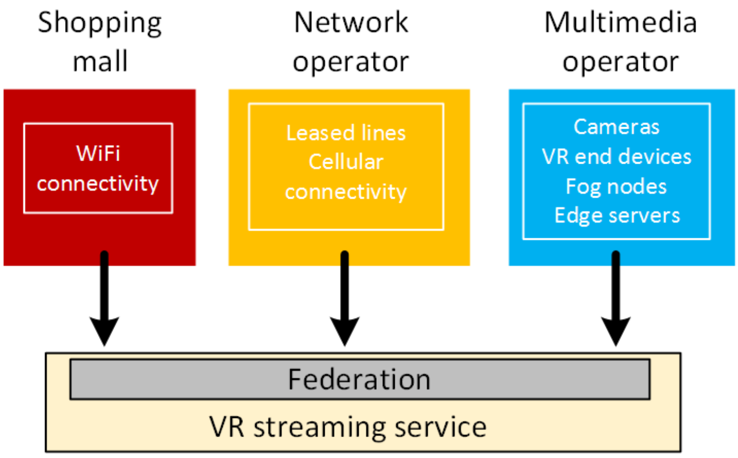

FIGURE 22: FEDERATION SCENARIO IN THE VR USE CASE.

Figure 22 illustrates the federation concept applied to the VR use case. The multimedia operator represents the main player and provides the VR live streaming service to the end-users. To this end, a federation scheme involving the shopping mall owner and the network operator is employed. The former owns Wi-Fi local networks inside the shopping mall and agrees to provide wireless connectivity for each VR terminal as well as each Fog node necessary to handle the viewport adaptive technology (for more details, see Appendix A2). Similarly, the network operator can offer leased lines and/or cellular connectivity to connect the shopping mall to the remote DC (located far off from the shopping mall, hence in the Cloud) allowing the VR streaming service to benefit from the high processing power available at the remote data centre. Furthermore, the multimedia operator can agree on licensing the shopping mall and the network operator to process and offer the VR content to their customers: for example, shopping mall customers can watch the live event on the premises, while the network operator can broadcast it within its network.

This federation scheme can be considered static, as it implies the establishment of agreements between the shopping mall and the network operator prior to deploying the service, and vertical, since a mix of Cloud, Edge and Fog technologies is employed.

5.3.3 Federation for the High-Speed Train

In High-Speed Train use case, when passengers are moving from the high-speed train to the train station which is co-located with the shopping mall, federation of resources at the Edge/Fog is deemed as necessary for providing the service migration functionality which will enhance the service quality for passengers. In particular, the end-user's services, which might require high bandwidth and low latency, will migrate among different pools of resources belonging to various domains with minimum interaction with core network. The service migration functionality leverages new applications deployed at the Edge/Fog for resource allocation during transition from one domain to another. Without adopting the federation, the service migration functionality could not be provided, hence passengers cannot experience the service continuity or extend the existing services capabilities. In addition, several key stakeholders are involved in the federation of High-Speed Train use case such as the high-speed train company, the telecom operator and the shopping mall owner. The federation scenario for the service migration in High-Speed Train use case is depicted in Figure 23.

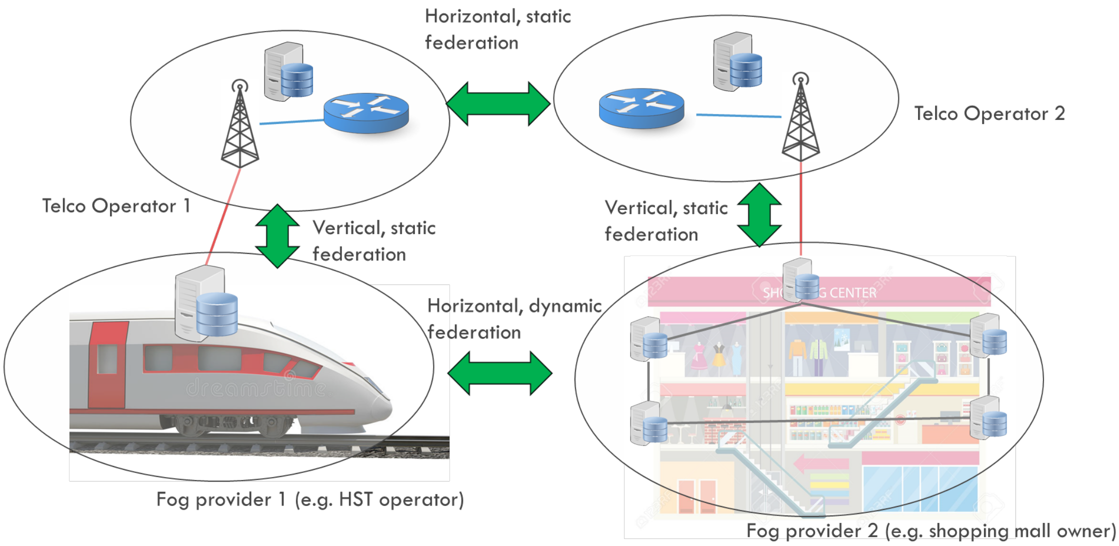

FIGURE 23: FEDERATION SCENARIO IN THE HIGH-SPEED TRAIN USE CASE.

Service migration requires a cross-domain collaboration among several actors – each managing the corresponding domain – to become operative and to provide real benefits to the high-speed train passengers. First of all, there is the high-speed train with its on-board Fog CD and communication infrastructure (Wi-Fi). It allows passengers to offload a computational load from the end-users' devices to the Fog CD as well as connectivity with the Internet from the cellular network to the Wi-Fi. While approaching the station, the service migration provider moves some of the processes to the train station (co-located with the shopping mall) which hosts a similar Wi-Fi and Fog infrastructure. It can be classified as another domain owned by a 3rd-party Fog provider. The federation between the high-speed train and the train station (shopping mall) domains - which is needed in order to make the migration process seamless – can be considered as a dynamic federation as it depends on the type of application being migrated, the number of passengers as well as the passengers' direction. It is also a hybrid federation, where the horizontal component is related to the resource-level federation establishment among peer entities (e.g. Fog infrastructures on-board the train and within the shopping mall). The vertical component, instead, is needed since the dynamic train-station federation caters for synchronization of the computing resources, which is achieved by leveraging the connectivity provided by the telecom operator. To this end, both train and station will create a vertical federation with the operator domain that will allow to control the data traffic between them. In addition, it might happen that user data need to traverse more than one core network. In this case, a horizontal federation can be required between operators so that the communication infrastructure can be reused. In both cases, since the nature and amount of resources used can be predicted beforehand, the federation can be seen as static.

6 Conclusions

The 5G-CORAL concept is foreseen to give new business opportunities as it makes it feasible for the network to cope with the stringent requirements of emerging applications that comes with the 5G mobile network evolution. This deliverable has analysed the business ecosystem with the key roles of this possible market. The edge and fog system provider will be one of the most important roles to foster this ecosystem and therefore one of the highlights in this deliverable was to analyse possible business model for that role. It is foreseen that system provider will use a PaaS based business model. They will have the contacts with hardware vendors, site owners and connectivity providers to set up the infrastructure and with system software vendors to establish the platform for applications. They will also have a close connection to the application/service provider who utilizes the platform to get applications from application/service software developers and who can offer the application and services to the end-users.

It will be possible for different players to take on the role of a system provider. It is also possible that one player takes on several of the above-mentioned roles. Looking at the business landscape as of today the two most likely players to take on the role as a 5G-CORAL system provider is a Cloud provider or a telecom operator. The Cloud provider can leverage on their expertise of Cloud platforms and software but they lack the locations close to the customers. Therefore, it is likely that they will focus on delivering platform software and let another player run the infrastructure and local installation/maintenance. The operator on the other hand can leverage on their network that covers many sites and locations where they are close to the end-users. By extending existing sites with Edge capabilities that can host a 5G-CORAL system they have the possibility to take an important part of the business potential.

It should be noted that the 5G-CORAL concept should be seen as a complement to traditional Cloud solutions since Cloud and Edge/Fog can target different types of deployment and applications with different requirements. However, with bringing the processing capabilities closer to the end-user as a natural part of the mobile network it is evident that that telecom and datacom markets are consolidated even further.

To understand how the business ecosystem can be shaped for different use cases the business model canvas has also been used to analyse the possible businesses for multi-RAT IoT, SD-WAN, Connected cars, high-speed train, AR Navigation, VR and Cloud robotics.

Finally, the concept of federation has been introduced in the context of 5G-CORAL and examples of federation considerations for some 5G-CORAL use cases has been given. The concept of federation will be further studied and discussed in the 2nd year of the project and will be presented in upcoming deliverables.

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Appendix

This section of the document reports new identified use cases apart from the ones already described in [1], i.e. SD-WAN and VR in Section A1 and A2. They are described following the same methodology already used in [1] for the other use cases addressed by 5G-CORAL. An updated 5G-CORAL architecture is also presented in section A3. Furthermore, the technical interpretation of the 5G-CORAL system-level requirements is provided in section A4 by taking the work of 5G-CORAL technical work packages (i.e. WP2 and WP3) into account. Finally, a deep dive description of the telecom operator's business models for Edge computing is given in A5.

A1 SD-WAN Use Case

Introduction

A Local Area Network (LAN) is used to connect devices within a limited area, for instance, a company office. When a few LAN networks are deployed in different geographical locations, and a connection amongst them is desired, to form a more extensive network, the term Wide Area Network (WAN) is used. This type of network extends over a large geographical distance that could be from cities to continents. Nowadays, the development of Software Defined Networks (SDN) and Network Function Virtualization (NFV) technologies has enabled the design and elaboration of the so-called SD-WAN solutions. SD-WAN applies SDN and NFV features to the connectivity among LANs, hence creating a Software Defined WAN. This is the scope of the use case, which tries to enhance SD-WAN networks by leveraging a decentralized Edge and Fog computing system, within 5G technology.

SD-WAN issues with current technologies

When comparing actual SD-WAN approaches with legacy WAN solutions, some benefits arise. First, cost reduction can be considered, since the number of dedicated Multi-Protocol Label Switching (MPLS) connections established to connect the different network branches can be reduced. However, this is not the only benefit. Instead of deploying on a closed network infrastructure with static firmware difficult to change. SD-WAN technology provides flexibility to control a network, considering that the control logic can be executed using software programs in many programming languages and different platforms, which can further be modified and migrated. Applications and services can be developed too, running on top of the network infrastructure, as virtual network functions to replace or enhance components, such as a firewall. The management of the network can be centralized and dynamically operated, where changes on the configuration can be issued on the fly.

However, principally SD-WAN solutions are considering Cloud environments where the company could have its applications on the Cloud [40] [41] [42], but the trend of Edge and Fog is not considered. The volatility and flexible conditions that Edge and Fog brings are still to be managed in current SD-WAN solutions, which does not foresee this type of hardware resources. Regarding RATs, access points are not unified for different radio technologies [43]. Thus, having some of them deployed, make it difficult to achieve efficient operations, traffic steering or aggregation of traffic flows.

How 5G-CORAL benefits the use case

Leveraging the 5G-CORAL system for Fog and Edge devices allows the deployment of network functions on the Edge of the network, closer to the users whose experience of use can be improved. Also, the company interested in the WAN network can use these resources by means of federation, without owning them and reducing investments, where the role of an Edge/Fog provider acquires importance.

With regard to the network control, the orchestration concept is brought, where the outstanding feature is dynamicity. Although SD-WAN solutions increase the level of flexibility, human control is needed in many steps. Leveraging the available context information gathered by the underlying resources and after processing it, the orchestration and deployment of network functions and control can be optimized to use the resources that best output produce in the system, and to manage the volatility of them. Monitoring context information is used to optimize the resource consumption and management of functions and applications life-cycle.

The main benefits of the SD-WAN use case compared with the traditional WAN approach are:

- Zero-touch deployment of SD-WAN, without technical knowledge needed on customer side
- Modularity and flexibility. Modularized features are activated or deactivated depending on the customer needs. Network configuration can change on the fly. New modules could be deployed reducing the time-to-market compare with old approaches
- Centralized and integrated network management
- Reduction of OPEX.

Finally, the support of multi-RAT permits to balance between different radio technologies considering the context conditions of each of them, not only providing more types of devices to connect to the infrastructure but optimize the use of the network.

Explanation of the scenario

The SD-WAN Use Case in 5G-CORAL is located in a shopping mall. The main objective is to provide WAN connectivity to businesses inside the mall by leveraging SD-WAN functions, to provide total connectivity to all of their company services. Thus, we can defined three applications of the use case. First, WAN connectivity to shops and organizations located inside the mall with WAN networks. Second, to provide POS terminals with a connection to the bank avoiding a direct VPN connection. Finally, occasionally to connect remote employees with its organization network. The SD-WAN use case is illustrated in Figure 24.

For instance, for the first objective, a business belonging to a multinational firm is willing to deploy internet connection and secure access to its company services in one of the branches located in a shopping mall. The employees of the new branch need to connect to a corporate service, in order to use an inventory management software, shared among all the businesses of the firm. The deployment of a SD-WAN network function allows secure access to the company Cloud services and communication with the headquarters and other business branches. The shop does not maintain neither the network or hardware infrastructure, which could be part of the shopping mall, owned by the Edge and Fog provider. The shop just needs to use a desired radio access technology, to access to the system, who will be in charge of routing it and balancing between all the WAN connections available, based in multiple parameters, such as, cost, latency, bandwidth available…etc.

For the case of Point Of Sale (POS) terminals, nowadays it can be expected that all the shops in the shopping mall accept credit card payments. Usually the procedure is to establish a Virtual Private Network connection between the terminal and the bank, which after process the payment. Leveraging SD-WAN, many POS can connect to the SD-WAN access point, which will establish a single VPN connection with the bank, instead of multiple connections for each device. Also the coverage can be enhanced inside the shopping mall.

Finally, configuration changes and new services can be issued on the fly, since the components are going to be virtualized and new software can be developed to provide the desired functionality.

Report on the RATS and resources involved

Below is presented the list of resources and RATs involved:

- Edge Server / Fog device: can run a virtualized WAN branch function. Needs connectivity to internet/network, and network interfaces depending on the configuration set.
- Branch infrastructure: virtual or real links that connect all elements involved in the SD-WAN service. Virtual connections, in order to connect the SD-WAN and RAT functions together.
- 802.11 and LTE access points. These RATs provide connectivity to the network and thus reach the EFS and OCS. Using context information, the system would balance between both technologies.

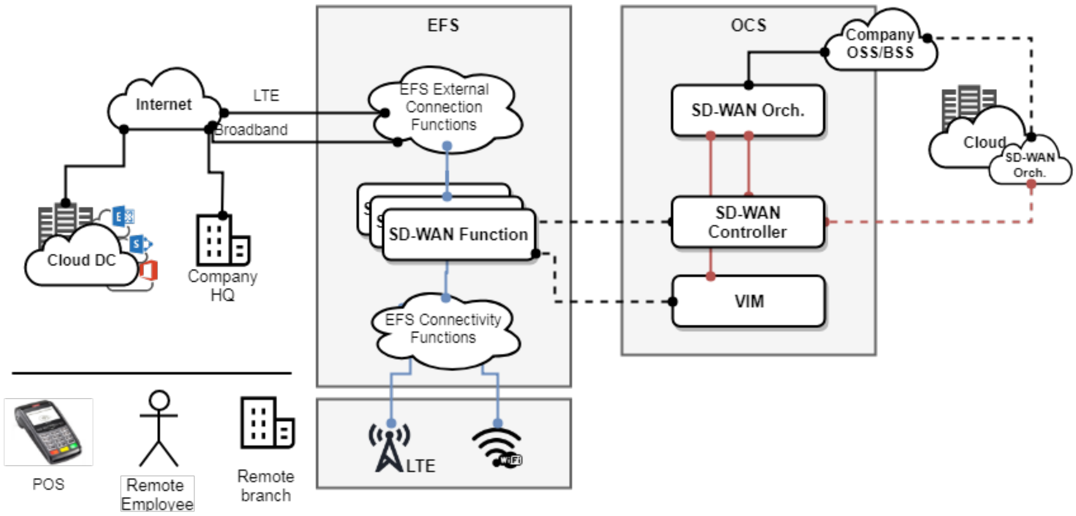

FIGURE 24: SD-WAN USE CASE DESCRIPTION.

A1.1 SD-WAN requirements and improvements brought by 5G-CORAL

TABLE 3: REQUIREMENTS AND IMPACT OF THE SD-WAN USE CASE.

Req. ID	Impact level	5G-CORAL improvement	Subelement (EFS/OCS)
FT-01	H	The SD-WAN function can be deployed and virtualized in heterogeneous resources	EFS
FT-02	H	Virtualization of network functions is a key feature	OCS/EFS
FT-03	H	The automatic discovery of resources will trigger the optimization of the deployment of SD-WAN functions	OCS
FT-04	L	--	--
FT-05	H	Federation with resources of the shopping mall not belonging to the customer	OCS
FT-06	M	The migration and placement of SD-WAN function enhances the experience of the user	--
FT-07	L	--	--
FT-08	L	--	--
FT-09	M	Mobility optimization should be performed	EFS

FT-10	L	--	--
FT-11	L	--	--
FT-12	L	--	--
FT-13	L	--	--
FT-14	L	--	--
FT-15	H	Monitoring data is given to the customer, and serves as input to the OCS	EFS/OCS
NF-01	L	--	--
NF-02	H	Availability is supported.	--
NF-03	L	--	--
NF-04	M	Placement of functions should take into account efficiency	OCS
NF-05	M	SDN will provide the isolation among different users	OCS
NF-06	H	Some services can be implemented like firewall, DNS or QoS using SDN technologies.	OCS
NF-07	M	Multi-tenancy	OCS
NF-08	M	New features can be developed using SDN, and network configuration is flexible	OCS
NF-09	L	React to network events, monitoring is needed	--
NF-10	M	Resilience support	EFS/OCS
NF-11	H	Functions should be deployed and migrated depending on scalability	EFS/OCS
NF-12	M	Security	EFS/OCS
NF-13	H	Descriptors are used to reduce the difficulty of operation and deployment	OCS

A1.2 Mapping of KPIs and innovations relevant to the use case

TABLE 4: MAPPING OF KPIS TO THE SD-WAN USE CASE.

KPI ID	Impact level	5G-CORAL impact	Subelement (EFS/OCS)
K-B1	M	TELCA will continue the development of this use case with private investment	EFS/OCS
K-B2	M	TELCA is a SMEs	EFS/OCS
K-B3	H	The Cloud robotics use case will be implemented using the ADLINK Fog OS platform, which is aimed at being a de-facto standard for Fog deployments	EFS/OCS
K-S1	L	--	--
K-S2	L	--	--
K-S3	M	Companies and industry can leverage SD-WAN to be used in its facilities to connect with other sites	EFS/OCS
K-S4	H	SD-WAN is a 5G enabler technology	EFS/OCS
K-S5	L	SD-WAN is part of the agenda of the Master in 5G and SDN/NFV where TELCA collaborates, with UC3M and Ericsson in Madrid.	EFS/OCS
K-P1	H	New service capabilities through SDN: QoS, Firewall, DNS, Routing, Cloud	OCS/EFS
K-P2	H	WAN deployment and creation leverage software to reduce time	OCS/EFS
K-P3	L	--	--
K-P4	L	--	--

TABLE 5: MAPPING OF PERFORMANCE METRICS TO THE SD-WAN USE CASE.

Perf. Metric	Impact level	5G-CORAL impact	Subelement (EFS/OCS)
PM-1	H	The location of the Cloud robotic control application in the Fog and Edge will contribute to the 1ms objective for this performance metric	OCS
PM-2	M	The continuous monitoring performed by the OCS, the relocation capabilities and the use of multi-RAT will contribute to the 7,9 reliability objectives for this KPI	OCS
PM-3	L	--	--
PM-4	M	The use of multi-RAT and convergence between the different RATs will contribute to the DL:9 and UL: 6.75 bit/Hz objective	EFS
PM-5	L	--	
PM-6	H	The application relocation capabilities provided by OCS will ensure the robot does not face any interruption while moving	OCS/EFS
PM-7	L	--	--
PM-8	L	--	--
PM-9	L	--	--

TABLE 6: KPIS AND INNOVATIONS COVERAGE FOR THE SD-WAN USE CASE.

		Innovation														
		IN-1	IN-2	IN-3	IN-4	IN-5	IN-6	IN-7	IN-8	IN-9	IN-10	IN-11	IN-12	IN-13	IN-14	IN-15
KPI	K-B1	X							X					X	X	
KPI	K-B2	X														
KPI	K-B3												X		X	X
KPI	K-S1															
KPI	K-S2										X					
KPI	K-S3			X	X			X	X				X			
KPI	K-S4	X		X					X				X			
KPI	K-S5															
KPI	K-P1	X			X					X	X			X		
KPI	K-P2	X			X			X		X	X			X		
KPI	K-P3															
KPI	K-P4	X														

TABLE 7: PERFORMANCE METRICS AND INNOVATIONS COVERAGE FOR THE SD-WAN USE CASE.

		Innovation														
		IN-1	IN-2	IN-3	IN-4	IN-5	IN-6	IN-7	IN-8	IN-9	IN-10	IN-11	IN-12	IN-13	IN-14	IN-15
Perf. Metric	PM-1				X				X				X		X	X
Perf. Metric	PM-2				X											
Perf. Metric	PM-3															
Perf. Metric	PM-4															
Perf. Metric	PM-5			X												
Perf. Metric	PM-6	X		X					X	X					X	X
Perf. Metric	PM-7				X			X	X							
Perf. Metric	PM-8										X					
Perf. Metric	PM-9	X									X					

A1.3 SD-WAN use case mapping to the 5G-CORAL system view

Figure 25 shows the mapping of the SD-WAN use case to the 5G-CORAL system view. The OCS is in charge of managing and configuring the SD-WAN functions. Two components are identified, the SD-WAN Orchestrator and SD-WAN Controller. The SD-WAN Orchestrator receives the infrastructure and virtualization descriptors, and based on this configuration will deploy the function using Fog05 and sets some parameters of the controller. Thus, the SD-WAN controller connects to the function, establishing the network control plane of it, and will manage the network functionality of the component.

On the other hand, the SD-WAN function will provide connectivity with other branches of the WAN network, e.g. bank or company network. It should be monitored via a monitoring service and provide an interface with the user. The OCS, based on the requirements and location, will instantiate the function optimizing the performance.

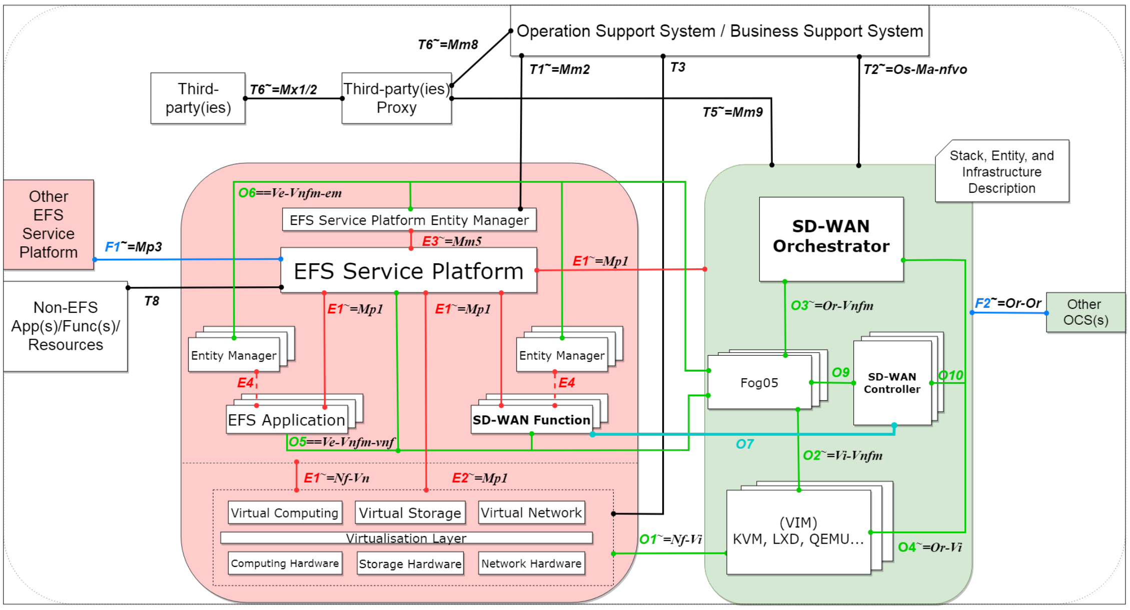

FIGURE 25: MAPPING OF THE SD-WAN USE CASE TO THE 5G-CORAL SYSTEM VIEW.

A2 VR Use Case

Introduction

The Virtual Reality demonstration aims to showcase the benefits of a 360° video live streaming service delivered by a number of 360° cameras located in specific points of interest inside a shopping mall. The main motivations for using this technology can range from offering an ultimate experience to users attending a live event, such as celebrity appearances, contests and sporting events, to help relieve overcrowded situations that can occur when a live event attracts a significant number of people in a limited space. In such cases, a 360° video live cast can offer the opportunity for everyone inside a shopping mall to watch the live event panoramically and cut the crowd management cost.

However, the 360° video delivery implies high bandwidth consumption and low latency requirements which are hard to achieve in conventional wireless networks. One of the solutions to reduce the bandwidth consumption consists of employing a viewport adaptive streaming technology. This technique relies on the clients' viewing orientation and aims to deliver the portion of the 360° video (e.g., viewport) being watched by the user in high quality/resolution, whereas the rest is delivered in low quality/resolution. Furthermore, viewport adaptive streaming is currently supported by the latest MPEG VR standard, Omnidirectional Application Format (OMAF), and MPEG video streaming standard Dynamic Adaptive Streaming over HTTP (DASH). Yet, tiled-based High Efficiency Video Coding (HEVC) transcoding/encoding adds extra computational complexity to the system, as tiled video streams have to decoded and re-composed into 360° video frame at the client side, which add computation into the devices and may not be supported by legacy devices.

Problem statement

Typical 360° video delivery solutions turn out to be highly bandwidth demanding and delay sensitive, and are not well suited to be deployed in conventional wireless networks. Specifically, offloading the computational load from the VR clients to a remote DC without introducing high latency should be guaranteed in order to meet stringent QoE requirement. In addition, wireless access points must be able to accommodate the huge amount of traffic transmitted from the cameras, processed in the Cloud and delivered to the VR clients.

5G-CORAL benefits

The distributed and multi-RAT nature of 5G-CORAL can significantly enhance the viewport adaptive streaming solution by allocating different tasks to different computing devices. As an example, a key component in the demo architecture is the orientation service, which provides the DASH streaming client with the client viewing orientation, thus allowing to deliver the viewport in high quality and the rest of the video in low quality. Furthermore, the distributed Fog computing platform will consist of multiple Fog nodes capable of offloading the burden of computing from the mobile devices. As shown in Figure 26, a number of Fog nodes deployed in the shopping mall are in charge of collecting clients' viewing orientation, decoding, composing and forming the 2D viewport video, while a more powerful Cloud computing system can handle most computational complexity tasks, such as 360° video acquisition from multiple cameras, stitching, tiled-based HEVC encoding and DASH live segmentation. In addition, the possibility of migrating EFS services, applications and functions from one Fog node to another will play a key role in this use case, given the low-latency requirement of VR.

Scenario description

In the VR scenario, the end-user can interact in multiple ways with the 5G-CORAL EFS platform. First of all, the user equipped with a smartphone or VR goggles can select one of the 360°

cameras deployed in the shopping mall, each delivering the live video streaming service. Next, the VR App media player consumes data decoded and reassembled by the DASH client sitting inside the EFS, while the orientation client communicates with the UE orientation service with the aim of tracking the user viewing orientation and efficiently optimizing the VR content delivery.

RATs and resources involved

The VR demo will rely on a wide variety of networking and computing technologies classified as follows:

- User smartphone (UE) – it will host the media player app as well as the camera selection app, which enable the video streaming consumption and the selection of the point of interest, respectively. Furthermore, the orientation client will be running on the UE and will be communicating with the DASH client application in the EFS.
- Head-Mounted Display (HMD) – it operates similarly to the UE with the additional capability of delivering a 360° immersive experience. The headset will be connected to a laptop which will communicate with the wireless points of attachment.
- Wi-Fi access point / LTE small cell – these two solutions will enable the communication between UEs, Fog nodes and Edge DC. A number of Wi-Fi access points and LTE small cells will be deployed in the shopping mall to ensure reliable and low-latency data transfer between the different entities.
- Fog CD – a number of Fog CDs will be deployed in the shopping mall and connected to different points of attachment, such as LTE small cells and Wi-Fi access points.
- Backhaul network – it is responsible for interconnecting Fog CDs with each other. It can be based on wired (e.g. Ethernet) or wireless (e.g. Wi-Fi, mmWave) solutions depending on the type of Fog CDs (static/mobile), ease of deployment (wireless approach allows ad-hoc network establishment) or costs (wired solutions tend to be cheaper).
- 360° camera – it captures and records the 360° video and delivers the video live streaming to the real-time acquisition server running on the EFS. A number of Insta360 Pro cameras will be installed in the shopping mall and located in specific points of interest.
- Remote Edge Datacentre – a high processing power server handling most of the computing tasks, such as DASH streaming, coding, decoding, etc. It will communicate with the camera and the end-user through wired or wireless connections.
- Local Edge Server – server machine located inside the shopping mall capable of processing some of the VR computing tasks. It will be equipped with a high-end graphic card to support the VR computational requirements.

Resource roles

The primary role of RATs is to deliver the VR multimedia content to the end-user in a timely and efficient manner. For this reason, LTE small cells and Wi-Fi access points are conveniently deployed inside the shopping mall and connected to a capable backbone infrastructure. Furthermore, RATs allow communication between the end-user, the Fog nodes and the Local Edge Server, thus enabling tiled HEVC encoding, viewport adaptive DASH streaming and all decoding operations needed at the client side.

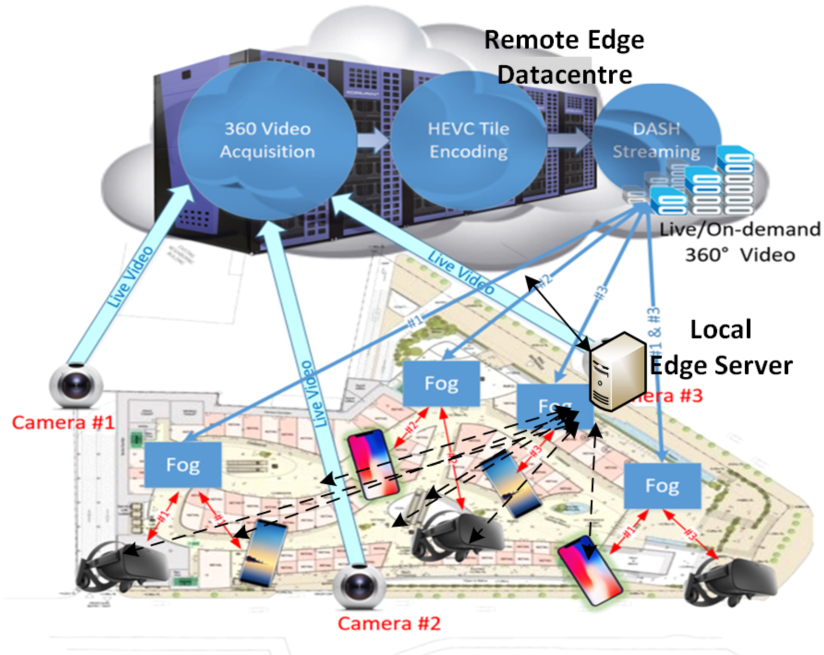

FIGURE 26: VR SCENARIO.

A2.1 VR requirements and improvements brought by 5G-CORAL

TABLE 8: REQUIREMENTS AND IMPACT OF THE VR USE CASE.

Req. ID	Impact level	5G-CORAL improvement	Subelement (EFS/OCS)
FT-01	H	EFS resources are highly abstracted and can be virtualized and then migrated based on specific function and service.	OCS/EFS
FT-02	H	Multiple Fog and Edge resources will be supported in this scenario, ranging from power-efficient mini-PCs to high capable Edge DCs.	EFS
FT-03	H	EFS resources are highly abstracted and can be virtualized and then migrated based on specific function and service.	OCS/EFS
FT-04	H	EFS resource discovery will be ensured through a convenient DNS solution, able to keep the list of EFS resources up-to-date.	OCS
FT-05	M	Bandwidth will be re-allocated depending on the number of video streaming requests.	OCS
FT-06	H	Integration and federation of different EFS resources will be fundamental to ensure a reliable delivery of the 360° live video content.	OCS
FT-07	H	The optimized placement and fast migration of EFS functions and applications will reduce the latency experienced by the end-user and maximize the efficiency of the orientation service.	OCS/EFS
FT-08	H	Provisioning of data services will be essential for the establishment of the end-to-end communication between cameras and end-users. The EFS shall offer not only the data streaming service, but also the option to select a different perspective any time.	OCS
FT-09	L	Interworking between multiple RATs will be used to accommodate data traffic generated by the cameras and directed to the VR end-users.	EFS

FT-10	L		OCS/EFS
FT-11	L		EFS
FT-12			
FT-13	H	Synchronization between EFS resources will be maintained to ensure reliable and bandwidth-efficient video delivery service.	EFS
FT-14	H	Out-of-coverage situations will be handled by the system by automatically restoring the end-to-end connectivity.	EFS/OCS
FT-15		--	
FT-16	M	Resources will be continuously monitored by the system to identify any potential fault.	OCS
FT-17		--	
FT-18	L	Adoption of DDS technology for EFS service platform	EFS
FT-19		--	
FT-20	H	Localization service is provided by EFS to estimate position of the user. It is key for the image/video augmentation. It can be accomplished through image recognition application as well as multi-RAT signal analysis.	EFS
FT-21		--	
MR-1	L	Possible use of multiple RATs allows switching between them if one of them is not available.	EFS
MR-2	H	D2D communication will constitute a base for arrangement of Fog CDs into network.	EFS/OCS
MR-3	H	Virtualized access points will be devised to 'follow' the user and minimizing at the same time handover delay.	EFS/OCS
MR-4	M	Multi-RAT will allow reliable transmission between user and Fog CD.	EFS
MR-5	H	EFS will use multi-RAT context information to determine location of the user.	EFS
NF-01	H	OCS will automatically control the placement of the EFS applications and functions.	OCS/EFS
NF-02	H	A mechanism of distributing computing tasks between EFS applications can handle growing amount of workload.	OCS/EFS
NF-03		--	
NF-04		--	
NF-05		--	
NF-06	H	By placing EFS application and functions close to the user (nearby Fog CD) the responsiveness of the system is improved. It is key to provide AR services.	EFS
NF-07	M	Monitoring of EFS resources, especially volatile Fog resources, will include availability parameter. It will allow traffic and load management to tackle volatile resources.	OCS
NF-08		--	
NF-09		--	
NF-10		--	

A2.2 Mapping of KPIs and innovations relevant to the use case

TABLE 9: MAPPING OF KPIS TO THE VR USE CASE.

KPI ID	Impact level	5G-CORAL impact	Subelement (EFS/OCS)
K-B1		--	
K-B2		--	

K-B3	H	Distributed computing, seamless migration, localization method as well as dynamic orchestration of resources developed for this scenario will push the innovative Edge for 5G related products spawned from 5G-CORAL.	OCS/EFS
K-S1		--	
K-S2	L	Due to the near user Fog CD deployment and related AR application burden offloading the battery consumption of the mobile phone is believed to drop significantly.	EFS
K-S3		--	
K-S4	H	Enhancing shopping experience is the main objective stemming from the AR Navigation use case. It aims at promoting AR related services for the phone users with no extra penalty in terms of additional equipment, battery drainage or monetary costs.	EFS
K-S5	H	Seamless migration, on-demand software deployment, traffic management are several examples of 5G skills developed with regard to AR Navigation use case.	OCS/ EFS
K-P1	H	Muli-RAT coordinated environment will ultimately allow increased user density.	OCS/EFS
K-P2	H	OCS capability to dynamically deploy EFS application and functions on Fog and Edge resources reduces AR Navigation service deployment time significantly.	OCS
K-P3		--	
K-P4		--	

Table 10: Mapping of performance metrics to the VR use case.

Perf. Metric	Impact level	5G-CORAL impact	Subelement (EFS/OCS)
PM-1	H	The deployment of EFS components near the shopping mall clients will reduce the latency of the AR Navigation service.	EFS
PM-2	M	The reliability will be achieved through the use of multi-RAT as well as constant EFS resource, applications and functions monitoring and control by the OCS	OCS/EFS
PM-3	M	Area traffic efficiency is supported by Fog CD collaboration to distribute computing tasks among themselves.	OCS/EFS
PM-4	M	Spectrum efficiency will be achieved through the use of multi-RAT transmission.	EFS
PM-5	H	A combination of multi-RAT and image recognition technique will yield precise localization approach.	EFS
PM-6	H	The application relocation capabilities provided by OCS will ensure the end-user does not face any interruption for shopping mall clients while moving within the shopping mall.	OCS/EFS

TABLE 11: KPIS AND INNOVATIONS COVERAGE FOR THE VR USE CASE.

	Innovation														
KPI	IN-1	IN-2	IN-3	IN-4	IN-5	IN-6	IN-7	IN-8	IN-9	IN-10	IN-11	IN-12	IN-13	IN-14	IN-15
K-B1															
K-B2															
K-B3		■		■			■	■		■				■	■
K-S1															
K-S2	■								■	■					
K-S3															
K-S4			■	■											■
K-S5	■	■							■	■					
K-P1							■	■							
K-P2	■	■	■							■	■				
K-P3															
K-P4															

TABLE 12: PERFORMANCE METRICS AND INNOVATIONS COVERAGE FOR THE VR USE CASE.

	Innovation														
Perf. Metric	IN-1	IN-2	IN-3	IN-4	IN-5	IN-6	IN-7	IN-8	IN-9	IN-10	IN-11	IN-12	IN-13	IN-14	IN-15
PM-1	■								■	■					■
PM-2					■	■	■	■		■					
PM-3			■						■		■				
PM-4							■	■							
PM-5			■				■	■							■
PM-6	■	■							■	■					

A2.3 VR use case mapping to the 5G-CORAL system view

Figure 27 illustrates the mapping of the VR use case to the 5G-CORAL system view. The NFV MANagement and Orchestration (MANO) block plays the role of the OCS, instating and managing EFS services based on the request made by the OSS component. Specifically, upon arrival of a request of executing the immersive video application, the OCS instantiates each single EFS component necessary to deliver the video data streaming to the end-user. Computing tasks are distributed between the remote Edge Datacentre, the Local Edge Server, the Fog nodes, and the UE. A crucial role is played by the orientation service located into the Fog nodes. This service fetches information about the tile visualized by the user and reports it to the orientation server, which determines which tile should be delivered in high definition, thus reducing the bandwidth required to deliver the service per each active user. In summary, a High Definition (HD) video streaming is generated by the 360-degree camera and then manipulated through sophisticated video technology in order to encode the tiles and reduce the bandwidth footprint. The video streaming is finally sent to the UE media player, which is also able to select the source camera, in case multiple 360-degree cameras are available.

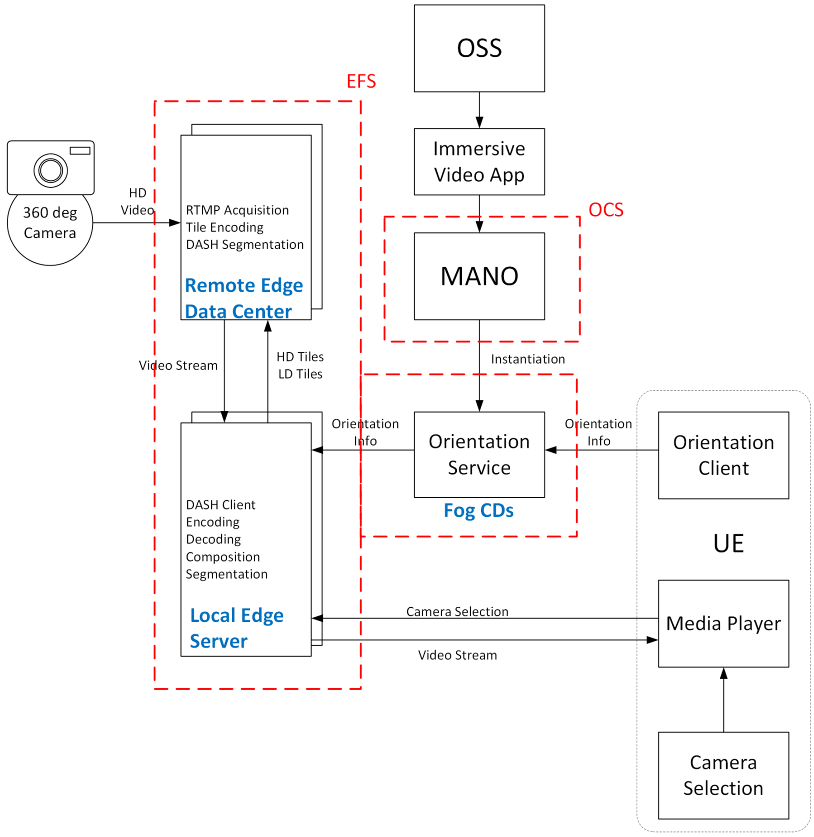

FIGURE 27: MAPPING OF VR USE CASE TO THE 5G-CORAL SYSTEM VIEW.

A3 Updated 5G-CORAL architecture

An updated 5G-CORAL architecture has been developed and the main changes with respect to the initial architecture in [1] are reported from [44] and [35].

- The Network Functions Virtualization Infrastructure (NFVI) has been renamed as EFS Virtualization Infrastructure (EFS-VI) as to encompass the capability to also host applications and the service platform.
- The Element Managers in the EFS have been renamed as Entity Managers to reflect the definition of EFS Application, Function, and Service Platform. Nevertheless, the Entity Managers play the same role of ETSI NFV Element Managers as initially stated.
- T8 interface has been extended as to also support non-EFS Resources;
- O5 and O6 interfaces connect also the EFS App/Func Manager to the corresponding EFS Application/Function Entity Manager.
- VNF Descriptor has been changed to Entity Descriptor to cover EFS Application, EFS Function, and EFS Service Platform Descriptor.

Figure 28 represents the revised 5G-CORAL architecture capturing the above-listed changes.

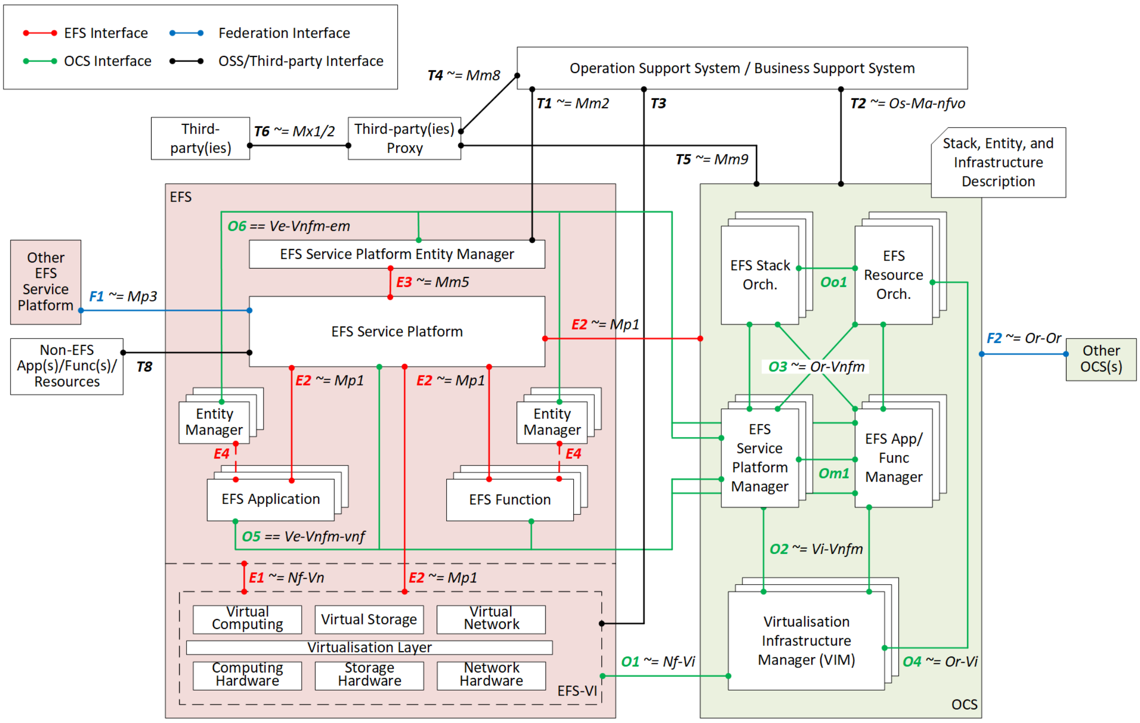

FIGURE 28: UPDATED 5G-CORAL SYSTEM ARCHITECTURE.

A4 Technical interpretation of the 5G-CORAL system-level requirements

This section deals with the mapping of the 5G-CORAL system-level requirements to the technical requirements of the two main building blocks of the 5G-CORAL solution, i.e. EFS and OCS. This mapping has been extensively described in 5G-CORAL deliverables [44] and [35], for both EFS and OCS respectively, and here summarized.

As reported in [1], the 5G-CORAL system-level (i.e. technical) requirements can be either functional or non-functional, with the former indicating a description of a needed feature or functionality. A non-functional requirement, instead, deals with constraints, targets, required interfacing, service levels and other system aspects.

When considering the EFS, the technical requirements have been grouped into two categories:

1. requirements pertaining to the EFS Virtualisation Infrastructure (EFS-VI) and
2. requirements pertaining to the EFS entities, i.e. EFS applications, EFS functions and the EFS service platform

The following tables, extracted from [44], present the mapping of EFS requirements with respect to the system-level requirements defined in [1].

TABLE 13: REQUIREMENTS FOR EFS VIRTUALISATION INFRASTRUCTURE (EFS-VI).

ID	Requirement	System-level requirement
EI-01	The EFS-VI shall support various categories of EFS resources, e.g. Fog and Edge resources	FT-01
EI-02	The EFS-VI shall support the abstraction and virtualisation of the EFS resources	FT-02
EI-03	The EFS-VI compute[1], storage and network nodes shall incorporate one or more Ethernet network ports for interconnection with other devices, e.g. Physical Network Functions (PNFs)	FT-05, FT-08
EI-04	The EFS-VI network node northbound links (i.e. towards the VIM) shall incorporate a variety of Multi-RAT links including Ethernet ports based on industry standards	FT-05, NF-08
EI-05	The EFS-VI network node east/west ports should exist for each additional compute/storage/network node	FT-05, FT-08
EI-06	The EFS-VI compute/storage/network nodes may support east/west Multi-RAT links	FT-05, FT-08
EI-08	The EFS-VI compute, storage and network nodes should be able to physically be interconnected with the minimum hops in order to cope with latency	FT-05, FT-08, NF-04
EI-09	The EFS-VI compute nodes shall incorporate support of host platforms, e.g. virtual machines or containers	FT-02
EI-10	The EFS-VI compute nodes shall incorporate minimum hardware requirements to run the virtualised hosts	FT-02
EI-11	The EFS-VI shall support occasional addition and removal of EFS resources that maybe mobile and volatile	FT-03, FT-09, FT-10
EI-12	The EFS-VI shall support localization of EFS resources	FT-11
EI-13	The EFS-VI shall support synchronization across the EFS resources that maybe distributed or co-located	FT-12

[1] Compute, Storage and Network nodes are defined as EFS-VI nodes that provide compute, storage networking functions, respectively, to the NFVI.

TABLE 14: REQUIREMENTS FOR EFS ENTITIES.

ID	Requirement	System-level requirement
EE-01	Support for discovery of EFS entities, i.e. EFS applications, EFS functions and the EFS service platform	FT-03, FT-07, FT-13, NF-02
EE-02	EFS entities shall expose APIs through which other EFS and non-EFS entities may communicate	FT-04, FT-07, FT-11, FT-12, FT-15, NF-01, NF-03, NF-05, NF-06, NF-08, NF-12, NF-13
EE-03	Support for placement, instantiation, migration, monitoring, configuration and termination of EFS entities	FT-06
EE-04	Support for synchronization across the distributed EFS entities	FT-11
EE-05	Support the subscription, authentication, registration, and admission to EFS entities from both inside and outside of the EFS	FT-04, FT-07, NF-12
EE-06	Support for the independent deployment of EFS entities, i.e. the deployment of any EFS entity does not depend on the existence of other EFS entities	FT-07, NF-05, NF-11
EE-07	Support for multiple technologies in the software stack of EFS entities, i.e. the use of different programing languages within each EFS application, EFS function and the EFS service platform	FT-07, NF-05
EE-08	Support for decoupling of the implementation logic of EFS entities from APIs exposed by the EFS entities	FT-07, NF-05, NF-12
EE-09	Support for loose coupling among the EFS atomic entities that make up the EFS entities. Loose coupling among atomic entities facilitates refactoring, upgrading and deleting modules without unnecessarily affecting other parts of the EFS entity	FT-07, NF-05, NF-10, NF-12
EE-10	Support for scaling of EFS entities	NF-11
EE-11	Support for isolation of EFS entities	NF-05
EE-12	Support for integration of 3rd party EFS and non-EFS entities	FT-05, FT-08, NF-11
EE-13	Support for multiple RATs via EFS functions	FT-08
EE-14	Support for the extraction and distribution of context information from RATs using the EFS service platform	FT-07, FT-08,
EE-14	Support for localization of EFS entities	FT-11

Regarding the OCS, instead, [35] distinguishes OCS requirements being either functional or non-functional and then maps them against the system-level requirements of the overall 5G-CORAL solution, according to the following tables.

TABLE 15: OCS FUNCTIONAL REQUIREMENTS.

ID	Requirement	System-level requirement
OF-01	Support of harvesting computing capabilities from low-end resources	FT-01, FT-02
OF-02	Support of harvesting computing capabilities from mobile resources	FT-01, FT-02, FT-09, FT-13
OF-03	Support of discovery, configuration, monitoring, allocation, … of relevant hardware capabilities (e.g. wireless interfaces, GPIO, GPU, SR-IOV, …)	FT-03, FT-06, FT-08, FT-13, FT-14, FT-15

OF-04	Support of integration including at runtime of heterogeneous resources in terms of software and hardware capabilities (e.g. different CPU arch, hypervisors, ...)	FT-04, FT-05, FT-09, FT-10, FT-11, FT-12
OF-05	Support of federation including at runtime of OCS components	FT-05
OF-06	Support of the interworking with resources external to the OCS (e.g. Cloud-to-thing continuum)	FT-06

TABLE 16: OCS NON-FUNCTIONAL REQUIREMENTS.

ID	Requirement	System-level requirement
ON-01	Support of deployment of OCS on low-end devices (e.g. battery-limited, form-factor, resource constrained, ...)	NF-04
ON-02	Support of deployment of OCS on mobile devices (e.g. car, robot, train, ...)	NF-04
ON-03	Availability and self-healing mechanisms in error-prone environments	NF-02, NF-09, NF-10
ON-04	Support of large deployments in terms of number of resources and geographic areas	NF-11
ON-05	Support of plugins for extensibility	NF-08
ON-06	Capability to adapt to workload changes by provisioning and de-provisioning resources in an automated manner	NF-04, NF-08
ON-07	Support of multiple tenants participating and co-existing in the same environment	NF-05, NF-06, NF-07, NF-12

A5 Detailed description of telecom operator's Edge computing business models

A5.1 "Dedicated Edge hosting" business model

In this business model the operator is an enabler of Edge computing services rather than a provider: it delivers and manages Edge-located compute/storage/networking resources which are pre-installed and connected to its own telecommunication network. Therefore customers will run their applications (e.g. a virtual CDN, a distributed Cloud stack, etc., see Figure 29) on top of operator's hardware resources dedicated to Edge only, achieving the flexibility to execute their applications across multiple operators for optimal service coverage, gaining value from the use of data and insights gathered from the network to further improve capabilities and performance of the offered services. From the operator perspective, this business model is relatively low-risk: the operator only invests to enhance its existing infrastructure – improving the related capabilities – and, once a relationship between the operator and a customer/partner is set up, a revenue stream is created, which is fed by set-up fees, hosting fees and additional features (e.g. APIs, value-added maintenance and monitoring).

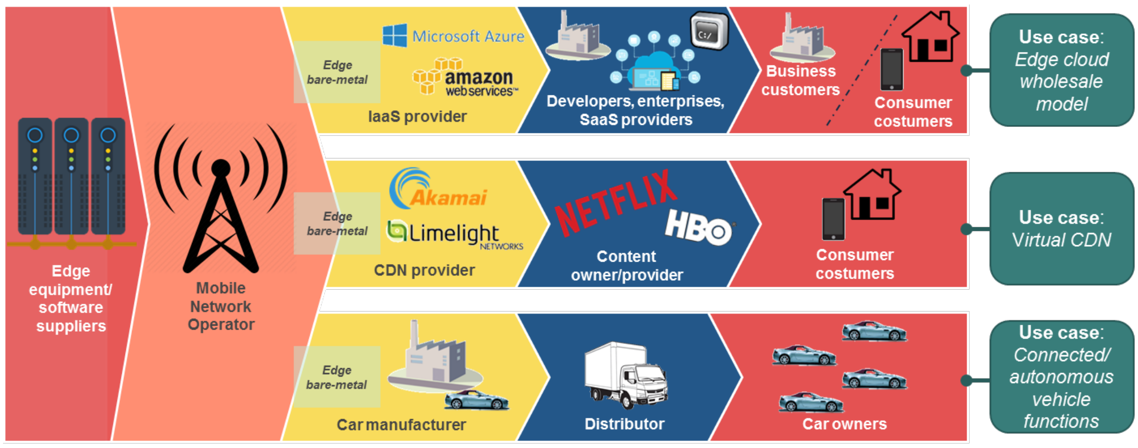

FIGURE 29: "DEDICATED EDGE HOSTIN" VALUE CHAIN.

A5.2 "Edge IaaS/PaaS/NaaS hosting" business model

The operator provides distributed compute, storage and networking capabilities to customers, a platform for developing applications on the Edge infrastructure as well as APIs and VNFs in an 'as-a-service' manner through a Cloud portal representing the customer interface. Basically the customer specifies the location of the Edge nodes across the operator's Edge infrastructure, indicates capabilities required and pays for resources (e.g. virtual machines) based on the actual use over time. Customers of the operator might be the ones interested in deploying applications on the Edge infrastructure hence making use of the benefits deriving from the Edge platform capabilities' exploitation (see Figure 30): IoT application providers, for instance, aiming at optimizing their applications in such a way that these applications can analyse data gathered from IoT devices in order to trigger actions in a timely manner. Other customers include start-ups, corporates, system integrators, CDN providers, content owners and Cloud providers. Compared to the "Dedicated Edge hosting" business model, there is a higher risk for the operator due to the fact that it has to invest in deploying a proper Edge Cloud infrastructure (servers, site equipment, …) – being able to guarantee enough coverage – before a revenue stream is established. In an effort to make Edge computing globally available (with standard interfaces), then there will be an increasing interest in developing applications and services exploiting the Edge capabilities which, in turn, will make the deployment of Edge computing more profitable and advantageous for the operator.

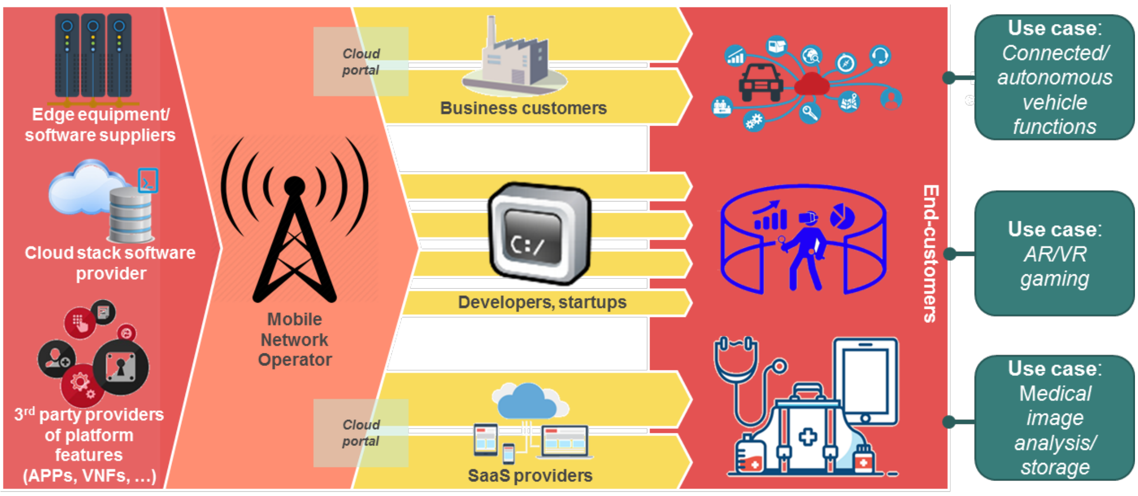

FIGURE 30: "EDGE IAAS/PAAS/NAAS" VALUE CHAIN.

A5.3 "Systems integration" business model

This business model is basically the re-interpretation taking Edge Cloud into account of an existing operator's business, which relies on offering customized solutions for enterprise customers (the so-called "Verticals") having specific requirements that can be fulfilled by Edge Cloud functionalities. As illustrated in Figure 31, Edge functionalities are likely to be part of a plethora of components being aggregated through the system integration project; other components may include hardware and devices, other operator's capabilities (not Edge-specific) as well as third-parties' capabilities. For instance, a government invests in an Edge computing solution for its Smart City project, which requires deployment of the Edge infrastructure and other specific hardware (sensors, actuators and devices), integration of different networks and systems as well as orchestrating the development of the Smart City applications benefiting from Edge Cloud key characteristics: low latency (for real-time applications), extended service coverage, security and network resilience. The revenue model is quite similar to a standard system integration project, which is typically specified based on the effort and resources required for each project's phase (i.e. capturing requirements, plan/design, implementation, support etc.). The price paid by the customer varies according to the specific items/features required for implementing the project, also considering the amount of Edge infrastructure that needs to be deployed. From the operator's point of view, this business model has some reduced risks with respect to the previous ones since the needed Edge infrastructure may be explicitly deployed for the customer – i.e. physically located and confined within its premises, e.g. in a manufacturing plant - therefore it does not require significant investment from the operator without an indication of returns on investment. Similarly to other system integration projects, partners represent an important part of the offering: from Edge-specific hardware, equipment and software suppliers for servers, operating systems, platforms and applications, to specialist (Vertical) project partners. The operator acts as the "orchestrator" of the whole ecosystem of different players providing tailored and reliable Edge-enabled solutions' implementations.

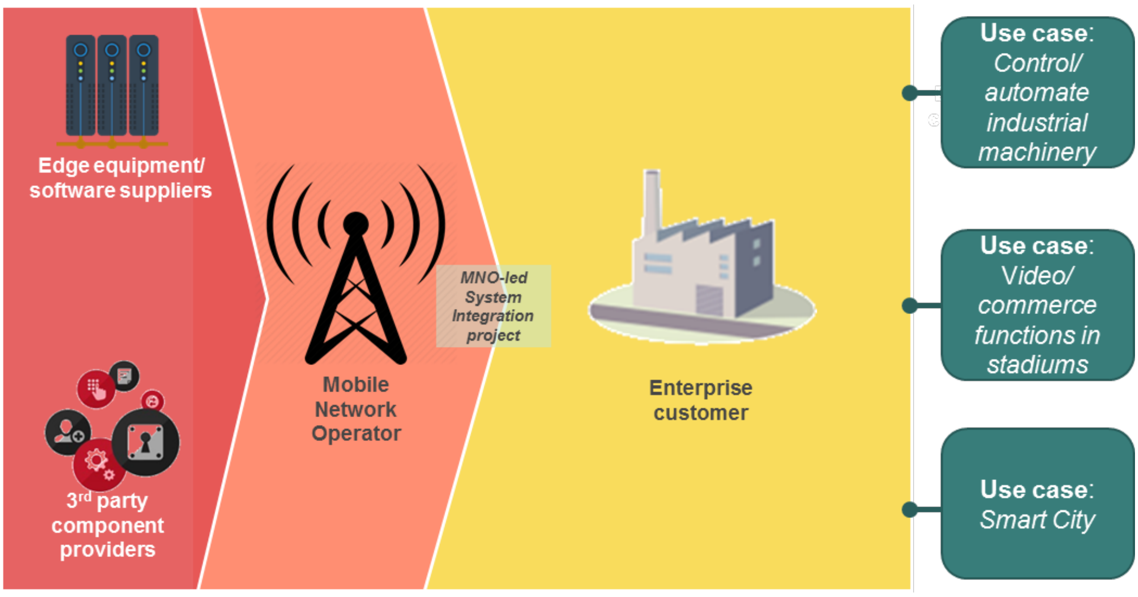

FIGURE 31: "SYSTEM INTEGRATION" VALUE CHAIN.

A5.4 "B2B2X solution" business model

With this business model the operator has the opportunity to create Edge-enabled business solutions for authorities (e.g. Government), big companies as well as Small Medium Enterprises (SMEs). These solutions might be either for the customer's internal purposes (e.g. for improving existing processes, similarly to the B2B approach) or for contributing to an end-customer offering (B2B2X). Generally this type of solution is very close to an "off-the-shelf" product and therefore much less tailored than a product resulting from the system integration model, which requires, instead, a significantly integration work. For operating based on this kind of business model, the operator needs to partner with solution technology vendors (to provide specific components and applications) as well as Edge suppliers (for hardware and software components). Furthermore, the operator might decide not only to sell directly to its customers, but also to partner with specialised re-sellers who are specified to intercept the needs of particular Verticals requiring particular enterprise solutions. Risks for an operator operating based on this business model are mainly due to the anticipated service development and to the uncertainty related to the proper adoption of the solution by the enterprise customers. Figure 32 is a possible representation for the operator providing a service for, e.g., big events with significant network congestion (sports stadiums or music concerts), enhancing the attendees' experience by using Edge computing to offer an immersive video experience, making use of a variety of live video streams from different viewpoints. Event organisers can either monetise this and offer it as an additional paid service for attendees, or bundle it within ticket prices to enhance the customer experience. Another example for this business model is the Closed Circuit Television (CCTV) video surveillance: transmission of all the captured video streams to the Cloud for further elaboration is detrimental for both network and application performance (other than being uneconomical). However if the video stream could be analysed at the Edge, only events deemed as important might be used to trigger a notification to the relevant emergency services and send the associated feeds to the Cloud.

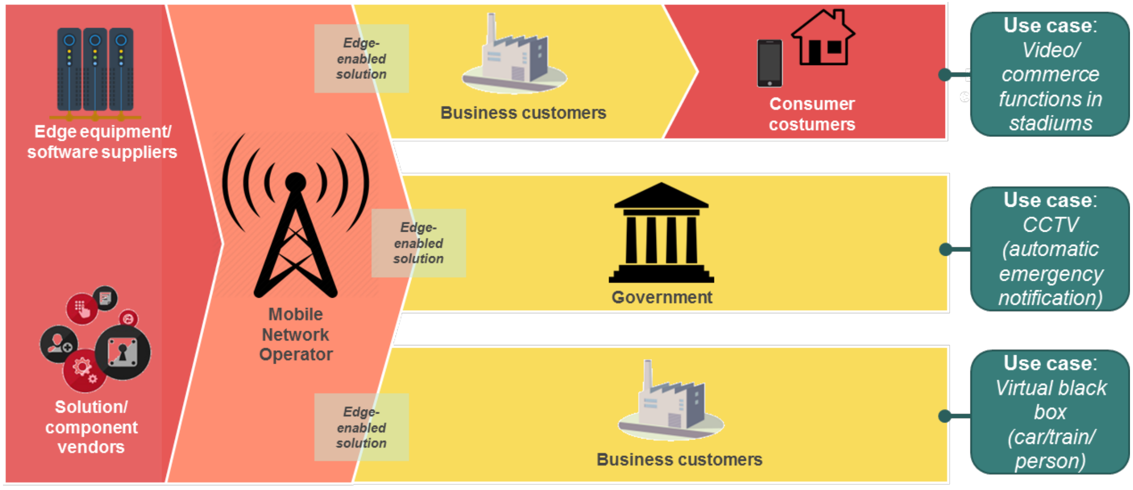

FIGURE 32: "B2B2X SOLUTIONS" VALUE CHAIN.

A5.5 "End-to-end consumer retail applications" business model

In this business model, the operator acts as a digital service provider for consumer applications. Similar to B2B2X solutions, the operator needs to partner with other players in order to deliver these solutions, e.g. Edge suppliers, application technology vendors or channel partners. Edge-enabled solutions originated with this approach leverage the benefits of Edge computing – i.e. low latency, high throughput and context awareness – to provide consumers with innovative applications which can include IoT, AR, VR and applications requiring real-time video transmission/processing. The operator might decide to extend its existing entertainment service by adding VR to its premium offering to enhance the user experience, also differentiating with respect to other operators' solutions. Conversely, the operator might offer these enhancements as paid add-ons to its existing services. Figure 33 represents the operator role in the context of the end-to-end consumer retail applications business model.

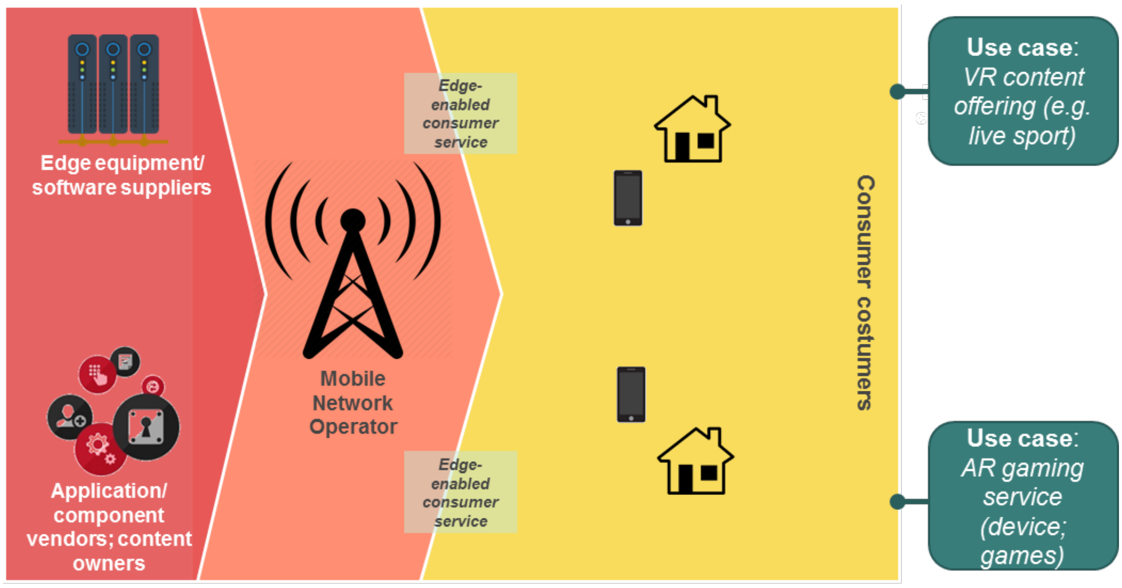

FIGURE 33: "END-TO-END CONSUMER RETAIL APPLICATIONS" VALUE CHAIN.

A5.6 What is the best business model for the operator?

When attempting to create value from Edge Cloud, the operator has to consider that, in many cases, economic benefits coming from the above business models are uncertain. This because none of the business models is a cash-cow and none individually justifies the investment in advance for deploying Edge technology in the whole network. On the other side, it might be beneficial for the operator to provide solutions in more than one area, hence exploiting synergy as a driver for achieving significant cash flows. Characteristics and skills needed to the operator for Edge operation change depending on the considered business model (Figure 34).

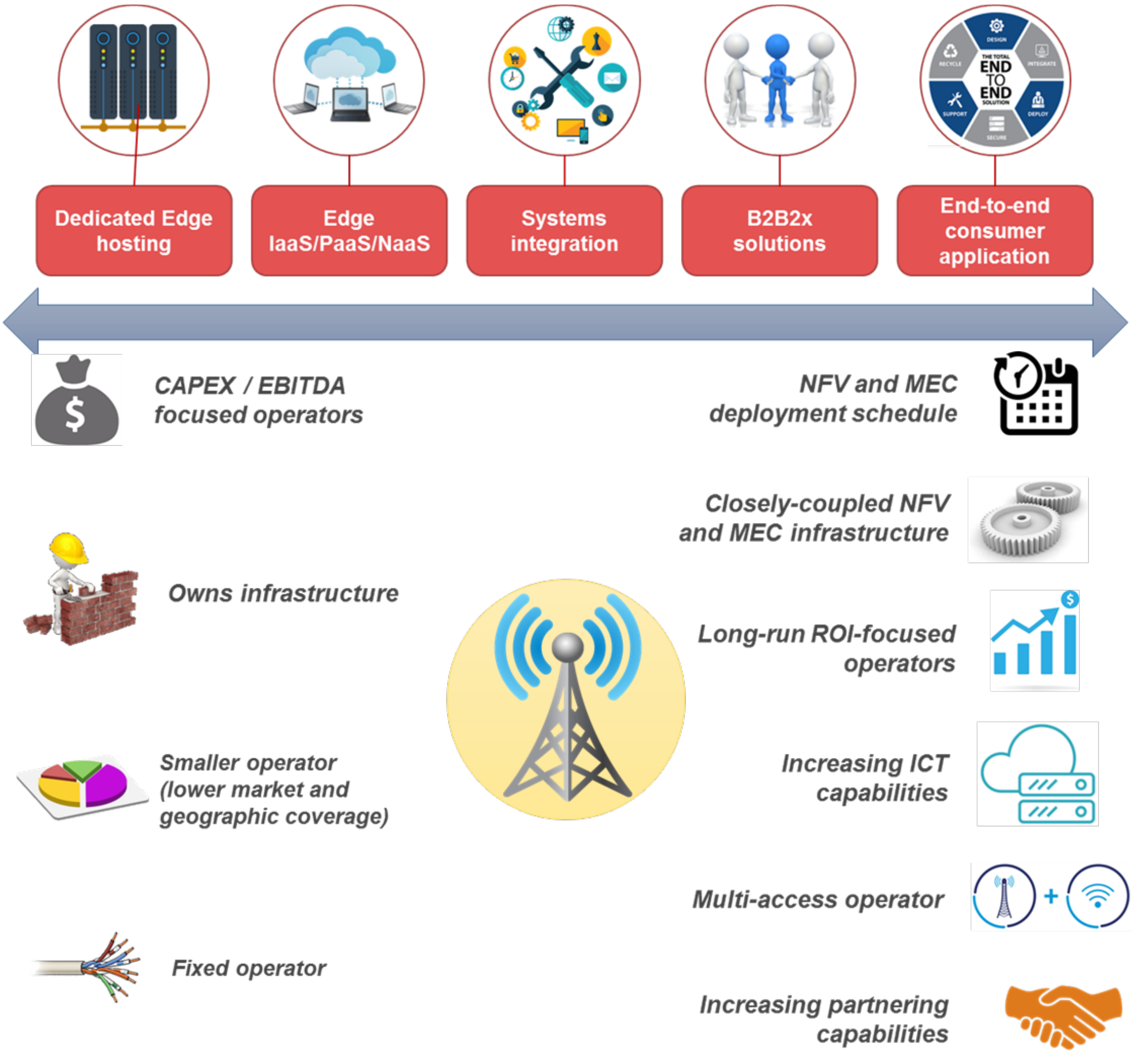

FIGURE 34: CHARACTERISTICS AND SKILLS NEEDED TO THE OPERATOR FOR EDGE OPERATION BASED ON THE BUSINESS MODELS.

Some aspects an operator should analyse when evaluating how to monetize from Edge computing include:

- *Identification of existing areas of strength and how can Edge computing help to improve them*. An operator having a successful existing “systems integration” business might start exploiting Edge Cloud for their solutions.
- *Possibility to align the chosen business model with operator’s existing customer base and network infrastructure*. An operator with a significant enterprise customer base and well-developed fixed-line network infrastructure might start with “Edge IaaS” or “B2B2X solution” business models. On the other side, an operator having a large consumer base on mobile network would probably consider “End-to-end consumer retail applications” business model to start.

- *Identification within the operator structure of the segment which drives the business effort required by Edge Cloud.* In case several initiatives related to Edge Cloud are ongoing (e.g. for both enterprise and consumer segments) it might be useful to coordinate among them in order to create and leverage synergies. Hence, for instance, a team developing "End-to-end consumer retail applications" might be the internal customer of an existing "Edge IaaS" offering.
- *Easiness in implementing a certain business model.* This aspect mainly depends on whether the considered business model requires significant initial investments and effort to enter the Edge market. For instance, by adopting "Dedicated Edge hosting" might be quite simple as it is a hardware upgrade of existing network sites, provided that the current operator's partners (e.g. CDN providers) require Edge functionality. Conversely, a new business based on "End-to-end consumer retail applications" model might be more difficult (and risky) to implement, as it requires significant investments in terms of Research and Development (R&D), hardware, product development, other than signing contracts with new potential partners.
- *Identification of a business model fitting operator's technology upgrade programme.* Edge Cloud should be considered as a way to complement and enhance an existing virtualization programme already started.
- *Risk appetite.* Some end-to-end business models (e.g. "End-to-end consumer retail applications") might bring considerable revenues only in the long run and in the face of significant initial investments. Operator s with a low-risk profile might focus on business models whose costs only incur when a substantial customer base is achieved, such as in "Dedicated Edge hosting" and "Systems integration" business models.

Probably operators will adopt a phased approach, i.e. they will start with a complementary business model to then expand towards other areas whenever demand grows and the technology becomes more mature and efficient. Deployment might depend on several factors such as the ongoing 5G standardization activity, the availability of internal resources and skills, the local regulatory and competition coming from other player in the operator's value chain (e.g. Cloud providers, non-telecom Edge Cloud service providers operating in unlicensed spectrum).

When referring to Edge computing, operators have a great advantage over large (but relatively centralized) Cloud providers: it is a matter of fact that operators have been developed both access and metro networks over long periods of time which are expensive to replicate. And, by definition, the access network is the closed network to the end-user. In this context, operators need to exploit this advantage by providing a set of services either directly to customers or a wholesale basis to third-party content and application providers. Operators have a lot of facilities which can accommodate distributed compute and storage, after being converted in micro DCs interconnected to each other and controlled in a SDN fashion in order to achieve highly-distributed and highly-available Clouds [45]. Some example locations can be:

- Cell sites and street cabinets: these assets are typically very close to end-users (e.g. less than a kilometre) but there are however some constraints that might limit their use as a typical site hosting a DC, e.g. environmental, security, space and power requirements.
- Enterprise server rooms: operators generally deploy equipment in the customer premises to provide WAN services. Small cells and Wi-Fi already use these facilities to host local applications needed for venue services.
- CO/local exchange, hosting functionalities used to aggregate traffic from street cabinets, e.g. Digital Subscriber Line Access Multiplexers (DSLAMs) for ADSL and Optical Line Terminals (OLTs) for Fiber-To-The-Home (FTTH).

- BSC and RNC sites: operators have sites that are (or were once) used for 2G Base Station Controllers (BSCs) and 3G Radio Network Controllers (RNCs). These functions have been progressively centralized year over year, but the facility often remains in operation and underutilized.
- Transport aggregation sites, hosting switching and routing equipment used for aggregating the access traffic. Operators generally have more than one level of aggregation, depending on their networks' size and geography.
- Cloud-/virtual RAN hub sites (also known as "baseband hotel"), where the equipment used for the baseband processing (BBUs) is deployed. These same facilities can be used to host Edge Cloud infrastructure and services: RAN virtualization (i.e. vRAN) facilitates the roll-out of Edge computing, because the physical location of the BBUs can become a good placement for some Edge computing functionality. For instance, when considering a shopping mall, the BBU location can also hosts the Edge server that manages location-based applications, which can then be made available to customers via multiple RATs, e.g. LTE and Wi-Fi. For operators which are currently deploying both vRAN and Edge equipment, a joint deployment approach might be very beneficial since the incremental cost of adding Edge computing to a new (and eventually optimized) deployment is typically lower than that of rolling out Edge over an existing infrastructure [46].
- Mobile Telephone Switching Office (MTSO), representing the mobile network facilities that house core network equipment; they are centralized to some extent, although more distributed than a national DC.

Exploitation of the above-listed facilities in order to make them available for hosting generic rack-based Edge Cloud infrastructure is quite challenging, due to its specific requirements. In some cases, refurbishment and/or optimized Edge data hardware might be needed.

A5.6.1 Resiliency and reliability at Edge DCs

One of the main characteristics of Cloud computing is the ability to offer highly reliable services using low reliability components. Indeed, in centralized hyper-scale DCs, failure of a single system does not have dramatic impacts on the quality of provided services since the Cloud management software rapidly moves services to new infrastructure. Therefore reliability, resiliency and failover are very different at the Edge: Edge DCs typically do not host a large amount of redundant hardware due to space, power and cost constraints. As a consequence, a system failure may have a big impact on service availability and user experience. Furthermore, these sites are often unmanned, hence it may take some time to repair, making the availability of each network entity infrastructure at the Edge of the network very challenging. In order to increase the reliability of Edge equipment – other than the use of more reliable DCs, e.g. with internal redundancy and better mean-time-before-failure characteristics – a SDN-controlled network fabric among DCs can be deployed, allowing workloads to be dynamically moved to an adjacent facility in case of failure.