MOBILIZADOR 5G

Components and services for 5G networks

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Sumário executivo

O presente relatório engloba duas categorias de casos de uso aplicacionais para redes 5G.

A primeira categoria encontra-se fortemente relacionada com a camada de rede e preocupa-se com o desenvolvimento de soluções capazes de otimizar os benefícios mais promissores da rede 5G: a latência e a largura de banda. Assim, esta categoria de casos de uso representa potenciais aplicações de *middleware* (MWA) concebidas para lidar com o *stream* de vídeo, a congestão de tráfego, os perfis de utilizador, etc., da forma mais eficiente possível.

A segunda categoria de casos de uso foca-se em aplicações comerciais (CA) que fazem uso das MWA para melhorar o seu desempenho. Os casos de uso desta categoria assentam em duas áreas principais: a realidade virtual em tempo-real e o *streaming* de vídeo ao vivo, as quais são extremamente exigentes em termos de latência e banda larga de modo a providenciar a múltiplos utilizadores uma Qualidade de Experiência e Serviço (QoE/QoS) aceitáveis.

Posto isto, os casos de uso apresentados neste documento encontram-se construídos sobre a premissa de que não seriam possíveis de implementar, ou a sua QoE/QoS seria drasticamente prejudicada, se não houvesse uma rede 5G a suportar o fornecimento dos respetivos serviços.

Executive Summary

The present report comprises two categories of applicational use cases for 5G networks.

The first category is strongly linked to the network layer and it aims to develop solutions capable of optimizing the main promising benefits of 5G: latency and bandwidth. Hence, this category of use cases portrays potential middleware applications (MWA) designed to handle video streams, traffic congestion, user profiles, etc., in the most efficient way possible.

The second category of use cases focuses on commercial applications (CA) that make use of MWA to enhance their performance. This category's use cases fall into two main areas: real-time virtual reality and live video streaming, which are extremely demanding in terms of latency and bandwidth to provide an acceptable QoE/QoS to multiple users.

Thus, the use cases presented herein are built on the premise that they would not be possible to implement, or their QoE/QoS would be drastically impaired, were there no 5G networks to support the provision of such services.

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Acronyms and Abbreviations

3D	Three dimensional
3G	Third Generation Wireless Systems
4G	Fourth Generation Wireless Systems
5G	Fifth Generation Wireless Systems
5GAA	5G Automotive Association
AAC	Advanced Audio Coding
ADC	Analog-to-Digital Converter
AI	Artificial Intelligence
AO	Authority Official
API	Application Programming Interface
Apps	Applications
AR	Augmented Reality
AS	Authentication Servers
BS	Base Station
CA	Commercial Applications
CAN	Controller Area Network
CAPEX	Capital Expenditure
CDN	Content Delivery Network
CPE	Customer Premise Equipment
DC	Data Center
DMM	Distributed Mobility Management
eMBB	Enhanced Mobile Broadband
eSports	Electronic Sports
FC	Flight Controller
FPS	Frames per second
GCS	Ground Control Station
GNSS	Global Navigation Satellite System
GPIO	General Purpose Input-Output
GPS	Global Positioning System
HAT	Hardware Attached on Top
HMD	Head Mounted Display
HUD	Head’s Up Display
I2C	Inter-Integrated Circuit
ICT	Information and Communication Technology
ID	Identification
IMU	Inertial Measurement Unit
IoT	Internet of Things
IPTV	Internet Protocol Television
ISA	Intelligent Speed Adaptation
ISABELA	IoT Student Advisor and BEst Lifestyle Analyzer
LEA	Law Enforcement Agency

LTE	Long Term Evolution
MEC	Multi Access Edge Computing
MIP	Mobile IP
mMTC	Massive machine type communications
MPEG	Moving Picture Experts Group
MWA	Middleware Applications
NEMO	Network Mobility
NFV	Network Function Virtualization
NR	New Radio
Oauth	Open Authorization Protocol (Standard)
OAuth2	OAuth version 2.0
OPEX	Operational Expenditure
OTT	Over The Top
P-App	Privacy App
PMIP	Proxy Mobile IP
PoI	Point of Interest
PoIn	Point of Incident
PS	Privacy Server
QoE	Quality of Experience
QoS	Quality of Service
ROS	Robot Operating System
RTK	Real Time Kinematic
RTP	Real Time Protocol
RTCP	Real Time Control Protocol
SDK	Software Development Kit
SDN	Software Defined Networking
SDP	Session Discovery Protocol
SFC	Service Function Chaining
SIP	Session Initiation Protocol
SMS	Short Message Service
SP	Service Provider
Telco	Telecommunications Company
UART	Universal Asynchronous Receiver-Transmitter
UAV	Unmanned Aerial Vehicle
UE	User Equipment
UHD	Ultra-High Definition
URLLC	Ultra-reliable and Low Latency Communications
USB	Universal Serial Bus
UVP	User Viewpoint
V2X	Vehicle to anything
vCDN	Virtualized CDN
VoD	Video on Demand
VR	Virtual Reality
VRU	Vulnerable Road User

1 Introduction

Over the last two decades technology has been steadily evolving in a variety of domains: machines are endowed with increasingly powerful processors and larger memory capacities; device-to-device communications open the doors to new exquisite inventions and realities; the user population grows more dependent upon technological solutions for everyday problems and needs; quality standards display a never-ending tendency to rise; and the cycle goes on.

With 5G networks promoting a greater bandwidth for data transmission and a lower latency in communications, the prospects put on standby due to 4G limitations are back in the game, along with some innovative ideas.

As a result, this report presents a series of use cases that explore 5G features and can be classified into two categories:

a) Middleware Applications (MWA) and
b) Commercial Applications (CA).

The goal of the first category is to propose a set of mechanisms/tools capable of minimizing latency and maximizing the resilience of a provided service. Despite the promise of lower latencies by 5G networks, it is important that the management of massive amounts of data produced by an application actively contributes to maintain those same latency levels. Consequently, this group of use cases shall address issues such as:

- Content distribution based on:
    - Intelligent caching;
    - Traffic management by user profile;
    - Prefetching;
- Dynamic resource allocation;
- Intelligent algorithms for optimizing uplink connections;
- Security mechanisms based on the concept of network slicing;

On the other hand, CA use cases shall develop solutions in two key fields:

a) real-time virtual reality (VR) and
b) live video streaming.

In VR, response times from communication networks are of utmost importance for movement fluidity and an authentic sense of reality. It is expected that 5G networks will allow the diffusion of VR in real-time applications, since a larger bandwidth and a lower latency may help solve the problem of motion sickness, while at the same time improving video quality in VR devices.

Furthermore, combining live video streaming with recent advancements in Drones and 360 cameras technology may constitute a new world of possibilities for all the aforementioned reasons.

Hence, in the context of this last category, the proposed use cases concern five main pillars:

a) public safety;
b) manufacturing;
c) transportation;
d) tourism and
e) entertainment.

It is expected that, by involving a variety of industry sectors, the potential of 5G networks in the development of innovative technologies becomes clearer.

Concluding, while MWA use cases dive into the world of machine-to-machine communications, CA use cases focuses on human communications by means of some machine. As such, the latter may benefit from the integration of MWA to enhance the services it aims to provide.

The use cases presented throughout the remainder of this report follow a common format:

- Context – explains which scientific field and industry sector the use case is related to;
- Motivation to 5G Networks – explains how the use case fits in the context of 5G networks;
- Description – of the use case scenario to implement;
- Initial scenario – the state of affairs prior to the scenario's playout;
- Step by step scenario – describes a sequence of events/actions that explain the playout of the scenario's description;
- Final scenario – the state of affairs posterior to the scenario's playout;

Each use case is then inserted into a cluster, based on its affinity to one of the categories previously described.

Finally, a section summarizing all the proposed use cases and the conclusions drawn from the present work is provided at the end of this document.

2 Background

2.1 Mixed Reality

2.1.1 Mixed Reality and Connectivity

There are a number of factors which contribute to the increased usage and pressure put on mobile networks through the consumption of multimedia content, such as the proliferation of devices like smartphones or tablets, the reach of various OTT services (e.g. Netflix) and large-scale live events, or the access to premium content like 4K, 360 or for AR and VR.

The development of new devices such as connected or virtual reality (VR) glasses, although not yet used by the overwhelming majority of users (or sectors) due to various factors such as price or inferior user experience (e.g. wire use, nausea), promise highly immersive experiences. With the resolution of these obstacles, it is expected that these devices will become much more attractive, which will further contribute to the increase in video consumption ratio over the total traffic transmitted on the Internet. Like the mobile phone, the true potential of these devices will be unlocked not only due to their computational capacities but also by their ubiquitous use, promising to affect diverse environments spanning entertainment, professional communication or industries such as manufacturing. An interesting case can be seen by the Paparmali company[1], which enriched the traditional way of reading books with Augmented Reality, allowing to increase the level of immersion in the presented contents or stories.

The appropriate support of VR and AR services - which will tend to combine both concepts, referred as Mixed Reality - through the Operator's network (fixed or mobile) will imply more stringent requirements on the network side, such as:

- **High transmission rates:** the transmission rate of a video in VR is higher than that of a conventional video; for example, to the naked eye, our perception of reality in a 4K VR video will be equivalent to a conventional video with 720p resolution, despite the former having a much higher definition. Thus, for the difference between an image and reality to be imperceptible to human vision, it would take about 12K in VR video[2]. In addition, the required data rate will vary according to the expected frame rate (variable or fixed, 30 vs. 60fps, etc.);
- **Low latency and jitter**: the combined processing of the physical and virtual environments requires sufficient coordination so that a real action (e.g. head rotation) is realistically translated into the virtual environment (e.g. change of field of view). Such coordination should be done in a way that results in a "natural" experience for the user, and the exact requirements will vary according to the levels of interactivity and locality of content associated with the service (e.g. video on demand streaming, gaming or high precision remote operations);
- **Robustness against network failures**: the requirements will also be variable, considering for example streaming services vs. real-time services such as gaming or critical operations (e.g. autonomous driving).

The challenges on the part of the Network operator to support this type of services can be seen from two distinct perspectives:

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[1] https://www.ourtechart.com/augmented-reality/commercial/augmented-reality-books/

[2] https://medium.com/visbit/making-12k-360%C2%BA-vr-streaming-a-reality-why-and-how-we-did-it-ce65e9aa0bc3

1. **End-to-end support of the service requirements** (e.g. transmission rates, latency, etc.) while taking into account the physical limitations of technologies and their "interconnection", maximum distances between interlocutors or devices, among others;
2. **Ensure the service requirements throughout its duration**, requiring robustness in the management of the service, continuous guarantee of QoE and SLO levels taking into account factors such as number of users and variable flows, inherent complexity of different types of technology (radio and not only), isolation of the resources associated with different Network Slices, among others. It also requires a strong monitoring component of both the network and the service, taking into account its current and historical state, as well as the context surrounding them.

The use of Content Delivery Networks (CDNs) allows today to ensure the transport of content, in particular video, more efficiently and with significant improvements in quality of service, by decentralizing content and bringing it closer to consumers. While public CDNs are typically positioned in public cloud data centers or collocation centers (where computational, connectivity, and storage space resources are available for "rental"), Operator CDNs (Telco CDNs) are exclusively used by Operators, for example for IPTV services, thus using dedicated resources and separated from public CDNs. Given the evolution in the infrastructure of the Operators resulting from recent advances such as SDN and NFV, there is great potential in the adaptation of CDN services to this new context, which originated the concept of vCDNs (virtualized CDNs). These should not only allow to respond to the growth of video consumption, but also benefit from the advantages of virtualization technologies, translating into a potential CAPEX reduction (less need for specific hardware acquisition), OPEX reduction (for simplification and automation of network operation), and the time-to-market of new services. In order to meet all these desired benefits, there is a long way to go in interlinking the various advances, where service and resource orchestration, governed by business and operational policies, plays a central role.

2.1.2 Support for Mixed Reality on the Move

An undeniable factor for the increasing integration of Information and Communication Technologies is their increasingly ability to be done via wireless technologies and while on the move, supporting good performance in different stringent use cases. Nowadays it is common for users to watch or even broadcast high-definition video while on the move. Moreover, an increasing number of connected devices (and types of devices) connect and consume (or generate) very different types of content. Therefore, it becomes necessary to integrate enabling mechanisms into the networking fabric, in order to cope with the demands of specific devices, services and scenarios. For example, nowadays large cities feature thousands of commuters accessing content while mobile, which imprints a growing need to confer connected capabilities to transportation systems for providing users with seamless and ubiquitous access to their content (e.g. streaming video, remote work). Still, current experiences in such scenarios are very much subpar comparatively to “static” (e.g. at home, at the office) scenarios. There are several reasons for this, such as the effect of high vehicular speeds in the connection quality, inferior and variable network coverage in non-urban areas, irregular terrain (e.g. mountains), or even mobility over a congested area. As such, it becomes common for people to experience adequate performance for their services while at specific parts of the city, but to notice a significant quality decrease in others (particularly when moving away from the city center).

In addition, communications are set to revolutionize all transportation sectors, by enabling a diversity of services spanning either safety, entertainment or productivity-related use cases. In order to support such service diversity, transportation systems generically comprise multiple communication modes. The user’s device can communicate / exchange traffic through the network or assisted by the vehicle (typically seen in public transportation such as bus or trains), with the latter minimizing the number of handovers for a potentially large number of users. From the perspective of the vehicle, and considering the impact and vision brought by IoT, we can consider it can communicate with:

- the network (acting as a mobile terminal itself),
- the transportation infrastructure (e.g. railway crossing, Roadside Unit),
- other vehicles (e.g. for information status exchange such as speed or route intentions),

- the inner terminals (acting as Mobile Network (NEMO) or for point-to-point communications),
- with external users or entities such as vehicles outside the context of the infrastructure, vulnerable users (e.g. for dissemination of imminent warning messages or status information).

Moreover, considering that users usually start to consume data services from a static position (e.g., home or office) before entering in fast mobility environments (e.g., mass transit), it is also necessary to consider the adoption of interfacing mechanisms between the enhancements produced over a fast mobility-enabled infrastructure, and the regular environment.

The inclusion of communication capabilities for vehicles, i.e. vehicular communication, has been addressed by research for some time, but only recently gained wide interest (and investment) from the industry. One representative example can be seen with the automotive industry, whose collaboration with Telecom operators and vendors, targeting added-value services enabled by 5G, led to the creation of of the 5G Automotive Association[3]. Relevant initiatives showing the application of vehicle-to-anything (V2X) communications for railways include Rail2X.

Nonetheless, such vehicle-based aspects have vastly inherited network mobility-based enhancements from prior mobility management research, which focused on Service Continuity [3], Always Best Connectivity [7] and IETF IP-based mobility management procedures such as MIP, PMIP and now DMM [4]. The performance capabilities brought by 5G systems are expected to impact the available service set from different perspectives, namely with:

- the enablement of existing services in previously unsupported mobile conditions or over more demanding circumstances (e.g. the support of higher transmission rates with reduced packet loss over higher movement speeds);
- the enhancement of existing services specifically benefiting from 5G architecture improvements for increased performance (e.g. Network Slicing, service-based principles);
- the emergence of new sophisticated services stemming from other factors such as:
    a) “data availability”, i.e. driven from the maturation of “IoT-centric” models which provide enhanced perception of the context and environment through collected sensorial information from the multitude of involved devices;
    b) disruptive business models and interactions (e.g. considering MEC platforms, network slicing, microservices or smart caching solutions).

With respect to VR content, when travelling in high-speed vehicles, users are subject to external forces and unintentional movements that may disturb the consumption of (VR) content. The following are two examples [8]:

- **Motion sickness**: is a common problem in VR environments, where the user is unable to adjust to the immersion of the VR experience caused by the visually-induced perception of self-motion, leading to symptoms that are similar to motion sickness. VR-content designers have been addressing this problem with techniques that ground the user motion within the VR environment to the real-world, such as adding visual anchors. In a moving vehicle, the motion sickness problem in VR becomes even further exacerbated by adding the motion of the vehicle (a source on its own of motion sickness) with visually-induced motion.
- **User interfaces**: the HMD worn by users to access the VR content acts also as the controller (in other cases it can be aided by other objects such as gloves), which means the movement of the head allows the users to interact with the VR content. The HMD-based controller sensors can be disturbed by the motion of the vehicle, similar to what happens nowadays when using smartphone applications that rely on the internal accelerometers for user interface.

2.1.3 Industry 4.0 and 5G Networks

The industrial world is currently going through a major evolution which is comprised by the adoption of new technologic paradigms such as IoT and cyber-physical systems. This transformation is referred as Industry 4.0, which serves as an indication that this evolution should be seen as the fourth industrial

[3] 5G Automotive Association: 5gaa.org

revolution. Even though there are several definitions of Industry 4.0 by different sources, the following covers its main aspects[4]:

"*the information-intensive transformation of manufacturing in a connected environment of data, people, processes, services, systems and production assets with the generation, leverage and utilization of actionable information as a way and means to realize the smart factory and new manufacturing ecosystems*."

In this definition, two pivotal elements are mentioned and should be highlighted: connectivity and making use of information. These two aspects also identify the potential contribution from network operators to the evolution to Industry 4.0, consisting of services integrating the network with computation. Therefore, in this transformation which is occurring in parallel with the evolution towards 5G networks, the telecommunication operators can play a relevant role by enabling and fostering it.

The term Industry 4.0 was first used in Germany in the beginning of this decade, where a multidisciplinary group gathered to define a strategy to increase the German industry competitiveness[5].

This group published a set of recommendations with the goal of enabling newer processes such as self-optimization, self-diagnosis and self-configuration. With this in mind, the following principles were identified as key elements:

- **Interoperability** – the connection and communication between cyber-physical systems, people and digital systems to enable the smart factory
- **Virtualization** – modelling and respective virtualization of the real-world for monitoring and simulation purposes
- **Decentralization** – distribution and systems capabilities to work independently
- **Real-time Capability** – all systems must be able to collect real time data, store or analyze it, and make decisions according to new findings, e.g. response to failures
- **Service-orientation** – production should be oriented to customer needs according to the principles of Internet of Services. The connection to end-clients' needs to be better capitalized and promote the optimization of production and enable more personalized products
- **Modularity** – if relevant markets are becoming more dynamic, then production also needs to be more dynamic and support the reduction of the lifetime of products. Moreover, the smart factory must support the dynamic adaptation of products according to the needs of the markets.

From the telecommunication perspective, more specifically regarding the evolution to 5G, the focus has been in transforming the network infrastructures to address the needs of vertical industries [1].

In that respect, three main service classes have been identified:

- **Enhanced Mobile Broadband (eMBB)** – here are included all services based on high-resolution videos or similar services with high requirements in terms bandwidth, e.g. augmented reality, virtual reality;
- **Ultra-Reliable and Low Latency Communications (URLLC)** – services with strict requirements regarding low latency and high availability, e.g. autonomous driving, smart factories;
- **Massive Machine type Communications (mMTC)** – typically IoT services, or in other words, services which involve connecting a very high number of devices to the network, e.g. sensors, smart cities, etc..

With these distinct classes, network operators hope to address the needs of vertical industries and also foster the introduction of new products and services.

[4] https://www.i-scoop.eu/industry-4-0/#The_fourth_Industrial_Revolution_and_the_third_industrial_innovation_wave_of_the_Industrial_Internet

[5] https://www.cleverism.com/industry-4-0/

The Boston Consulting Group refers to Industry 4.0 as the convergence of the following areas[6]:

- Smart Robots
- Addictive Manufacturing
- Augmented Reality
- Simulation
- Vertical and Horizontal Integration
- Industrial Internet
- Cloud Computing
- Cybersecurity
- Big Data and Analytics

Looking at this list, it should be noted the alignment with the service classes foreseen for 5G networks, where, for example, smart robots may belong to mMTC or URLLC service classes depending on their context or even augmented reality which is a perfect example of the eMBB service class.

2.2 Aerial Drones

Unmanned Aerial Vehicles (UAV), commonly known as drones, trace their origins back to the First World War, where they were initially used to carry heavy payloads of explosives across long distances. The applications for aerial drones have since grown immensely and, by virtue of their versatility, reliability, and ease of use, drones are now used for aerial photography, geographic mapping, remote safety inspections, assistance of law enforcement, and more.

Aerial drones are particularly well-suited for repetitive tasks like aerial surveillance and image gathering, or the transportation of cargo in areas without supporting ground infrastructure. Such conceptually simple tasks are crucial for scenarios of search and rescue, disaster management, and catastrophe recovery.

Drones of various shapes and sizes rely on Flight Controllers (FC), devices responsible for performing control tasks and stabilization adjustments required to keep the vehicle in a steady and balanced state, while also enabling external control of said vehicle. This control is commonly provided by the drone user himself who triggers the desired adjustments to the aircraft's throttle, pitch, roll, and yaw using sticks on a separate radio controller. In turn, a radio receiver aboard the drone transmits these inputs to the flight controller by means of a physical connection.

Several flight controllers allow for more advanced handling: as opposed to directly inputting fine control parameters, the user can request simple tasks such as autonomous take-off and landing, waypoint flight, and return to the take-off location. More complex tasks such as planning and automatic path following are also possible in some state-of-the-art flight controllers. Most of these tasks rely heavily on GPS-assisted control.

2.2.1 Flight Controlers

We now discuss flight controller offerings from two major drone vendors: DJI and Emlid. **DJI**, a Chinese vendor, sells UAVs that are affordable, reliable, and easy to use, and quickly established themselves as the number-one brand in the field of aerial drones. After success with their initial offering of UAVs, FCs and gimbals, their range now includes drone cameras and camera stabilizers as well.

DJI's latest advancements in UAVs and FCs include the Matrice UAV Series and the A3/N1/N3 FC Series. The Matrice UAV Series is aimed at resilient and adaptable UAV frames on top of which users

[6] https://www.bcg.com/publications/2016/lean-manufacturing-technology-digital-sprinting-to-value-industry-40.aspx

can add external sensors as needed. The A3/N1/N3 FC Series extends UAV capabilities by allowing greater precision and improved SDK tools for programmatic flight parameter interaction and control.

The A3 FC is the current flagship of DJI, available in Basic and Pro versions, and retailing for ~€1000 and ~€1600, respectively. The A3 Pro ships with a full set of sensors and parts, while A3 Basic features only a minimal set of parts that can be expanded as desired. Its major features include Real Time Kinematic (RTK) positioning, triple redundant GPS and IMU sensors, and SDK support.

The N3 FC is a more cost-effective controller, similar to the A3 FC but retailing for ~€350. The N3 features dual redundant IMU sensors and SDK support and can be upgraded with an A3 upgrade kit to enable triple and dual redundancy for IMU and GPS sensors, respectively.

DJI offers robust solutions of UAVs and FCs, and although their offerings retail for higher than the competition, the ease of usage and reliability of DJI's products is typically superior. On the other hand, DJI's FCs run closed-source firmware, limiting their use as a platform for research.

Another UAV vendor is **Emlid**, a Russian company focused on precision RTK Global Navigation Satellite Systems (GNSS) and FCs for UAVs. Emlid started out with two FCs (Navio+ and Navio2) and an RTK GNSS (Reach RTK), and now sells a new FC named Edge. Emlid's FCs can be interacted with via a Python API and are based on an open-source project (ArduPilot) thereby allowing full firmware customization.

Navio2 is an FC focused on the core requirements for a UAV. It supports up to 12 servos/motors, plus UART, I2C, and ADCs for interfacing with sensors. A dual IMU is built-in for increased precision. On Navio2, the ArduPilot software runs directly on a Raspberry Pi over an Unix-based system, and its sensors are built on a HAT (Hardware Attached on Top) that connects directly to the Pi's General Purpose IOs (GPIOs). The choice of running a full operating system enables full networking capabilities and allows for an easier integration with external sensors and control platforms.

EDGE is the current flagship FC from Emlid, retailing for ~€700. Edge features dual IMU and power supplies for increased precision and redundancy, FullHD video streaming, a dedicated CPU for navigation, and a second CPU operating a Linux system. The platform provides a pair each of USB, CAN, and UART ports, plus support for up to 12 servos or motors.

Emlid offers a robust open-source platform with the FC software running on top of a full operating system, which allows for greater flexibility and customization at all levels. Emlid's Navio2 FCs are advertised as the more general-purpose platform, while the Edge FCs are aimed at providing FullHD video streaming from the drones.

2.2.2 Drone Platforms

High level drone control is typically achieved through the use of a Ground Control Station (GCS), which can also provide features such as live-streaming of video from cameras mounted on the drone, or real-time monitoring of multiple sensors aboard said drone.

UAV Navigation provides flight control software for helicopters, multicopters, and fixed-wing vehicles. Their (Windows-only) GCS solution, named Visionair, includes advanced features of mission planning and execution. The solution includes multi-drone capabilities with support for up to 16 drones, and an "Auto Grid Flight Plan Generation" feature that automatically generates flight plans to cover an area. Its compatibility is, however, limited to flight controllers developed by UAV Navigation itself, and proprietary communication hardware is required for every form of remote control. UAV Navigation recently announced a "Formation Flight" feature for Visionair which will enable the control of up to three UAVs as if it were a single drone. A sample communication setup using UAV Navigation's offerings can be observed in the figure below.

Figure 1 – UAV Navigation communication setup[7]

Airware, an American company, offers a cloud platform with a set of collaborative tools to analyze, process and share aerial images generated from UAVs. From the limited information available on the company's website, the platform appears capable of generating orthoimages, 3D ground models, and of detecting changes between current and earlier ground surveys.

FlytBase is a web-based platform that provides a toolkit for the development of cloud-based drone applications. It supports C++, Python, ROS, and Javascript, and features both complex path planning capabilities and telemetry links to pull status information (e.g., battery, position) from the drones. The solution features a simulator which allows users to test their applications in a controlled environment. It is also compatible with DJI flight controllers, along with any drone based on ArduPilot or PX4 firmware. Although the platform allows multiple drone connections at once, collaborative tasks are not available out-of-the-box and must be implemented by the user.

Drone platforms that target Android and iOS mobile devices are also available. One such platform is **DroneDeploy**, which focuses on mapping operations. The platform enables the planning and execution of complex paths while simultaneously generating interactive maps and models using images captured along the UAV's flight path. Drone compatibility is limited to DJI's offerings, and not expandable to other vendors. The application also has no multi-drone capability and requires a radio controller to be connected to the drones at all times.

2.3 Video Streaming

Despite the large variety of new applications, with various quality of service requirements, (live) video streaming is and will keep on being one of the applications that requires a considerable amount of network resources. Thus, analyzing the impact of such applications on any type of network is of the utmost importance.

Currently, video streaming in 3G/4G can be made in two ways: using the network IP multimedia Service or using the Internet as an over the top service. The current speeds possible on the 3G/4G network range from 314Kbps (3G) to 300Mbps (4G LTE Advanced) on the downlink over cellular data, which makes possible video streaming of multiple real-time streams on the downlink. On the upstream, bandwidth is more limited.

IP Multimedia Service standard protocols like SIP (*Session Initiation Protocol*), SDP (*Session Discovery Protocol*), RTP/RTCP (*Real Time Protocol*/*Real Time Control Protocol*) and related Video and Audio

[7] https://www.uavnavigation.com/sites/default/files/Full_FCS_Schema_HE3_0.png

Codecs can be used together with the cellular network installed Application Servers to stream media to UE (user equipment, typically mobile terminals).

Using the Internet running as an over the top (OTT) service, we can use the same protocols or other proprietary or non-proprietary or open source protocols to do the exact same thing. This guarantees compatibility with other solutions on the Internet, does not lock the user down to 3G/4G or the operator or the Application Server vendor, and enables the user to migrate the solution to 5G when it becomes available.

Lastly, video streaming in future 5G networks will be easily supported by the underlying architecture of the 5G network, mainly due to its very high bandwidth capacity that may reach 1000 times the capacity of current 3G/4G networks.

2.4 Privacy-Preservation for Smart-City applications

Emerging mobile apps provide a wide spectrum of services, ranging from basic civil services such as accessing/editing your personal information, passing through more private apps such as e-Health, up to very critical apps such as e-banking. All such apps provide enhanced quality of life to citizens, but have access to highly sensitive vital personal information, which require the highest level of security to protect such information from forgery or even worse being hacked and used for malicious purposes.

Nowadays, the most reliable and widely used authentication and authorization protocol for mobile apps to gain access to services hosted by remote service providers (SP) is the OAuth protocol. To address the technical challenge described in last paragraph, we propose an OAuth2-based protocol for Smart City mobile apps that addresses the citizens' privacy issues, since it allows the users to authenticate towards the authentication servers without revealing identity or account information to the browser installed in the smartphone, other smartphone apps, or to eavesdroppers. It is worth mentioning that previous work carried-out by a research group [9] already provides a privacy preserving user authentication mechanism based on OAuth2. However, the previous proposed approach is based on Elliptic Curve Cryptography with bilinear pairings, which increases the computational complexity. For the Mobilizador 5G project however we aim to adopt a credential system [6] which does not relay on bilinear pairings, thus it is more convenient to be implemented in low capable mobile devices.

Therefore, there is a clear need for resilient authentication and authorization solutions that enable secure access to data with such paramount importance. Nowadays, the most reliable and widely used authentication and authorization protocol for mobile apps to gain access to services hosted by remote service providers is the OAuth protocol. The OAuth protocol is widely adopted by the most famous service providers, such as Facebook, Microsoft and Google [5]. The OAuth protocol was primarily developed to authorize third-party websites to gain access to resources hosted by SP on behalf of end-users. Nonetheless, once OAuth was widely embraced by big industrial names, major service providers (the likes of Facebook and Google) have endorsed it for their user authentication. Additionally, the OAuth protocol was applied to mobile and web applications. In conclusion, OAuth protocol has since become the major authentication and authorization protocol for mobile apps. OAuth2 is the most recent version of OAuth; OAuth1 has since become obsolete. Despite the wide adoption of OAuth2 protocol and the high-profile endorsement through the adoption by big names (e.g. Facebook), the OAuth2 protocol is still vulnerable to security attacks targeting users' data and credentials.

3 Cluster 1 – Middleware Applications

3.1 Introduction

This section addresses functionality that can be useful for a variety of applications and, thus, can be looked at as middleware applications. Specifically, we will look into 5G video streaming and 5G privacy preservation. In the scope of this project, these will be proposed and analyzed in the context of two scenarios:

1) A human-in-the-loop application for assisting students in their daily activities, which includes both live video streaming between students and teachers, and access to a repository of recorded classes; the case study may help understanding the impairment, in what concerns user experience, in dense environments like university campuses;
2) A privacy-preserving protocol for use in smart cities context, with the objectives of preventing unauthorized access to user information and increasing user confidence and participation in collaborative environments; with the widespread use of apps that collect and process large volumes of user information, many of which may be quite sensitive, privacy mechanisms are key to the success of future networked environments.

3.2 Applications

3.2.1 App 1 – 5G Video Streaming App

3.2.1.1 Context

This case study specifies two modules of a video streaming application that will run on the Internet over any supporting network. The objective is to test and compare the performance of these modules in 3G, 4G and 5G networks, when running OTT (*Over The Top*) on these networks.

Both modules are intended for integration with a prototype App being developed at the University of Coimbra, called ISABELA (*IoT Student Advisor and BEst Lifestyle Analyzer*), that collects a variety of data for supporting students in their daily life. ISABELA's objective is to provide student support functionality. This comprises a set of functions that assist the student in taking decisions that may help him/her maximize the academic performance. For this, a set of physical, emotional and social parameters are collected, using a variety of environmental sensors, smartphone sensors and social sensors. In addition, the ISABELA application intends to take advantage of 5G functionality to **I)** support both live and offline video streaming between students and teachers and **II)** between students and a video repository.

Thus, these two goals translate into two modules. The first module consists in developing support mechanisms for live video streaming and live online chat between students and teachers. This can be looked at as an online-teacher facility. The second module shall provide access to a repository of past classes, which contains videos and other teaching support documents.

3.2.1.2 Motivation for 5G networks

As some App functionality relies on video streaming, it is essential to have adequate bandwidth to provide appropriate quality of experience. Moreover, 5G may enhance the overall connectivity of the application, and good Internet connectivity has been proven to improve the general mood of the users.

3.2.1.3 Description

Both modules - on-line teacher and repository - will feature video streaming services to the users. The on-line teacher module will provide live video streaming conferencing, possibly with M conference rooms and N users. This may be limited by design and/or by the available bandwidth. In a first phase, the system will be designed for android phones (running java) and java-based servers. There is the possibility that this module supports the recording of videos and chats, depending on user authorization, which can then be stored in the repository. The repository module provides access to previously recorded video files and to other teaching materials.

After both modules are developed, they will be integrated in the ISABELA application, thus becoming regular system functionality. We will only do that after both modules are fully tested in standalone mode. The process of developing each module will be the following:

1. Developing and correcting the code;
2. Testing the code through unit testing;
3. Test the module functionality on an emulator;
4. Test the modules on a mobile phone;
5. Integration with mother app and deployment.

As for video encoding, the modules will use the android class MediaRecorder and the android Camera class. The user will be prompted for permission to record video and audio through the camera and microphone of the UE in use. The video and audio codecs and output formats for encoding will be the following:

- For audio encoding we will use AAC (Advanced Audio Coding).
- For video encoding we will use H.264.
- For the combined output format that will be transmitted and received by the support schedule application we will use MPEG TS.

Basically, these are the encodings used in MPEG 4.

The video transmission is done at the same time for all the video clients on each room in one data connection, with each video codified in the same way at it is received (MPEG_TS) from the source. Each video client receives all video sources from the room and transmits its own video signal on the same data connection back to the media server.

The on-line teacher module supports chat messages, to all users and directly between users, within the rooms, through the connection with the session controller server. The module also supports recording of the users chat history. In order to record user chat history, the session controller must have the users' authorization, which is requested when users join or create the chat room.

The session controller always records some historic data, which does not involve personally identifiable data (personal data as for standards), but includes data about who authorizes what, for historic reference and auditing.

The on-line teacher chat record is kept in historic records. Video recordings are saved to a specific folder. Historic records of chat and other historic data are also saved to another specific folder. The repository can then access these folders and transfer files to its storage space and organize these files in a way it sees fit so they can be later retrieved for utilization.

3.2.1.4 Initial capabilities

A plain video streaming functionality for the basic support of on-line teacher and repository access will be integrated in the application. In the case of the on-line teacher, this will be a simple video call functionality. In the case of the repository, a simple video download will be implemented, assuming that the user already knows the name of the video file.

3.2.1.5 Additional functionality

Following the implementation of the initial scenario, additional functionality will be added to the modules, e.g., negotiating and scheduling video sessions with teachers, browsing existing files in the repository, traffic offloading to available Wi-Fi networks, video caching, etc.

3.2.1.6 Tests and final phase

The functionality to be included in the final phase will depend on the tests and user feedback. A set of tests will be carried out in order to assess the overall performance of the application over different types of networks (e.g., 3G, 4G, 5G, Wi-Fi).

3.2.2 App 2 – Privacy-Preservation Protocol for Smart City Apps

3.2.2.1 Context

Within the Smart City concept, diverse intelligent mobile applications (Apps) have emerged as a vital player to enhance and ease the life of citizens. Such applications are usually provided by a third-party Service Provider (SP). Developers usually benefit from the powerful connectivity of mobile devices to create useful mobile apps, which are ubiquitously accessible.

On the other hand, in the context of mobile applications within smart cities scope and not only, malicious mobile apps may be disguised as harmless useful apps; hence installed on by citizens on their mobile device, they may endanger their data and credentials. Such security attacks do not only threaten citizens' data and information, but also impose risks on their safety, since citizens physical location can be extracted through location information that may be embedded in exchanged messages. These threats still discourage citizens from fully embracing the Smart City and its mobile apps. For users/citizens to fully take advantage of the concept of Smart City and enhance their quality of life through its vast apps, resilient security solutions to tackle loopholes in authentication and authorization of citizens in mobile apps have to be developed.

3.2.2.2 Motivation for 5G Networks

5G Networks are pointed to enhance greatly the mobile experiences of millions of smartphone users. They will also help to enhance homes through the emerging Internet of Things (IoT), to the point of enhancing the very cities we live and work in. The provision of faster data speeds, higher data capacity, better coverage, and lower latency (a combination of elements to enhance smartphone usage), will have the impact to enable the smart city concept - which means citizenship interactions with several entities. One of the drawbacks on the motivation for usage of many third-party applications is related to privacy constraints that users experiment, especially with their personal data. This component scenario aims to give a response to this issue in 5G networks, and involves both privacy concerns, complexity of security-based protocols, taking into account mobile capacity in comparison with high capacity computers.

3.2.2.3 Description

The proposed authentication preservation implementation, based on the OAuth2 protocol, is mainly supported on browser redirection. The mobile app redirects the browser to the AS, which then interacts with the user, and finally it redirects the browser back to the mobile app. The AS is the entity responsible for performing the authentication of the user.

Once authenticated, the mobile app is then connected to the user. The user then has to determine if she/he grants or denies authorization for the mobile app to access her/his protected data. If the mobile app is granted access, the browser is redirected to the mobile app with an authorization code. The mobile app then requests an access token from the AS. The mobile app hence gains access to the user's protected resources hosted in the Resource Server.

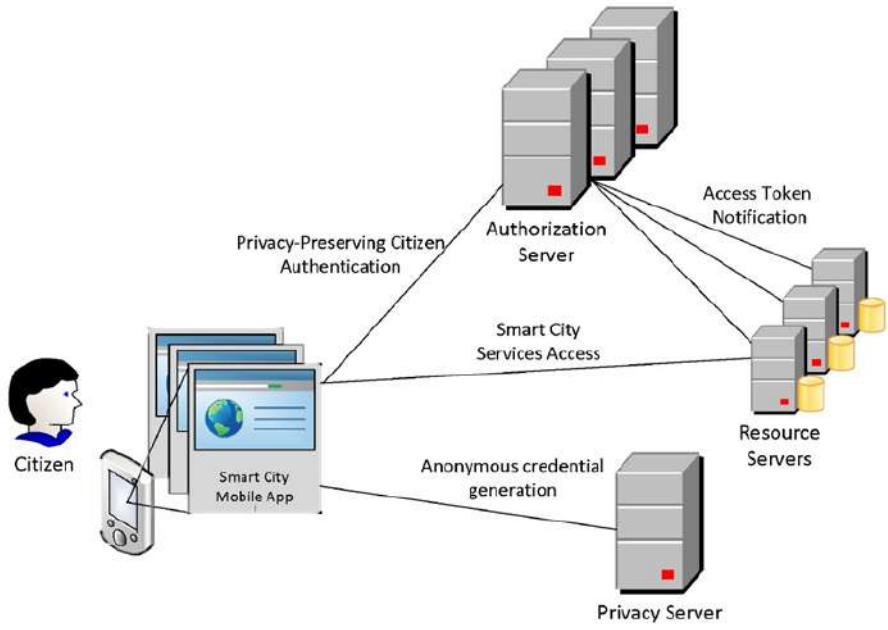

Figure 2 – Proposed architecture for privacy-preserving OAuth2-based protocol

3.2.2.4 Entities

The group of entities formed by the mobile app operated by the user (citizen), authorization server, privacy server and resources server, ensures the execution of the privacy-preservation protocol and its communication system (see previous figure).

3.2.2.5 The protocol step-by-step

In more detail, the OAuth2 protocol flow for mobile apps, depicted in Figure 3, consists of 6 steps, as follows:

1. The flow starts by the mobile app redirecting the browser to the Authorization Server (AS) to request an Authorization Code (msg 1 and 2). More precisely, the mobile app sends a message to the AS via the browser consisting of: i) the response type (t=code); ii) the mobile app identifier app id assigned during the registration process with the AS; iii) the requested permission scope p; iv) an optional state parameter s to maintain the state between the request and response; and v) a redirection URI, which the AS will use to redirect the browser back if access is granted or denied.
2. The AS requests credentials from the user through sending an authentication page (msg 4) to the browser. The user is then prompted by the browser to provide her/his credentials (msg 5). The user provides her/his credentials through the browser, who forwards them to AS (msg 6 & 7) for authentication. The AS then validates the received credentials (msg 8).
3. Once the user is authenticated, the AS proceeds to determine the specific permissions that the user would like to grant to the mobile app (msg 9 & 10). The user then provides her/his preference to the AS, through the browser (msg 11 & 12).
4. After authenticating the user and the permissions are granted, the AS redirects the browser back to the mobile app using the redirection URI. The AS also provides the browser with the Authorization Code *authz code* and the state parameter s, provided in Step 1 (msg 14 & 15).
5. The mobile app may now request the access token from the AS. In doing so, the mobile app sends a message with the grant type (g=authorization code), the Authorization Code *authz code*, the redirection URI and the mobile app identifier app id (msg 16). The AS validates the parameters in the received message (msg 16).

6. The AS provides the mobile app with the requested access token and a refresh token, which is optional (msg 18)

The steps are presented in the following figure:

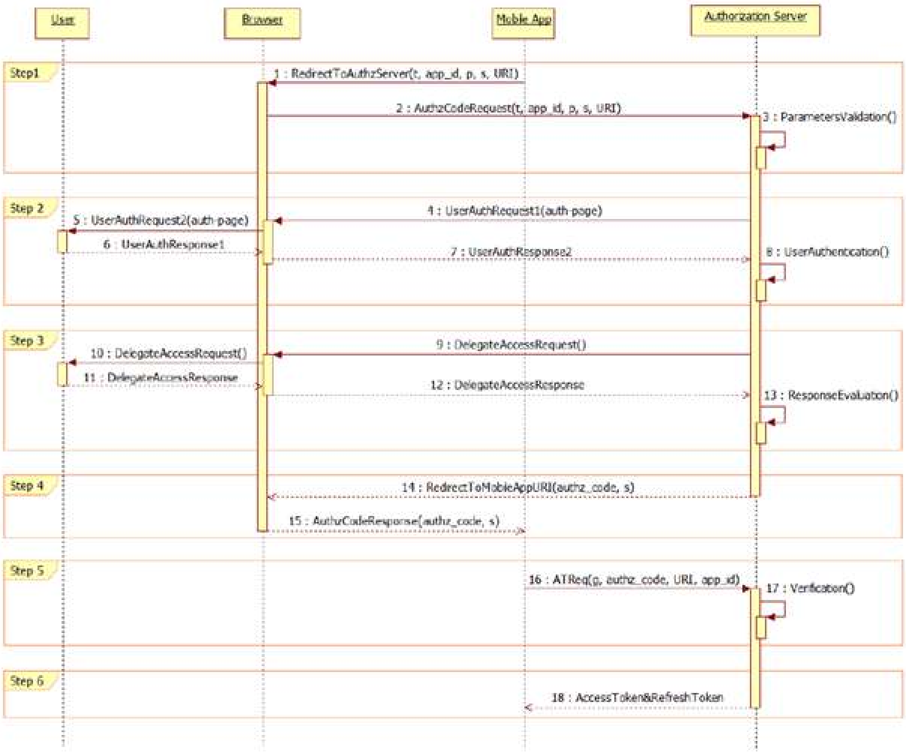

Figure 3 – Oauth2 Protocol step-by-step

3.2.2.6 Privacy of the Smart City user

The citizen can preserve its privacy when using the communication system, avoiding malicious applications to get access to personal and sensitive information. The citizen will then feel more confident integrating the IoT and Smart Cities environments.

4 Cluster 2 – Commercial Applications

4.1 Introduction

The following group of use cases highlights most of the concepts intrinsic to 5G networks: edge computing, network slicing, latency and bandwidth. In order to better understand the extent of these concepts, the use cases herein presented took inspiration from current technologies and industry sectors that seemed to best illustrate their true potential. Henceforth, the presented use cases shall address innovative solutions for the sectors of manufacturing, transportation, entertainment, public safety, etc., while embracing technologies such as drones, virtual and augmented reality, HD live video streaming (with 360º view), among others.

Thus, by the end of this chapter, it should become clear how 5G networks will be able to improve service quality/experience while, at the same time, give rise to new services with extremely demanding requirements.

4.2 Use Cases

4.2.1 UC 1 – Multimedia Services in Transportation Scenarios: Dynamic HUD-based notification

4.2.1.1 Context

This use case addresses two one main aspect which affects user's quality of experience when in demanding mobility environments: the ability for passengers to watch and interact with increasingly demanding multimedia traffic while in the vehicle (e.g. UHD video, VR), pushed by the penetration of mobile multimedia consumption in daily routines.

4.2.1.2 Motivation for 5G Networks

Use cases involving in-vehicle HUDs generally target the display of information characterizing the vehicle status (e.g. speed, tires pressure, fuel) or the user communications (e.g. caller ID, number dialing), disregarding further potential of communications for displaying richer information and enabling more advanced use cases.

With 5G networks, high-performance communications will be commonly present in both the user terminal and the vehicles themselves (which currently support little more than eCall services), promising huge potential to allow very fast and reliable transmission of both vehicle-sensed, infrastructure-related or user data, which may then be customized, processed and selectively visualized among different displays (e.g. HUD, user's mobile phone, etc.). This should greatly improve the timely driver awareness to the driving infrastructure status, emergency situations or any other relevant notifications.

4.2.1.3 Description

This use case reflects scenarios providing an overall improved awareness to the vehicle operator or driver, involving the transmission of events and information relating to the driving experience and user safety. Considered information may be classified according to the urgency degree or latency transmission requirements as follows:

- **Type 1**: Non-urgent nature: transmitted information may include real-time weather conditions at a specific region / road sector, proximity to area with statistically relevant characteristics (e.g. dangerous road / crossing, regular presence of vulnerable road users (VRUs)), changing road pavement conditions (e.g. recent pothole ahead), or ad-hoc events implying route modification (e.g. annual city marathon).
- **Type 2**: Urgent nature: transmitted information would consist of real-time data such as driving status and intentions (e.g. speed, direction, lane change), which could be processed by the vehicle for identification of high risk event notifications (e.g. eminent accident or stopped car ahead, high-speed vehicle at crossing). To assure the relevance of the information, correlation with up-to-date local map information is necessary.

4.2.1.4 Initial Scenario

Several vehicles drive on the same road / highway. The road manager entity recently invested in the evolution of his information / road management platform and is now able to send information relating to a given area only to the vehicles / pedestrians that circulate in it. Thus, relevant events are processed and quickly disseminated to vehicles located in the same region.

4.2.1.5 Step-by-step Scenario

1. A sudden heavy fog has formed, affecting km's 57 to 65 of the road. The infrastructure management entity immediately registers the information (coordinates, type of event, urgency) in its reporting system.
2. All vehicles sufficiently close (e.g. at least 2 km prior to the affected area) will be promptly notified, and drivers will see the warning on the HUD of the vehicle. Additionally, newer models including Intelligent Speed Adaptation (ISA) may see their current speed significantly decreased for prevention measures.
3. After crossing the foggy area, one driver arrives at the city he had planned to visit during the weekend. As he gets closer to the city center, his vehicle is notified of the imminent presence of a pothole, only 200m ahead. As the user doesn't know the road, he conveniently decreases the car speed, until crossing the pothole, returning then to his previous speed.

Figure 4 – HUD-based notifications

4.2.1.6 Final Scenario

Drivers have been quickly notified through their HUD about relevant information, allowing them to manage risk and act in a timely manner, minimizing impact on the traffic flow and their vehicles conditions.

4.2.2 UC 2 – Multimedia Services in Transportation Scenarios: Advanced Passenger Infotainment services

4.2.2.1 Context

This use case shares a similar context as the previous one. However, this case particularly addresses the collection and combination of sensor-based information either for the improvement of the multimedia service experience itself, or for the user's and vehicle's increased perception of its surroundings (which can be applied e.g. towards increased transportation safety, identification and notification of context relevant for the user, etc.).

4.2.2.2 Motivation for 5G Networks

Current networks strongly rely on CDNs for delivery of data-intensive traffic, in particular video. The support of increasingly demanding traffic under the highly fast conditions permitted by vehicles (e.g. cars, bus, train) will require improved network caching strategies (e.g. considering user speed, profile and other context such as content popularity), in strict coordination with the handover management process.

The use of VR in vehicles requires or simply benefits from the consideration of applications that use the minimum resources of the HMD, transferring the most demanding computational tasks (e.g. 3D modeling, environment processing) either to Cloud servers, the vehicle, or both. In a 5G architecture, these Cloud servers (i.e. the corresponding virtualized functions) will be available at a much lower distance, translating respectively into a latency about 10 times smaller than accessing a current Operator data center. In addition, current radio technologies do not allow the quality of service required for this type of service.

4.2.2.3 Description

This case explores the consumption and delivery of multimedia content by vehicle passengers, extensible to all vehicle inhabitants when considering autonomously driven vehicles or collective transportation solutions. The shown cases focus on the mobile delivery of network-demanding traffic such as Virtual Reality. The consumption of the latter traffic in moving vehicles raises new opportunities and challenges that can be seen as complementary to traditional and static VR experiences.

With this in mind, VR-based mobile experiences can be enhanced by considering inputs from the physical world (e.g. speed, direction) for generating virtual content, allowing to reduce or remove known motion sickness effects driven by virtual reality; additionally, such inputs may be used to create and adapt the virtual setting, aiding to provide effective immersion when experiencing virtual experiences on the move.

Thus, the scenario described below explores the support of HMD-based services consumed on the move, aiming to demonstrate the relevance of being able to access these contents ubiquitously, while ensuring a satisfactory experience.

In order to secure the quality of the service and taking into account service requirements (in particular data rates and latency), the network should apply necessary transport and optimization mechanisms. For instance, replication to a nearby user cache can be performed dynamically during the course of the service, based on network, service or user status and prediction, e.g. high number of requests of the same content in a given geographic area, pre-congestion / congestion of a certain link or user mobility.

4.2.2.4 Initial scenario

Several passengers move in a public or shared transportation vehicle (e.g. train or bus), each enjoying different on-demand multimedia experiences enabled by virtual reality. One user (User 1) acquires a VR application that allows him to have remote meetings, which he will use during his travel to have a meeting with friends / family.

A second user (User 2) is traveling in a car and acquired VR content that allows him to immerse in a virtual environment for entertainment. Alternatively, the user could have had access to the VR headset and associated services by either its taxi or shared driving / carpooling service, on which he now is a premium user.

4.2.2.5 Step-by-step Scenario

1. **Beginning of the service** – User 1 selects one of the available VR-based meeting rooms, which is based on a platform that mimics the vehicle motion. Prior to the start of the meeting, the VR content synchronizes with the vehicle motion by using the information captured by the vehicle sensors. The service will continuously capture such information for assuring coherence between the vehicle movement and the generated meeting room.
2. **Interaction with the VR service** – During the meeting, the user wishes to present some multimedia material such as slides, photos and videos. He can do that by using the HMD and gestures to control the presentation, and the way (i.e. timing, position) that contents are shown to remote participants.
3. **VR car experience by a different user** – In another vehicle, User 2 is experimenting its “VR Immerse” service, consisting of a simulated environment which is adapted to the vehicle’s mobility, so that the virtual experience (e.g. speed, acceleration) matches the user’s sensory system. For instance, a Jurassic World is reproduced, where dinosaurs and the rest of the Jurassic ecosystem can be seen around the user. The user sees himself sitting in one of the dinosaurs instead of the train/bus, whereas the movement of the dinosaur is adjusted according to the vehicle’s movement.

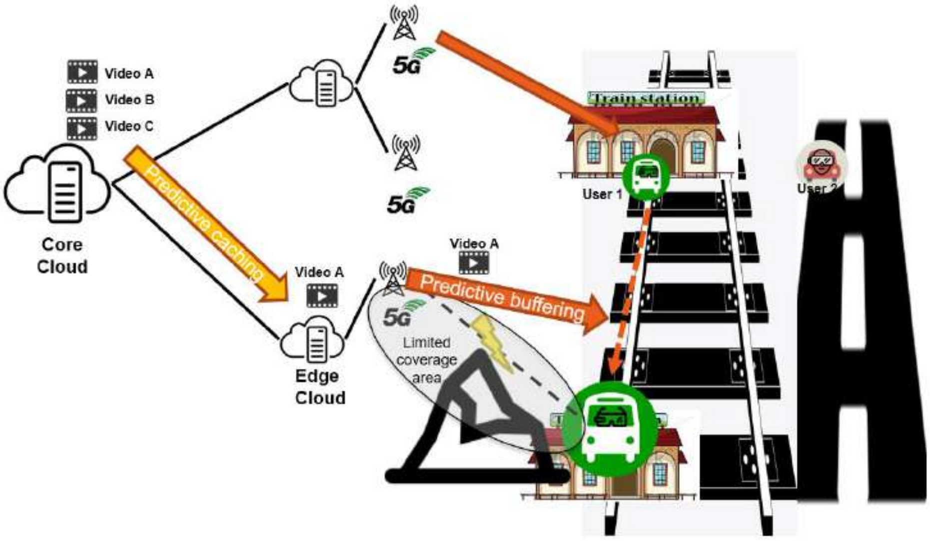

Figure 5 – Content Fetching Architecture in Public Transports

4.2.2.6 Final scenario

Both users can reproduce the VR experience without motion sickness, interruptions from limited connectivity and interference of the vehicle’s motion on the HMD-based controller.

4.2.3 UC 3 – Entertainment Services Supported by Mixed Reality: Context-aware VoD-VR

4.2.3.1 Context

The use case presented in this section addresses conditions which require the replication and transmission of content from network points near the user such as Base Station (BS) or CPE, and where the vCDN service requires different functionalities.

4.2.3.2 Motivation for 5G Networks

The increased requirements associated with Virtual Reality devices and traffic, and their limited capabilities, both stimulate the interest in offloading more demanding computing tasks to the network, if they are near the network. To this end, it is essential to benefit from the technologies that will complement the 5G architecture, namely SDN, NFV or MEC, that allow to maximize the efficiency in the use of the resources of the infrastructure, and the optimization of the way the content is transported and stored. Although already partially exploited in 4G architectures, these technologies are fully incorporated into the Core 5G-based architecture and will be the basis for the realization and management of Network Slices corresponding to different classes of services (and requirements). For these requirements to be supported end-to-end and ubiquitously, it is also clearly key to use new radio communication protocols (i.e. 5G New Radio - NR) and associated spectra, which allows higher bit rates and higher spectral efficiency (bit / s / Hz) and, consequently, the demand of VR video services, but also a greater number of users in the same region.

4.2.3.3 Description

This scenario, an on-demand movie streaming service is available for consumption through high-resolution Virtual Reality devices (e.g. between 8K and 12K), and different fields of view (e.g. 100º, 200º) which can be supported for greater immersion experience. The service enables different levels of awareness to the user's context, which can be made superposed on the goggle's display: examples include events related to the home environment (presence or absence of people in the room, ringtone, favorite contact call, etc.).

Based on the policies defined for the VoD-VR service, its requirements (e.g. frame rate or video resolution, QoS or associated QoE), as well as the current state of the network, content is replicated in a virtual cache positioned at a point next to the user (e.g. MEC platform in base station or CPE, distributed data center), from which it will be transmitted. The scenario explores the rapid allocation of the service, for which it is necessary to specify the distribution of functions (e.g. received movie processing) and resources (processing, memory, etc.) between the head-mounted display (HMD), network equipment (CPE) and the network itself (MEC and Cloud).

In this case, the video replication operation on a new node is triggered by the user's logon request, based on the device and content properties.

4.2.3.4 Initial scenario

A consumer has purchased his new VR equipment and has decided to test its capabilities by subscribing a compatible Video over an on-demand service. When the user first uses the movie service, it configures experience options associated to the device usage, as well as options for external notifications. Enabled notifications are superposed on the movie, and may or may not interrupt the movie, depending on the associated urgency or priority. For example, the user may choose to be notified of ringing, new mail, call coming from priority contacts, etc..

After analysis, the user decides to activate three options: "Identification of nearby people", which depicts people in the room through avatars, "Auto-pause", which interrupts the video in case of absence or sleep, and "Phone calls", for displaying calls towards its phone. He leaves the option "Notification of new emails" disabled. After setup, the consumer accesses the list of movies and chooses the one he wants to watch.

4.2.3.5 Step-by-step Scenario

1. **Extra-Movie Notification** – The user receives the ring-tone notification and decides to pause the movie to see who it is. He accesses the transmission from the outside camera of the house from the glasses and verifies that nobody is in the door. For this reason, he resumes the video.
2. **Intruder in the room** – The user's housemate enters the room, a notification appears, and the avatar represents the person on the screen. The user pauses the movie to talk to the colleague for a few minutes, then resumes the session again.
3. **Drowsiness detection** – The device detects drowsiness in the user by monitoring the position of the eyes (also used to estimate the area of the image where higher resolution is required). The movie is stopped, and you are asked if you want to stop the session. The user chooses to stop viewing the movie and go to sleep, as he feels tired.

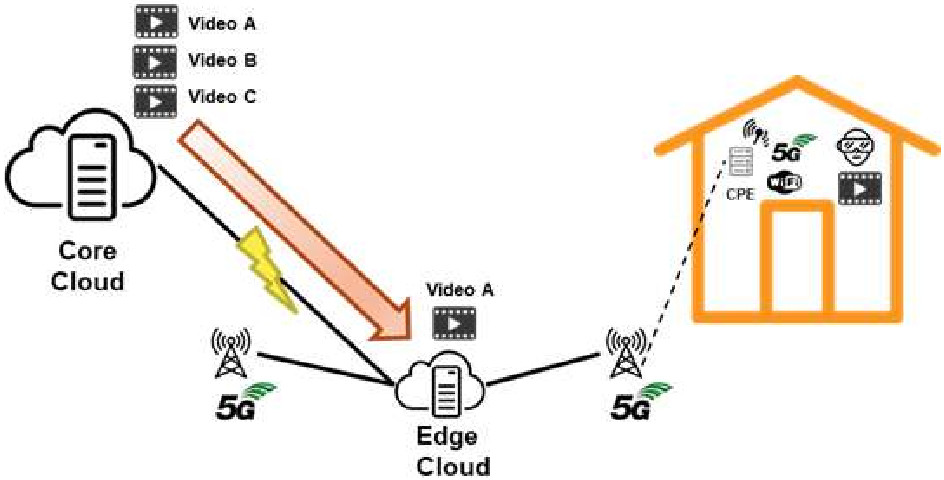

Figure 6 – Content Fetching Architecture for Content-Aware VoD-VR

4.2.3.6 Final scenario

The movie ends, and the user decides to review the credits to learn more about an actor he did not know about. As the credits are interactive, the user can directly access the information about the actor. The service analyzes the reactions of the user (visual data of the user, etc.) to evaluate the degree of satisfaction and interest for the film, not explicitly requesting an evaluation of the experience.

The user saw the content without interruptions or loss of quality, and the service benefited from the transmission of the video from the edge of the network, thus reducing the influence of the Operator's network in the degradation of the video. In addition, the application was able to more easily adapt the video to fluctuations in the access network.

4.2.4 UC 4 – Entertainment Services Supported by Mixed Reality: Live VR streaming

4.2.4.1 Context

This use case shares a significant part of the context from the previous use case. vCDNs may help to offload traffic of distinct nature, from text files to video. The way that such packets are processed, transported or replicated by the vCDN system is also different according to the type of video being delivered. This use case addresses real-time streaming of video.

4.2.4.2 Motivation for 5G Networks

Currently available VR content is essentially of an "on-demand" nature; 5G networks are expected to play an essential role in enabling the consumption of this demanding content in real-time, combining the multiple performance improvements and resource placement distribution. It is important to assure <u>low latency</u> in content transmission (downlink), after sending commands from the local device that imply changing the video source (e.g. camera).

4.2.4.3 Description

This case exploits functionalities of a real-time immersive video service, applicable for example to broadcast games, concerts or others. It considers an Augmented Reality mode, enabling the visualization of context information in the connected glasses while the content is transmitted solely on television, as well as a Virtual Reality mode, in which all the content is received through the glasses, namely both the video captured by the cameras present at the event, and support / contextual information.

The replication in a close cache node is based on the correlation between knowledge about future and past events (e.g., duration, dimension and popularity of the event), user context (e.g. profile, history) and network status. Thus, the caching decision is potentially taken before the content is generated (proactive caching), as the number of receivers benefited and the impact on the network are high.

4.2.4.4 Initial scenario

A consumer and a friend decide to test their VR equipment on a new immersive Soccer service from one of their homes. Since they are using the service for the first time, both need to setup options such as the initial perspective (e.g.: dynamic and ball-centered, full field view, etc.). After the settings configuration, and with a few minutes left before the game starts, the transmission of the stadium environment begins.

4.2.4.5 Step-by-step Scenario

1. **Perspective change** – After the game starts, it is possible to choose the perspective associated with a specific player or stadium section. The user chooses the player # 11, since he is very active and has scored many times this season, while the friend chooses his favorite player #7.
2. T**ransfer the video to the background** – The user must go to the kitchen to put the meal in the oven. The game is minimized in a small window of one of the display lenses, allowing the user not to have to remove the VR device and not lose track of what is happening in the brief minutes that he is absent from the living room.
3. **Game break** – At game intervals (and later at the end of the game) the user can choose to see the main statistics or see the main moments of the game, which appear indexed and organized temporarily.

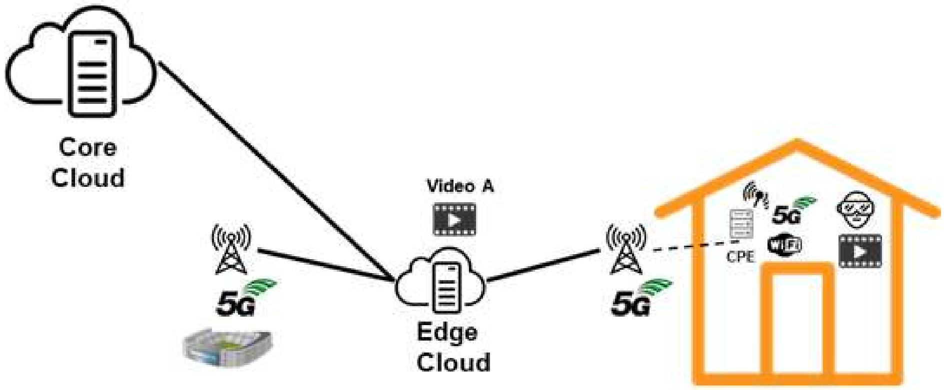

Figure 7 – Content Fetching Architecture for Live VR Streaming

4.2.4.6 Final scenario

The game is over, and the user is quite happy with the new service: he had an excellent and immersive experience, and still was able to follow the whole game while efficiently completing personal tasks. He was pleased to view the game from the perspective of any player, especially when viewing the most interesting replays.

4.2.5 UC 5 – Predictive Maintenance in Manufacturing

4.2.5.1 Context

With the evolution for 5G Networks, one of the expected novelties is the adoption of the MEC architecture through the distribution of DCs on the edge of the network and closer to the end-clients, independently of being residential or enterprise clients. These edge DCs will enable the local deployment of systems based on Big Data and AI, and also analytic applications, which by using network slices according to the before mentioned services classes will be able to connect to the various industrial systems and components.

When looking at these types of solutions from the industry perspective, there are several advantages such as:

- The maintenance and operation of network infrastructures demand specific knowledge, thus requiring a considerable investment in an area that is not directly related to their core business
- The new business models based on X-as-a-Service paradigm enable the optimization of operational costs and reduce the expenditure on infrastructure related assets

Although there are other advantages beside the ones mentioned here, these two are the most visible from the perspective of a closer relationship between the telecommunications and manufacturing industries.

Augmented Reality is a good example on how to establish a bridge between the physical and the virtual worlds. Augmented reality glasses can be applied in multiple scenarios, allowing the display of digital information in overlay with the real world and also the capture of information when used as sensors. The displayed information can be customized and adapted to each individual worker, enabling their access to digital tools designed to enhance their performance. One good example of this practice is the case of the company Thyssenkrupp which sells and provides maintenance services to elevators and escalators. Thyssenkrupp workers use HoloLens glasses[8] to assist them during maintenance jobs, allowing them to be connected to the company's internal operational support systems. Through these glasses, the technicians can locate and identify the malfunctioning components and rapidly repair or replace them.

[8] https://www.microsoft.com/pt-pt/hololens

On the most complex cases, the glasses also enable the specialized assistance with bidirectional visual communications: on the one hand the glasses make use of their cameras to capture images and videos and on the other hand they also provide visual assistance in overlay with the real world, i.e. augmented reality[9]. Through this use of HoloLens, the company has managed to reduce in four times the average time per assistance, thus constituting a practical example of how new technologic advances can optimize maintenance operations.

4.2.5.2 Motivation for 5G Networks

Besides the Cloud Telco approach associated with 5G, which can be used by verticals to deploy applications and operation support systems, 5G connectivity services will also play a pivotal role. The different service classes previously mentioned, identify the distinct requirements in terms of connectivity that need to be fulfilled to enable the transformation of the manufacturing industry. Technologies such as IoT or Augmented Reality will only be possible with the evolution to 5G.

4.2.5.3 Description

Within the context of Industry 4.0, maintenance is one of the areas which attracts more attention and investment due to the foreseen beneficial impact. Herein, the approach has been centered on the use of analytic systems making use of AI to predict the optimal time for maintenance procedures and the use of augmented reality to assist and enhance the performance of technicians[10].

The figure bellow shows a scenario where a manufacturing company uses a platform to assist and optimize the work of their personnel. This platform uses augmented reality glasses to enable the input and output of information from the worker perspective. All the information sent and received by the glasses considers the context of the worker within the company. The platform itself is deployed in a DC located on the edge of the network and close to the company's premises. The traffic associated with each device is sent to the various applications according to the worker context and needs by using technologies such as SFC, thus optimizing resource usage.

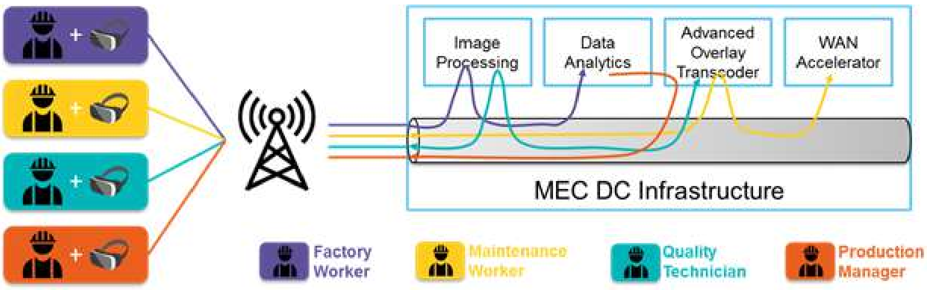

Figure 8 – Predictive Manufacturing Platform Architecture

By using this type of platforms, managers can track the different parts along the production line by using the cameras mounted on the glasses and from the information being collected from different sensors and from the machines themselves. All collected data is afterwards processed by specific analytic applications which use an AI mechanism (e.g. machine learning) to predict and schedule an optimal time to perform predictive maintenance on the machines and related components, thus reducing downtime. During production, analytic systems are able to predict the deteriorating performance of one of the production machines, which, if it is not taken care of, will lead to considerable production constraints.

[9] https://www.thyssenkrupp.com/en/newsroom/press-releases/press-release-129248.html

[10] https://www.i-scoop.eu/industry-40-virtual-reality-vr-augmented-reality-ar-trends/

4.2.5.4 Initial Scenario

To prevent the scenario of machines constraining production due to the deteriorating performance, the operation support systems generate an alarm to indicate the need to perform maintenance operations on the impacted machines. The notification is sent to the production manager with additional and required information, so that he can analyze the situation and approve the maintenance operation. After the approval, the maintenance procedures can be scheduled.

4.2.5.5 Step-by-Step Scenario

1. The maintenance workers receive a notification on their display to start maintenance procedures on one of the production line machines. Visual aids are used to identify the specific machine
2. When the workers are getting close to the machine, the display shows all the activities that are needed to be performed during the maintenance procedure. Also, visual assistance is provided to maintenance workers for each of the activities to be performed.
3. During the procedures, the auxiliary tools are performing tests to validate the success of each activity and the correct functioning of the machine's systems. During one of the tests an error is found that the maintenance team is not able to fix, therefore they decide to call support from specialists.
4. At the vendor premises, one of the available specialists receives the request for help and establishes a connection to the maintenance team.
5. Through the collected data (obtained from the machine itself and from the cameras located on the augmented reality glasses), the specialist quickly identifies the problem and sends the necessary information to the maintenance team.
6. At the production line, the maintenance team is now able to finish the procedures using visual assistance obtained from the specialist.

4.2.5.6 Final Scenario

After the conclusion of the maintenance operation, the production line resumes normal operations and the respective notification is sent to the production manager.

Analytics systems collect all the data related to the maintenance procedures, including the request for specialized assistance, so that in the future it can be used to plan and optimize the predictive maintenance and reduce downtime.

4.2.6 UC 6 – Tourist Drone

4.2.6.1 Context

Throughout this last decade, many research companies have been putting a great effort into building Drones with sundry capabilities and features for multiple purposes. Some Drones are known for their economic size, others for their high-quality cameras, flight dynamics, robustness, weather resistance, flight time, programmability, and so forth. This growing diversity of the Drones' technology, allied with other developments in the fields of Communications, VR/AR and the Digital World, may provide developers with the opportunity of extending their reach to more complex subjects. Thus, a Tourist Drone aims to explore the latest achievements in the aforementioned fields by allowing the public to gain *real-time* awareness of a given point of interest (PoI) regardless of distance, commutation or time hindrances.

4.2.6.2 Motivation for 5G Networks

Tourist Drones are equipped with full 360° cameras that should be capable of live streaming the surroundings of a PoI to thousands or even millions of users. Therefore, this use case is aligned with the goals of 5G Networks in the sense that it is imperative that we have a network infrastructure with enough bandwidth for massive data transmission in real-time.

4.2.6.3 Description

Tourist Drones receive flight missions from users by means of a mobile or web application to fly over a specific destination. The application displays a series of information such as all the available drones, flight areas and ongoing missions. Other users can join an ongoing mission according to their authorization levels.

The drone live streams the entire mission to all connected users and provides additional information regarding on-site meteorological conditions, among other valuable information/events related to the PoI. Once it has reached its destination, the drone surveys the area to provide the user with a real-time view of the PoI from multiple perspectives. The Tourist Drones are fully autonomous; at no time shall they require the user to command their trajectory. The survey is to be performed autonomously within the limits of the destination area.

Finally, a set of triggers can determine the mission's termination: the drone is running out of battery/gas, the user uses the application to terminate the mission, the survey has reached its time limit, the drone's safety has been compromised, among others.

4.2.6.4 Initial Scenario

A Headquarters has several Tourist Drones ready to fly on demand.

A User wants to obtain some insights on a PoI to help him/her decide whether he/she should actually go to that location.

4.2.6.5 Step-by-step Scenario

1. A User connects to the Tourist Drones' App;
2. The Drones' App displays all the available drones and flight zones that they are allowed to fly;
3. The User chooses a PoI/destination area for an available Tourist Drone;
4. The Drone takes off and live streams the entire mission in full 360° until it reaches its destination;
5. (Other users using the App may join the same Tourist Drone's mission.)
6. The Drone arrives to the destination and surveys the area;
7. The Drone sends information regarding the weather and nearby events;
8. The Drone receives a trigger to terminate the mission;
9. The Drone returns to the Headquarters.

4.2.6.6 Final Scenario

The Tourist Drone that was sent on a mission safely returned to its Headquarters.

The user collected enough information to decide on whether it is worth it to visit the PoI.

4.2.7 UC 7 – Patrol Drone

4.2.7.1 Context

Throughout this last decade, many research companies have been putting a great effort into building Drones with sundry capabilities and features for multiple purposes. Some Drones are known for their economic size, others for their high-quality cameras, flight dynamics, robustness, weather resistance, flight time, programmability, and so forth. This growing diversity of the Drones' technology, allied with other developments in the fields of Communications, VR/AR and the Digital World, may provide developers with the opportunity of extending their reach to more complex subjects. Thus, a Patrol Drone aims to explore the latest achievements in the aforementioned fields by assisting authority officials (AO) in their routines and investigation procedures.

4.2.7.2 Motivation for 5G Networks

Patrol Drones are equipped with full 360° cameras that should be capable of live streaming the surroundings of a patrol area to the investigation headquarters. Also, it is of utmost importance that the connection between the VR devices and the Patrol Drones does not interfere or compromise the AO's operation in any way. Therefore, this use case is aligned with the goals of 5G Networks in the sense that it is imperative that we have a network infrastructure with enough bandwidth for live streaming in multiple incident areas, in addition to an extremely low latency.

4.2.7.3 Description

Patrol Drones receive flight missions from authority officials by means of a mobile or web application to fly over a specific incident area. The application is shared with an Emergency Agency that is constantly receiving phone calls of incidents. The Emergency Agency escalates the incident according to its criticality to the Police/Law Enforcement Agency (LEA) that also shares the same application. The application displays a series of incident points in a geographic map and the LEA sends off a Patrol Drone to quickly pre-scan the point of incident (PoIn).

The drone live streams the entire mission to the LEA which, additionally, can make use of VR devices to take control of the drone and more thoroughly analyze the incident/crime scene before it gets contaminated. Furthermore, the AO would be able to freely survey the surroundings of the Drone or choose the right pace to scan a crowd and even pursue a suspect. This will allow the LEA to timely manage their resources and decide on the most appropriate course of action.

The advantages of a Drone in this kind of scenario are numerous. A Drone can get to the PoIn much faster than the AO since it is not hindered by traffic lights and congestion. It could also be a much better solution in examining areas that can be dangerous for humans to adventure in (e.g. cliffs, gas leakage, etc.).

The LEA can also use the application to create pre-defined missions for Patrol Drones, which correspond to automated routine patrols over several areas. Hence, not only will they be able to optimize the use of the Patrol Drones' capabilities, but also bridge the gap between unpatrolled areas and available resources. Moreover, sending off Patrol Drones on pre-determined paths can speed up the process of having a drone reach a nearby PoIn.

However, it does have a few drawbacks or issues that need to be properly addressed. Patrol Drones will need to have a close-to-perfect Collision Detection-Avoidance system (CDA) since it will most likely be flying in moderately obstructed areas. Also, due to its power of vigilance, it is of utmost importance that the situations in which a Patrol Drone is to be used are appropriately justified and that the data it collects are safely transmitted. Moreover, the data ought to be safely transmitted and its use authorized by some Data Protection Authority (DPA).

It is yet worthy of note that, since the Patrol Drones will be using 360° cameras, the application on the LEA's side ought to recognize and censor the view into surrounding infrastructures (street view should be the patrol focus). In case of absolute need, for the application to allow a detailed view of the infrastructures, the agent must first issue a request justifying such need and wait for the Data Protection Officer's approval.

4.2.7.4 Initial Scenario

The Patrol Drones' App is continuously running on the LEA's Headquarters.

The LEA's Headquarters has several Patrol Drones ready to fly on demand.

4.2.7.5 Step-by-step Scenario

1. A PoIn appears on the map of the Patrol Drone's App;
2. An AO sends an available Patrol Drone to the PoIn;
3. The Drone takes off and live streams the entire mission until its destination;
4. The Drone arrives to the destination and surveys the area;
5. The AO connects to the Drone via VR devices and takes control of its flight;
6. The AO collects information of the incident area and acts accordingly;
7. The Drone autonomously returns to its Headquarters.

4.2.7.6 Final Scenario

The Patrol Drone that was sent on a mission safely returned to its Headquarters.

The AO was able to collect all the important data and decide on the best course of action without wasting time on fruitless endeavors.

4.2.8 UC 8 – Emergency Drone

4.2.8.1 Context

Information and communications are very important in all decision-making situations on emergency situations. When human lives are at risk, the immediately available information may be the difference between life and death. In situations such as earthquakes, fires, floods, etc., it would be very useful to have access to information and maintain communication capabilities, even if all or some of the local infrastructures are not operational.

Using drones carrying a 5G antenna, that can take advantage of the 5G technology, and assuring 5G connectivity to the catastrophe area, would help to make the information about the event available to the decision centers, while allowing to provide 5G network communications between crews in the field and even to the population affected by the catastrophe.

4.2.8.2 Motivation for 5G Networks

Compared with the actual 4G, the 5G technology will allow data rates 10 or 20 times greater than the 4G, better energy efficiency, a much better positioning accuracy, 10 times larger reliability and 100 times more device density. All these features allow for a much better response for UAVs in emergency situations. For instance, a 4K RAW video streaming at 30 frames per second, consumes about 10Gbps, which is much larger than the peak data rate of 4G. The RAW video from a drone is useful because, for instance, if the drone is flying at a 500m altitude, a 45º photo will cover one square kilometer, meaning that each square meter will roughly be covered by only 8 pixels. This implies that the compression in this case may easily eliminate people in the video. The reduced energy consumption from the 5G will also be of great value for drone autonomy. With a 5G micro cell over high population density areas, in case of an event that renders a network failure, a single drone would be able to allow the connection of 1 million devices, compared with the 10 thousand limits of a 4G antenna.

4.2.8.3 Description

The technical and human resources in emergency situations are often limited. Usually in these situations the communications infrastructure is also damaged, leading to difficulties in the management of the rescuing crews, finding injured people, etc.

The possibility of using UAVs in emergency situations, may cover most of these necessities, namely management and communications, if there is any kind of data connection available (3G/4G/5G). This connection can be provided by other sibling drones, by creating an array to ensure a connection is available. A drone with capacity to transmit video images and other information about the environment in real time, as well as assuring the communications between the decision centers and crews and for the general population, would allow a more effective response to the emergency event.

There are a large number of possible scenarios where video streams from the disaster area and the reestablishment of connectivity are critical for an adequate response to the emergency. We will present two very different scenarios as examples of the multiple capabilities of such an UAV.

In most cases the drone(s) could be deployed right after the event is acknowledged by the security forces, even before there is much information about it. The details of the mission could be transmitted when the drone is already travelling to the site.

1 – A large earthquake

A large earthquake over a densely populated metropolitan area would cripple the communications network, especially in the event of a generalized power failure. With the capability of connection one million devices, a few drones with 5G antennas would be enough to guarantee a very good coverage of the affected area.

2 – Forest Fires

The drone would be able to reach the fire area much before the firefighters, allowing the command center to be aware of the real situation in advance, with the real time video streaming. The 5G antenna could also allow the communications between the crews in the field and the command center which could be hundreds of kilometers away. Danger to villages, roads and other infrastructure would be identified with great advance, allowing the early warning of potential victims and the better organization of the fire response.

4.2.8.4 Initial Scenario

A Fire Station or Emergency Station have several Drones ready to fly on demand.

An alert is received by the central authority. The orders for deployment of the nearest drones are sent to the local authorities.

Also, when the drone's autonomy is near its end, the drone is able to return to his home or ask where it can be recharged.

4.2.8.5 Step-by-step Scenario

a) Large Earthquake

1. The drones will start travelling to the target area, while being able to receive detailed information about the mission;
2. After reaching the target area, the drones will start streaming video, thermal and other information to the authorities, which will be able to define priorities for the response teams;
3. The drones can be autonomously configured to search for people and signalize their presence to the authorities. The drones will also be able to identify devices connected to themselves and use triangulation to locate the source of the signal (triangulation possible with 2 drones in range, each with a 5G antenna);
4. The drones will be able to create a 5G micro cell, allowing for connectivity in the affected area for the response teams and the general population.

b) Forest Fires

1. The drones will start travelling to the target area, while being able to receive detailed information about the mission;
2. After reaching the target area, the drones will start streaming video, thermal and other information to the authorities, which will be able to define priorities for the response teams. Knowing that it’s a fire event, the drone can autonomously find the current fire perimeter, and identify people and infrastructure in danger;
3. The drones can be autonomously configured to search for people and signalize their presence to the authorities. The drones will also be able to identify devices connected

to itself and use triangulation to locate the source of the signal (triangulation possible with 2 drones in range, each with a 5G antenna). A drone can also be configured to send SMS and call the phones within its reach with an automatic message informing of the danger situation and asking to call to an emergency number.

4. The drones will be able to create a 5G micro cell, allowing for connectivity in the affected area for the response teams and the general population

4.2.8.6 Final Scenario

The drone successfully completed its mission and safely returned to its headquarters.

4.2.9 UC 9 – Jump Travelling

4.2.9.1 Context

Some activities are simply not possible to experience, or too dangerous to try, such as flying above an active volcano. Some are possible, but most of us are fearful of trying, for instance parachute jumping, or swimming among sharks. Others are possible and "safe", but hard to experience for most people, since they are not at or near the location, for example, flying above the fields of Alentejo, in Portugal, on a hot-air balloon.

Jump Travel, is a service to be offered to anyone, anywhere in the world, using virtual and augmented reality, 5G communications, drones and, when available, a mechanical apparatus coupled with wearable computing devices, that provide for sensorial stimulation replicating some of the sensations one would feel if it was experiencing the selected travel experience.

Some of the travel experiences will be in real-time, where the user controls the drone in the selected scenario. Others will be pre-recorded, in which the user will simply experience the movement previously executed by the drone – but still having the possibility to select, for instance, the degree of adrenaline desired.

4.2.9.2 Motivation for 5G Networks

The need for 5G arises from multiple requirements, driven by either the real-time aspect of very high-quality video transmission, the simultaneous multicast aspect for pre-recorded travel experiences, and of course the large number of sensor connections needed to provide full sensorial immersive experience. The quartet of 5G fundamental technologies, namely, millimeter waves, small cells, beamforming and massive MIMO, will all be required to achieve the needed <u>bandwidth and latency for the immersive experience</u>. To a smaller extent, network slicing and behavioral analysis content pre-fetching will also be areas where the new advances proposed by the 5G architecture will be required.

4.2.9.3 Description

Users at specific locations, let us say a theme park, would like to experience a new type of roller coaster – one in which they could enjoy jump travel, from one location to another around the world, and experience a 360-degree view from a flying drone, using immersive technology. This jump travelling between locations will be performed using a Human-Machine user interface based on sensors detecting hand movements coupled with augmented reality and voice recognition.

These jumps can either be to pre-recorded flight paths (in fact, multiple repetitions of flight paths, each with various characteristics, such as speed, risk, etc., that can be selected in real-time by the user) or to real-time flights in which the user will control, again using body movements tracked by sensors, the flight path during the experience.

Naturally, not all users will be able to jump to a specific real-time location, not only due to availability – since only one user can control an individual drone at any given time – but also due to the maximum distance allowed between the source (i.e. user location) and the destination (i.e. drone location), which has a direct impact on the amount of latency tolerated by this type of application. However, this restriction can be mitigated by a clever mechanism applied to image processing.

The location of the user is not bound to a fixed location (e.g. the theme park previously referred). In fact, 5G deployment will make it possible for this type of experience to be carried out from any location (user's home, for instance). In this scenario, Network Slicing (real-time experience) and Pre-fetching (pre-recorded experience) become very relevant in order to guarantee an acceptable Quality of Experience.

Network Slicing, will be necessary to guarantee Quality of Experience by pre-allocating resources before the streaming starts. In addition, since it is expected to have multiple drones available at most locations, dynamic network slicing will be required to provide the best quality possible for the number of simultaneous drones flying at any given time.

Network monitoring will also be required, to help the applications present optimal options to the user. This will help minimize the simultaneous number of drones flying in a certain location that is currently suffering from a bandwidth bottleneck.

Some of the locations where the drones will be placed there will be no 5G traditional Base Stations available and, therefore, a different solution must be implemented in order to maintain the required quantity of bandwidth. Small Cells dedicated to both regular communications (for instance, mobile subscribers in the vicinity) and to this specific application will be deployed. These small cells will connect to the one attached to the drone during the entire flight path using millimeter waves. However, millimeter waves have a major drawback. They do not easily travel through obstacles and are easily absorbed. The solution is to provide two drones that fly in tandem, but the top drone is always in line-of-sight with at least one small cell. This way, using another one of the fundamental building blocks of 5G networks (beamforming), both drones communicate using beamforming and the top drone relays the information to the nearest small cell. This small cell is placed in a topology that has either line-of-sight to another small cell or can transmit directly to a traditional Base Station.

Each drone will be streaming 360-degree non-compressed images (compression will be added if/when necessary according to the network's capacity). However, the user only sees at any given time a limited subset. This can be used in order to relax the latency requirement. Research has shown that to achieve motion parallax in a virtual environment, the delay between head movement and image update should be less than 200 milliseconds. If we consider a network overhead of 50%, this would mean a one-way propagation delay of at most 50 milliseconds. From this value we can calculate the maximum distance the user could be from the drone being controlled (which in this case is 9.000 miles). Other studies point to the fact that the delay should be below 100 milliseconds in order to prevent the sensation of nausea, which would mean the maximum distance should be less than 4.500 miles. Since signals travel slower than the speed of light in non-vacuum, it is safe to assume the upper bound is in the vicinity of 3.000 miles, which is just enough to have a user in New York controlling a drone in Los Angeles!

Nevertheless, if we realize that the image that must be shown to the user once he moves his view point is already being transmitted, the end-device just needs to re-calculate the image to be shown, while it waits for the new feed to arrive. The constant movement of the drone (assuming it is not stationary) makes this re-calculation harder and causes itself a delay, but still allows for the maximum distance between user and drone to be increased to the point where virtually from anywhere a user can control any drone around the world.

User controlled drones will require failsafe mechanisms that will prevent users from damaging drones, as well as to determine when/where it is safe to land (due to, for instance, energy requirements).

If the user selects pre-recorded flights, the network will firstly provide the optimal feeds based on both user profiling and content proximity. This optimization will continue in real-time, since the user can at any given time jump to another flight experience, which means the network will monitor, for instance, all users in a given cell, and suggest the same flights simultaneously to all of them.

4.2.9.4 Initial Scenario

A user heads to an entertainment center where it can wear a head-mounted display (HMD) and, additionally, other types of wearables that may improve its experience (gloves, microphone, etc.). Besides all the hardware/devices necessary, the entertainment center has purchased the Jump Travel application to run the experience.

Each location allowed to *Jump Travel* has a nearby Headquarters with available drones.

4.2.9.5 Step-by-step Scenario

1. The user is properly equipped for the Jump Travel experience;
2. The HMD displays to the user a list of locations where it can jump to;
3. The user performs gestures to select the geographic location X, 1.000 miles away from its actual location;
4. The user is virtually transported to the location X where a drone is transmitting a 360-degree view of the area;
5. The user, fully immersed in the location of its choosing, controls the drone through gestures to experience the environment in real-time;
6. The user makes use of the HMD to select a different geographic location Y, 2.500 miles away;
7. The weather conditions are not favorable to send off a Drone to location Y. The user is virtually transported to Y, where there is currently no drone transmitting a 360-degree view of the area;
8. The user experiences a pre-recorded flight path in Y;
9. The user takes off its equipment and the drone returns, autonomously, to its base station.

4.2.9.6 Final Scenario

The user virtually experienced several geographical areas that it would not or could not physically experience. The user felt perfectly immersed in the environment without the sensation of motion sickness nor noticing lag throughout the journey.

4.2.10 UC 10 – Multiplayer Games Using VR

4.2.10.1 Context

eSports is a form of competition using videogames, typically referring to organized events of professional competitors. Although being a part of the videogame culture since several years ago, the popularity of this sort of competition has only increased significantly by the end of the last decade with the participation of professional teams. In 2015, the global audience reached 226 million people and with a rising tendency.

Currently, a high number of game companies is focusing its business on eSports and improving its experience. The most popular genres associated to this kind of competitions are real-time strategy, combat, first-person shooters (FPS) and multiplayer online battle arena (MOBA).

One of the greatest challenges intrinsic to the development of eSport games is minimizing the latency's impact on the network's communication data in order to provide the best possible experience to its players. Currently, 4G networks guarantee a latency between 40 and 60ms, which can be considered a relatively low latency in several scenarios, but it may turn out insufficient in the explained context.

4.2.10.2 Motivation for 5G Networks

Due to the characteristics inherent to eSports, game developers, players and the public in general hold high expectations of the possibilities that 5G networks (and their potential in lowering latency) can bring throughout the upcoming decades.

In another area, a considerable number of entities involved in the videogame industry is exploring the possibilities of 5G networks in the fields of virtual and augmented reality. In 2018, it is expected that the number of applications that make use of augmented reality in mobile devices continues to grow. However, the processing capacity and energy consumption of current devices are still a large hindrance to this technology. Along with hardware advancements (camera, processor, memory, etc.), it is foreseen that 5G networks will allow a significant part of the data processing related to augmented reality systems to be delegated to cloud computing. Consequently, this possibility will make mobile devices less expensive and more accessible to the public.

Meanwhile, 5G networks also promise to make virtual reality games more accessible to regular consumers. Currently, virtual reality requires a great investment in expensive hardware, namely in powerful graphics cards, processors and VR equipment, such has Oculus Rift or HTC Vive. Without this level of investment, a consumer can hardly take advantage of the immersive experience in virtual worlds. In this sense, 5G can offer an alternative solution by providing adequate access to the computational power of cloud computing that current mobile networks cannot provide.

4.2.10.3 Description

This scenario consists of an online multiplayer game where a minimum of two opponents can perform virtual battles in a virtual arena. All players must be equipped with VR devices and interaction sensors that detect their movements. Each player makes use of a virtual melee weapon to attack or defend the opponent's attacks. These movements ought to be transmitted in real-time so that all players can react accordingly.

The efficacy of this experience is strongly correlated with the latency of the communication between players. If the network does not allow the communication of each player's movements within an acceptable time interval for real-time interaction, it will only increase the players' frustration and the experience will have been a failure.

4.2.10.4 Initial Scenario

Each player connects to the game from distinct locations. The playground area is enough for the player to move without the risk of hitting surrounding objects. All players are equipped with the VR devices necessary for the immersive experience and can connect to a 5G network. In turn, the devices are connected to a machine with enough capacity for processing the graphics of the 3D environment.

4.2.10.5 Step-by-step Scenario

1. A player P1 runs the game and the initial menu is displayed;
2. P1 selects the multiplayer game option and a list of available arenas is presented. (Alternatively, P1 could create a new arena, name it and protect it with a password);
3. P1 puts on its VR equipment and joins an arena with room available for another player;
4. P1 chooses its weapon and starts battling in the arena with other players. The VR interaction devices will simulate the chosen weapon;
5. P1's character and movements are detected by VR sensors and transmitted in real-time to the other players within the same arena (using a 5G network);
6. P1, as well as other participants, react in real-time to each other's movements;
7. P1 wins points whenever it successfully hits other players;
8. The game ends when only one player stands in the arena;
9. The points of each player are disclosed.

4.2.10.6 Final Scenario

All players were able to experience the VR battle in real-time.

The response to their in-game movements was fluid and without any noticeable latency.

They could successfully react to other player's moves without ending up frustrated by a delay in the communications.

4.2.11 UC 11 – Live Events in VR/AR

4.2.11.1 Context

Having the chance to *feel* immersed in a specific environment or venue (sport fields, music halls, etc.) is one of the most promising benefits of 5G networks; it may allow people to feel more connected to the main actors of an event and even provide them with a whole new level of freedom to improve their experience. For instance, in a soccer stadium, users are limited to the perspective from where they stand throughout the entire game, instead of having the possibility to freely select a viewpoint they find interesting (e.g. behind the goalie, above the player carrying the ball, always following the referee, etc.). The following use case explores this concept and presents an approach to solving this hindrance with the aid of Virtual and Augmented Reality technologies.

4.2.11.2 Motivation for 5G Networks

In order to allow users that are physically located at a venue to select their desired viewpoint in real-time, regardless of what other users may select, a series of communication network features must be taken into account. Some of which are well known, such as Network Initiated Handover, but they must be improved to reduce the time required for the handover process (by performing optimization measures in the control plane). Others, such as very low latency rates, are new key-features needed to prevent a noticeable gap between reality (the event that is happening in some physical space) and the images transmitted to visualization devices (VR / Augmented Reality Glasses / etc.).

4.2.11.3 Description

Users at a venue, let us say a soccer stadium, can follow the game from different Viewpoints, which can also change over time for each individual user. In order for that to be possible, an operator places several cameras around the stadium: some at the ground level, others above ground (for instance, carried by drones) that capture images from multiple Viewpoints.

The captured Viewpoints do not necessarily correspond to the number of cameras serving the event. In other words, a user can select a Viewpoint that is extrapolated, in real-time, by merging the angles captured from different cameras. For example, four cameras placed at the four corners of the field can provide the Viewpoint that corresponds to the center of the field without ever having to place a camera at that location.

However, the number of User-Viewpoints (UVP) is limited due to reasons that will become clear further ahead. In this scenario, users make use of a Virtual Reality Head-Mounted Display (HMD) that allows them to seamlessly select different UVP. Additionally, the user can switch between the real game, i.e., the view from where it stands, and the video stream being transmitted to the HMD.

For a given event covered by ***n*** Base Stations (BS), an operator determines a provision of ***k*** UVP. This means that, initially, the maximum available bandwidth will be allocated to **k/n** slots per base station, for multicast transmission.

Each BS will be assigned a specific set of UVP regardless of how many users are actually demanding that UVP.

Once the transmission starts, each user receives the selected video stream from the BS that was assigned to multicast that stream.

When a user requests a new UVP, if that new UVP is allocated to a BS different from the one the user is currently connected to, the network initiates a Network Initiated Handover in order to transfer the user's connection to the correct BS.

If the network detects a reduced number of users requesting a specific stream, it initiates the procedure of stream quality degradation by reducing the bandwidth allocated to the stream and reallocating the channel to new possible UVP, increasing the total number of UVP from ***k*** to ***k+1***.

Simultaneously to this procedure, the network will inform the Edge Computing infrastructure to provide the new stream to the BS.

The increase and reduction of UVP are performed dynamically over time based on the users' demand and resource availability (not only with regard to channels but also to the computational power at the edge infrastructure).

Another point to take into consideration is the possibility of prerecorded streams via caching. If a user decides to view a previously transmitted stream, a fetch content request is sent to the caching infrastructure that will in turn transmit the correct stream via one of the available BS. In such a case, several optimizations are required:

1. Channel allocation must be performed. This can be done dynamically, or a percentage of re-transmissions channels can be reserved ahead.
2. All content must be recorded by the Edge infrastructure and available for re-transmission at any time.
3. Multiple cached streams are multicast at once, allowing the users' device to use (and store) the selected stream without requiring new multicast transmission for that set of streams. This multicast will likely be performed at a lower quality.
4. The network must adapt the channel allocation to reduce the quality of live streaming based on the users' behavior (e.g. after a goal, the next few seconds of live game will be ignored by all users regardless of the UVP, since it is likely that most will want to re-live the goal from different UVP).

4.2.11.4 Initial Scenario

A soccer game is taking place in a football stadium. The stadium has cameras placed at strategic locations, both on the ground and air.

Each member of the audience (User) is given an HDM to access the interface of virtual UVP.

The HDM connects to a server that manages the entire operation and provides the service.

4.2.11.5 Step-by-Step Scenario

1. The User puts on its HDM for VR/AR;
2. A list of available UVP is displayed on the User's HDM;
3. The User selects the desired UVP using the HDM;
4. The game's referee indicates a fault and the User chooses another UVP from the list that best allows it to revisit the moment that led to the fault;
5. The User adjusts its experience by selecting different UVP throughout the remainder of the game.

4.2.11.6 Final Scenario

The audience was in full control of the viewpoints they found the most interesting to watch the event from.

The audience could not tell any gaps between the real event and the viewpoints they chose to watch it from.

The network mechanisms to provide the service were not noticeable to the audience.

The audience felt completely immersed in the event and closer to all the action, thus providing them with a better quality of experience.

5 Conclusions

This document presented a series of use cases derived from each of the research areas introduced in the Background section. The use cases contributed with innovative ideas across multiple industry sectors and provided an initial set of guidelines for the implementation of specific scenarios. Each use case was able to capture some key features of 5G networks, without which would not be possible to move on to the next level in the world of Information and Communication Technologies.

The use cases were split into two categories: Middleware Applications and Commercial Applications. The former focused on presenting applications that will support common functionalities necessary in the context of the 5G IP network, whereas the latter turned to a variety of technologies currently targeted worldwide (drones, virtual reality, 360° cameras for live streaming, etc.) to demonstrate the potential of 5G in human communications.

The initial efforts that have been carried out and portrayed in this report will be supporting the next stage of architectural specification that is to be developed in the upcoming deliverable for the Mobilizador 5G project.

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