# Paving the Path to 6G: The 6G-PATH Project's Vision for Advanced Telecommunications' Infrastructure and Use Cases


João Fernandes*, Luis Rosa*, Ioannis P. Chochliouros†, Luis Cordeiro*, Almudena Días Zayas‡, David Guillen§, Nicola di Prieto¶, Juan M. Losada‖, Andy Edmonds**, Cristian Patachia-Sultanoiu††, Ovidiu Ana‡‡, Qi Wang[x], Anna Brunstrom[xi], Donal Morris[xii], Nils Lahmann[xiii], Andreea Corici[xiv], Gregor Liebscher[xv], Susana Sargento[xvi], Filipe Pinto[xvii], Panayiotis Verrios[xviii], Ronald Legallais[xix], Marilena Paraskeva[xx], Tarik Taleb[xxi], Rafael Marin-Perez[xxii], Efthymios Serpetzoglou[xxiii], Mirana Khanom[xxiv], Peter Gray[xxv], Uthayasankar Sivarajah[xxvi], Piyush Harsh**

*OneSource, Consultoria Informática Lda., Portugal, Email: {joao.fernandes, luis.rosa, cordeiro}@onesource.pt;
†Hellenic Telecommunications Organization (OTE) S.A., Greece; ‡Universidad de Malaga, Spain;
§Telefónica Innovatión Digital S.L., Spain; ¶Hewlett Packard Enterprise, Italy; [xxv]CloudSigma AG, Switzerland;
‖Agencia Estatal Consejo Superior de Investigaciones Científicas, Spain; **Terraview GmbH, Switzerlan;
††Orange Romania S.A., Romania; ‡‡Fundatia Orange, Romania; [x]University of the West of Scotland, UK;
[xi]Karlstads University, Sweden; [xii]RedZinc Services Ltd., Ireland; [xiii]Charité - Universitätsmedizin Berlin, Germany;
[xiv]Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V., Germany; [xv]MCS Data Labs, Germany;
[xvi]Instituto de Telecomunicações, Portugal; [xvii]Altice Labs S.A., Portugal; [xix]Airbus DS SLC, France;
[xviii]Sistimata Tilepikoinonion Antonis Georgiou Monoprosopi E.P.E., Greece; [xxvi]University of Bradford, UK;
[xx]eBOS Technologies Ltd., Cyprus; [xxi]Ict-Ficial Oy, Finland; [xxii]Odin Solutions Sociedad Limitada, Spain;
[xxiii]Appart AE New Technologies Computer and Telecommunications, Greece; [xxiv]F6S Network Ireland Limited, Ireland



***Abstract*—The path towards 6G is underway as 5G matures and is deployed worldwide, both publicly and privately. While 5G brought a step up in many fields, such as performance and efficiency, more is always expected in terms of efficiency by the overall community and in terms of performance by industry and technology providers who want to increase their offerings and products further. Continuous demands for higher throughput, lower latency and more energy-efficient communications must be supported by relevant use cases (UC)s that can claim and demonstrate the needs for these requests. This paper discusses the SNS-JU 2023 6G-PATH project vision, which builds upon an extensive B5G/6G infrastructure where a set of core architectures and domain-specific capabilities are brought together and made available for integration of applications and use cases to conduct large-scale pilots and trials. 6G-PATH fosters the development and integration of new and improved tools and products from EU companies with 5G/6G while measuring relevant KPIs and KVIs. To achieve this, the project includes designing and developing an integrated experimentation platform integrating 7 testbeds and 10 use cases spread across 4 key verticals: Health, Education, Smart Cities and Farming. Moreover, to further involve the community and obtain more metrics and outcomes, it's envisioned to integrate 2 new pilot sites and extend the testbeds with 10 additional technologies and 30 new use cases through Open Calls.**


## I. Introduction

The evolution of mobile telecommunications that brought us 5G was a success, as demonstrated by the commercially available deployments worldwide leveraging the technology and improving mobile services. These improvements include greater performance, flexibility, and scalability, benefiting a whole ecosystem of end users, operators, and technology providers. However, now that 5G is somehow a mainstream technology, we must aim for what comes next. This is first assumed as a Beyond 5G (B5G) environment, which may include 5G advanced concepts and technology initially but will culminate in the ubiquitous 6G currently gathering much attention from the research community and industry alike. Therefore, it is essential that requirements are set and both new and demanding Use Cases (UCs) are specified as means of setting the challenges for 6G and supporting its validation in realistic scenarios. Such validation remains complex due to the diverse technological components, varying deployment scenarios, and the need to ensure interoperability among multiple systems and standards. This publication provides an overview of the 6G-PATH project [1], an SNS-JU 2023 project running from January 2024 to December 2026 to foster the development and integration of new and improved tools and products from EU companies with 5G/6G while also measuring relevant Key Performance Indicators (KPIs) and Key Value Indicators (KVIs). This publication covers the 6G-PATH experimentation architecture, testbeds, and use cases, providing insights into ongoing experimentation plans. The paper is structured as follows: Section II overviews related projects inspiring 6G-PATH. Section III presents the concept and vision of 6G-PATH. Section IV details the testbeds. Section V describes the verticals and use cases. Section VI discusses the impact. Section VII provides the concluding remarks.

## II. Related Work

This section categorizes the related work into three topics: trials and experimentation-focused research, 5G/B5G technology enablers of 6G-PATH, and finally, use case projects extended in 6G-PATH. Regarding trials and experimentation-focused research projects, the 6G-BRICKS project leverages 5G-PPP ICT-52 platforms to provide reusable 6G testbed infrastructures. 6G-PATH will integrate insights from 6G-BRICKS [2] in its conceptual framework. The 6G-SANDBOX [3] project brings a modular facility for the European experimentation ecosystem and introduces the concept of Trial Networks. 6G-PATH will build on that to support new verticals and use cases. Likewise, 6G-PATH will also take on the initial knowledge from IMAGINE-B5G [4], a project focused on providing an accessible end-to-end (E2E) 5G platform for Large-Scale Trials and Pilots to expand the number of testbeds while introducing new use cases and verticals. The 5G European Validation platform, developed by the 5G-EVE [5] project, will also be considered in designing the 6G-PATH open APIs and experimental procedures. Moreover, 6G-PATH will harness the insights from similar experimentation research projects, such as the 5GASP [6] experimentation platform, the 5G performance assessment capabilities of the 5G-SOLUTIONS [7] and 5GMediaHUB [8] platforms, the concept of the disintegration of complex B5G private networks as proposed in FUDGE-5G [9], the 5G experimental infrastructure and experimentation methodology of 5GENESIS [10], and the 5G-EPICENTRE [11] platform components. In terms of 5G/B5G technology enablers, 6G-PATH will take into account the 5G+TACTIL [12] solutions for deterministic communications and B5G NPN scenarios, the concept of autonomous orchestration proposed in CHARITY [13], the 5G programmability tools developed within the EVOLVED-5G [14] project, the concept of elastic virtual infrastructures developed to deliver end-to-end transfer, processing and storage services as discussed in the MARSAL [15] project, and the notion of federated AI-governed zero-touch cognitive and secure management capabilities as developed in RIGOUROUS [16]. Regarding the integration of insights from use case-centred projects, 6G-PATH will further advance the 5G-HEART [17] use case of wearable video for paramedics in urban search and rescue incidents, the digital education in primary and secondary schools from the Digitalia Romanian program, the wearable video for nurses in ultrasound training and out-of-hours community support for frail/elderly cohort derived from the HEALTH-5G [18] project and the lessons on the integration of new use cases in Media & PPDR vertical industry from the FIDAL [19] project.

## III. 6G-PATH Concept and Vision

6G-PATH aims to foster the experimentation of new B5G/6G technologies in close collaboration with other 6G-IA projects and through Open Calls (OC) to engage European companies to further innovate B5G/6G. The pilots grouped in various UCs across four verticals (i.e., Health, Education, Smart Cities and Farming) will leverage the 6G-PATH experimentation platform to assess their behaviour. Such pilot and UC validation will drive additional platform requirements and KPIs/KVIs and promote the development of 6G.

6G-PATH builds upon an extensive B5G/6G infrastructure where core architectures and domain-specific capabilities are brought together and made available for integrating applications and use cases and conducting large-scale pilots and trials. The results of these pilots and trials will be collected and analysed in detail to generate appropriate lessons and requirements for 6G and to identify and characterize leading-edge business models towards the commercialisation and exploitation of 6G use cases and technologies. The overall 6G-PATH architecture (Fig. 1) offers a unified and simplified experimentation platform for pilot configuration, scheduling, execution, collection and visualization of KPIs/KVIs. 6G-PATH platform focuses on two different analyses: the performance of Network Applications and their impact on their use cases.

In brief, the objectives of 6G-PATH are: (i) To integrate a large set of testbeds following 3GPP Releases 18-20; (ii) To use these testbeds for systematic integration of B5G/6G innovations developed in other 6G-IA projects and/or by third parties; (iii) To offer a experimentation platform to streamline the technical integration of UCs and applications and the collection of relevant metrics during the pilots and trials. (iv) To integrate, demonstrate and evaluate a wide range of demanding UCs in four verticals; (v) To perform a comprehensive validation of technological innovations and pilots to ensure a clear path towards 6G; (vi) To perform an extensive analysis of potential business models for the UCs.

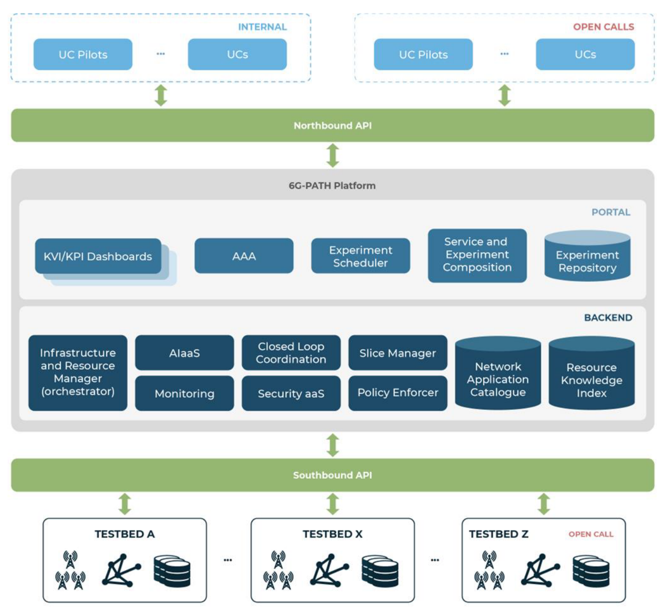


Fig. 1. 6G-PATH Architecture

## IV. European B5G/6G Testbed Facilities

6G-PATH testbeds provide infrastructure for researchers and developers to assess the performance of their 6G experiments. Follows an overview of each testbed.

**Instituto de Telecomunicações's (IT) testbed** (Fig. 2), operated in Aveiro, Portugal, integrates Smart Lamp Posts/Wall boxes with 5G and Multi-access Edge Computing (MEC) for urban use cases. It includes a 5G private network, with devices like UEs, CPEs, and gNodeBs, centrally managed by Software Defined Networking (SDN). The network is split into vehicular and 5G domains, with SDN controllers managing vehicular handovers and edge-based 5G user functions. It supports advanced services like network slicing and uses Ethernet, millimeter-wave, and satellite links for backhaul, with TSN technologies ensuring high-quality routing.

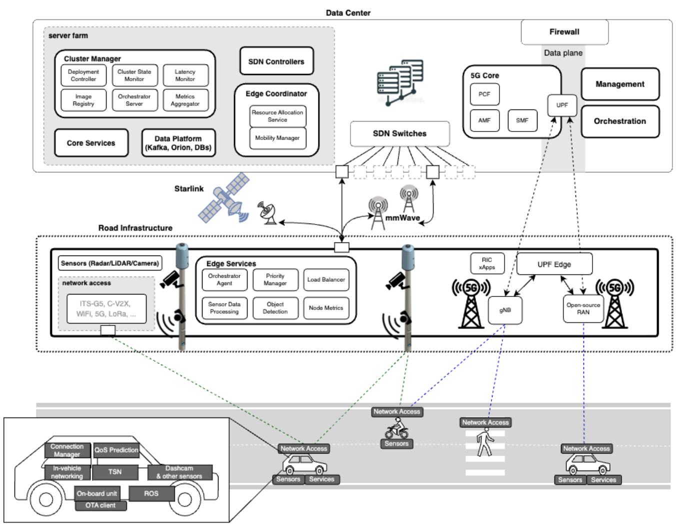


Fig. 2. IT's Testbed General view and Key components and capabilities

**Orange Romania's (ORO) testbed**, shown in Fig. 3, operated by POLITEHNICA Bucharest National University of Science and Technology, is part of the "Orange 5G Lab," a research and testing environment for next-generation networks. It is connected to a similar 5G Lab at the Gheorghe Asachi Technical University of Iași, Romania, via 100Gbps broadband. Both testbeds fully implement a 5G Standalone (SA) 3GPP Release 16 compliant infrastructure and support advanced use cases like XR/VR/AR and V2X, offering eMBB, URLLC, and dynamic orchestration of network functions. The infrastructure features Kubernetes, OpenStack, and edge computing integration with low latency and high throughput.

**The Fraunhofer FOKUS Testbed**, located in Berlin, Germany, shown in Fig. 4, supports the development and testing of 5G and 6G technologies. It features a multi-vendor SA 5G Core-RAN integration for proof-of-concept demonstrations and supports various RAN vendors, UEs, and backhaul options. The testbed includes the Open5GCore software, which is highly configurable and supports key 3GPP network functions, and advanced features like network slicing, non-3GPP access,

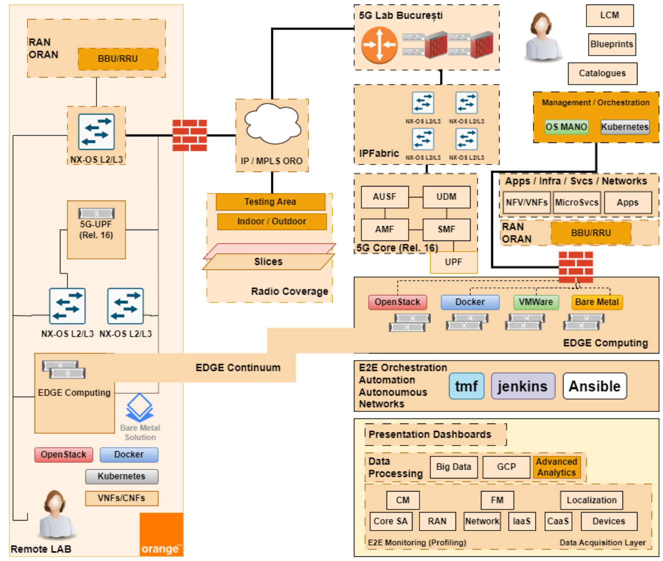


Fig. 3. ORO's Testbed General view and Key components and capabilities

and location services. It integrates 5G base stations from multiple vendors and operates in the 3.7-3.8 GHz band, offering indoor and outdoor coverage around the premises. The testbed also supports satellite backhaul via Starlink for Non-Terrestrial Networks (NTN) use cases, allowing remote node connections to the 5G Core (5GC).

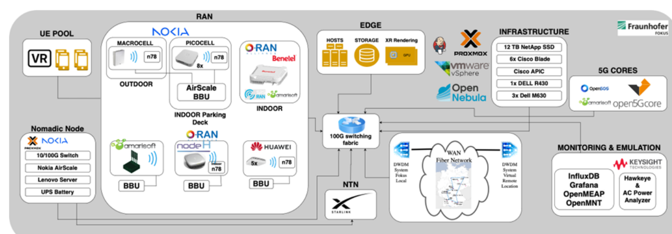


Fig. 4. FOKUS's Testbed General view and Key components and capabilities

**The University of Málaga's (UMA) testbed**, represented by Victoria Network, shown in Fig. 5, includes multiple 5G deployments. The University campus hosts a 5G private network with Nokia radios in both FR1 and FR2 bands, featuring microcells for outdoor coverage and picocells for indoor coverage. Features dynamic UL resource allocation and adaptive re-transmission. The La Mayora network is under deployment, with 5GC and edge computing. UMA's testbed is equipped with an HPE 5GC Network, fully virtualized and compliant with 3GPP standards. The HPE 5GC includes monitoring capabilities via Prometheus and offers APIs for external system integration and automation.

**The Communication Advanced Research Laboratory Wireless Testbed (CARL-W) at Karlstad University (KAU)**, Sweden, shown in 6, is part of the Northstar Testbed, managed in collaboration with Telia and Ericsson. The testbed integrates 4G, 5G, WiFi, and Starlink technologies over a fiber

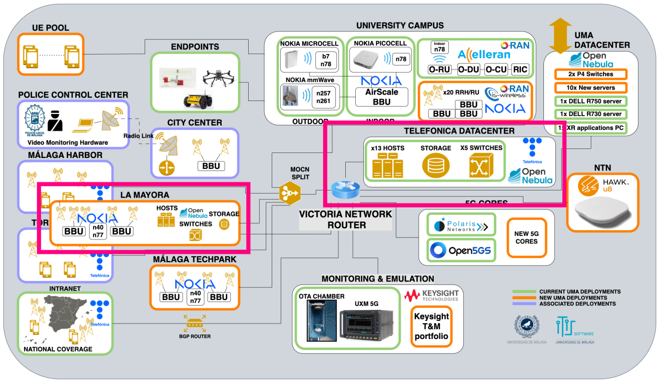


Fig. 5. UMA's Testbed General view and Key components and capabilities

and 10GbE network, supporting various end-user equipment like mobile phones, Internet of Things (IoT) devices, and virtual machines. Equipped with Ericsson Radio Dot for 5G SA, it covers both the university and the nearby Innovation Park. The setup supports low-latency edge capabilities on a 100MHz N78 spectrum, validated with 5G hardware, making it ideal for high-demand use cases like VR/AR and smart industries.

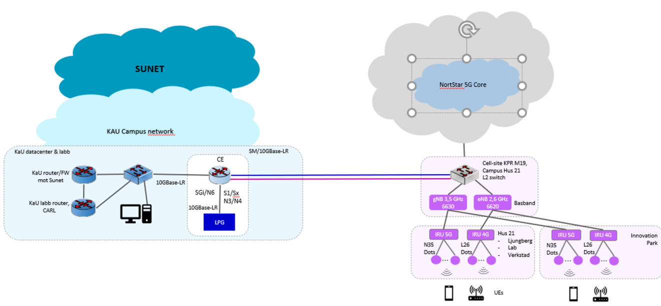


Fig. 6. KAU's Testbed General view and Key components and capabilities

**The Beyond 5G Testbed at the University of the West of Scotland's Paisley Campus (UWS)**, shown in 7, supports both 4G and 5G networks using Open Air Interface software. The infrastructure includes five Dell T5810 machines, each equipped with 12 cores, 2TB HDD, and 32GB RAM, connected through a 10Gb network. These machines are divided into three zones—Edge 1, Edge 2, and Core—allowing for flexible service deployment. The testbed also features multiple UEs connected via Ettus USRP B210 for network access. Management is handled through physical and virtual machines, with advanced orchestration and micro-service capabilities provided by OpenStack Wallaby, MaaS, and Juju controllers.

**The OTE Lab testbed**, based in Athens, shown in Fig. 8, operates a 5G SA architecture. It includes a Radio Access Network (RAN) using Ericsson equipment with NR technology and a cloud-native 5GC based on 3GPP Release 16. The testbed features containerized Network Functions (CNFs) for flexible service deployment, edge computing support via OpenStack, and network slicing capabilities. The Slice Manager allows for the creation, update, and management of network slices, providing tailored Quality of Service (QoS) for different use cases.

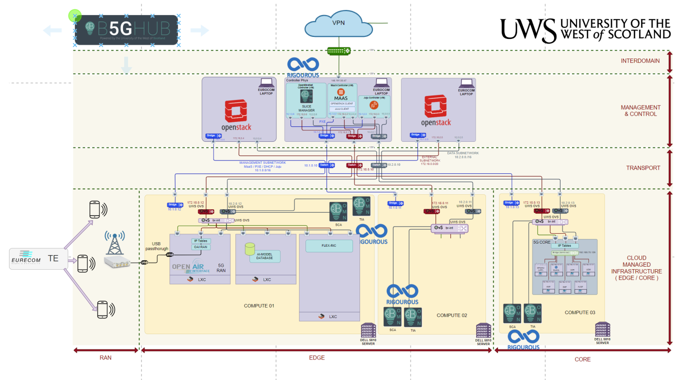


Fig. 7. UWS's Testbed General view and Key components and capabilities

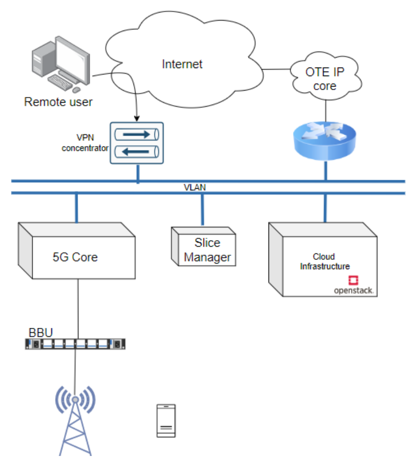


Fig. 8. OTE's Testbed General view and Key components and capabilities

## *A. Innovations*

6G-PATH has already identified key innovations to focus on as follows.

**Native AI, AI-Driven Networks, Intelligent Cross-Domain continuum management and 6G RAN** prediction capabilities are key features in the 6G roadmap. They aim to move traditional centralized processing to a ubiquitous approach, giving network elements the capabilities for intelligence processing. These intelligent capabilities will heavily rely on data compression, improved communications, and the distributed computational power introduced by distributed and federated learning. In 6G, AI will assume a disruptive role, bringing automation and supportive mechanisms (e.g., resource prediction) to optimize the whole continuum orchestration.

**Deterministic, Reliable and High-Resolution Localization Services**. Moving from the 5G 10cm 2D precision to the expected 1cm 3D in 6G will be key to supporting the advances of Extended Reality (XR) technologies, the concept of the Internet of Senses, Holographic communications, or even ultra-precision manufacturing. 6G localization services will be further improved to meet the new requirements of new use cases and applications. Furthermore, there is a growing need for deterministic and reliable services which can consistently operate even in various environmental conditions and be resilient to interference disruptions.

**Non-Terrestrial Networks** are being considered as a solution for extending cell coverage, especially in locations where terrestrial networks are difficult to deploy, such as across oceans, or are not cost-effective for traditional operators, such as rural areas. NTNs will not only allow reaching the targets of 100% coverage but also increase the reliability of communications in cases of failure in the terrestrial coverage.

**Time Sensitive Networks and Time-sensitive IoT-Edge-Cloud Continuum** address the need for a more deterministic network, which is required by time-sensitive scenarios, such as IoT applications or, more significantly, the emerging Industry 5.0 concept. As such, TSNs are being actively researched, and their addition to some of the existing testbeds will open the possibility of testing new applications and deriving new analyses and results.

**Next-Generation of Core, Backhauling and Micro-Networks**. Through its rich experimentation and heterogeneous testbed facilities, 6G-PATH will be a means of excellence to continue the (re)evolution in re-imagining 6G. For instance, backhauling is not a new concept, but new types of deployments are being considered. This concept needs to evolve accordingly. In most cases, the increasing number of private network deployments need a medium for reaching the public network. This can be achieved by considering NTNs or even commercial 5G/6G networks connecting the underlying private 5G/6G networks to the world. Similarly, the concept of nomadic edge nodes and micro-core networks suitable to be deployed in rural areas will be further evaluated in 6G-PATH.

**E2E Control Programmability, Extreme E2E slicing and resource isolation** similar to the above, network slicing and network control programmability are not new concepts. Even though, in 6G-PATH they will be pushed to new levels. Additional extensions, flexible APIs and programmable interfaces will be considered. Likewise, E2E network slicing will be investigated to provide dynamic and scalable (i.e., thousands - several levels of magnitudes) and conflict-resolution techniques based on 5G Quality of Service Identifier (5QI) and QoS mapping applied.

**De-biasing of metadata and co-creation**, through the project's approach and methodology for the KPIs and KVIs, and the AI as a Service (AIaaS) containing metadata for AI/Machine Learning (ML) datasets and each AI/ML training set will be accompanied by information on how data is collected and annotated. Provide new insights to be conceptualised from end-user perspectives and include a gender-sensitive framework, resulting in recommendations that add new insights, e.g., what gender-sensitive provisions are needed regarding the design, deployment, and usage of the enablers.

**Energy efficient Core and management platform** through the usage of advanced AI algorithms that are energy-aware and orchestrate energy-efficient solutions, including the optimization of the edge-core continuum. Through energy monitoring, power consumption indicators will be fed to the intelligent algorithms during training and reinforced learning.

## V. Verticals and Use Cases

As B5G/6G evolve, significant disruptions are expected in many industries and verticals (e.g., new immersive virtual and augmented reality (VR and AR) experiences, real-time remote control of autonomous vehicles, and the deployment of large-scale IoT networks, which were previously not feasible). 6G-PATH focuses on understanding them through KPI/KVI assessment. For instance, improvements in public safety coordination, response times, decision-making, and resource management. Moreover, network-related KPIs such as reliability, availability, and QoE improvements will be measured alongside enhancements in processing time, route optimization, and safety. 6G-PATH will also focus on increasingly relevant AI KPIs/KVIs, such as inference accuracy and explainable AI techniques. For verticals like healthcare, education, and agriculture, KPIs related to diagnosis improvements, energy efficiency, network performance, and user engagement will be tracked. Additionally, resource efficiency, sustainability, and reductions in cloud dependency are key evaluation metrics. These KPIs and KVIs provide critical insights into the effectiveness and value of 6G technologies across multiple sectors. 6G-PATH groups the envisioned innovations to each vertical and use case as follows.

**The Farming** vertical, composed of two use cases (water saving and smart vineyards in UMA), will be used to evaluate different types of deployments (off-grid, intermittent and interconnected), network slicing with support for different kinds of QoS (i.e., enhanced Mobile Broadband (eMBB), ultra-reliable low latency communications (URLLC), enhanced machine-type communication (eMTC)) and the integration with AI-driven capabilities and Edge-Cloud computing.

**The Education** vertical, mainly devoted to Extended Reality (XR) and Holographic-based educational scenarios, comprises three use cases (XR rural schools in ORO, classroom of the future in UWS and XR Health Training in KAU). This vertical will be used to experiment with the concepts of location-sensitive processing and how the network and continuum infrastructure can natively support the KPI and QoE measurement. Moreover, the education vertical will also evaluate AI-driven video and data processing capabilities.

**The Health** vertical, composed of two use cases (3D hydrogel patches and elderly monitoring in FOKUS), will be used to evaluate the concept of micro and nomadic edge nodes and networks, Ubiquitous, Reliable and Secure connection Over-The-Top 5G Mobile Network Operators and NTN integration, XR with ultra-high bandwidth (¿50 Gbps) available to the XR platform and ultra-low latency (¡3ms). This vertical will also be used to test security-related KPIs (e.g., mutual authentication and authorization of communication between the edge-core and the core network across third-party backhauls, temporary user profiles for authentication and authorization to edge-core to maintain the active sessions during the backhaul handover).

**The Smart Cities** vertical, composed of three use cases (automated logistics in OTE, security coordination and connected and sensing city in IT), will focus on exploring and testing the integration of large-scale extreme IoT-Edge-Cloud scenarios. This includes differentiated QoS support (e.g., Extended Ultra-Reliable Low Latency Communication (xULLC), massive Machine-Type Communications (mMTC)) applied to Mission Critical Services (MCX) communications and extreme high-throughput video/data streaming. This vertical will also serve for evaluating the emerging deterministic, reliable, and high-resolution services and the resilience, safety and security of the next-generation networks, a key aspect for Public Protection and Disaster Relief (PPDR) and emergency-related applications.

## VI. IMPACT

The 6G-PATH infrastructure and platform enable extensive evaluation of advanced technologies in realistic scenarios, promoting innovation in subjects such as E2E resource management, radio optimization, and cybersecurity. The 6G-PATH platform bridges cutting-edge technologies and experimentation tools for accurate and robust research. Moreover, the standardization of the experimentation process and the access to realistic KPIs/KVIs improve data replicability and scientific relevance. The intersection of experimentation with the new use case requirements drives further 5G/B5G innovation. Additionally, open-source contributions aligned with industry standards will grant researchers and academia invaluable access to 6G technologies, maximizing their impact. 6G-PATH platform accelerates feasibility assessments and product refinement, reducing integration efforts and promoting vertical uptake. Furthermore, 6G-PATH fosters quick technical progress and market readiness by supporting solution validation and exploration of synergies. The early identification of viable business models attracts investment and fosters cross-sector collaboration. Engagement with stakeholders, including SMEs and the academic community, drives innovation and competitiveness. The repository of requirements and lessons learned guides decision-making and optimizes investments, creating new markets and revenue streams. By collecting new requirements, technology providers obtain a competitive edge, enabling them to meet evolving customer needs and capitalize on emerging domains.

Overall, 6G-PATH also provides crucial inputs for industry, academia, regulators, and policymakers, promoting technological advancements while safeguarding public interests. Supporting differentiated use cases promotes inclusion and universal access to essential services. Lastly, by organizing multiple dissemination events, 6G-PATH raises public interest in 6G technologies across diverse stakeholders, promoting inclusive and equitable digital societies.

## VII. CONCLUSION

In conclusion, the 6G-PATH project is poised to pave the way for the future of telecommunications by building an extensive experimentation B5G/6G infrastructure. With the integration of seven testbeds and plans to expand through Open Calls, the project aims to support a wide range of innovative applications and use cases across key verticals such as Health, Education, Smart Cities, and Farming. By fostering collaboration among EU companies, the project will drive the development and validation of new technologies, ensuring they meet the rigorous demands of real-world scenarios. Through large-scale pilots and trials, 6G-PATH will also generate valuable insights and requirements for future 6G communications, helping to shape the next generation of mobile networks.

## ACKNOWLEDGMENT

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