6G Initial Developments for Flagship Applications Experiments

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***Abstract*—As the world transitions into the next generation of wireless communication technology, namely 6G, the potential for revolutionary advancements in connectivity and data transfer becomes increasingly evident. With the growing demands for higher bandwidth, ultra-reliable low-latency communications, and massive machine-type communications, 6G is expected to address the limitations of existing networks and unlock new possibilities for transformative use cases in the year 2030. This research paper aims to provide a comprehensive analysis of the new software requirements needed for the transition towards future networks, drawing on currently available 5G Stand-Alone (SA) experimentation testbeds that implement the 3GPP Release 16 standard. It also looks at the new envisioned use cases for 6G, developed in the context of EU founded research and innovation projects, focusing on the projected trends, requirements and initial developments that will shape the 6G landscape. Additionally, with its focus on the KPIs needed for B5G and 6G applications, the paper highlights the pressing need for an updated architecture to accommodate the unique challenges posed by the future cellular networks standards.**

***Keywords*—6G networks, softwarization, virtualization, cloud-native, experiments, standardization.**

I. INTRODUCTION

The rapid evolution of wireless communication technologies has propelled the advancement of modern societies, connecting individuals and enabling a multitude of applications. With each new generation of wireless networks, significant improvements in speed, capacity, and reliability have been achieved. As we approach the anticipated era of the sixth-generation (6G) wireless network technology, there is a growing anticipation for groundbreaking use cases that will redefine the way we communicate and interact with our surroundings. The deployment of 5G networks marked a significant leap in terms of data transfer speeds, network capacity, and reduced latency. However, as demands for higher bandwidth and more advanced applications continue to escalate, it has become apparent that a new generation of wireless networks is necessary to meet the ever-increasing connectivity requirements. This is where the promise of 6G lies. 6G, expected to be fully deployed by the year 2030, presents an opportunity to revolutionize wireless communication technology once again. Building upon the foundations laid by its predecessors, 6G aims to address the limitations of existing networks and unlock new capabilities that will pave the way for transformative use cases [1].

In the envisioned landscape of 6G, there are several key trends that are projected to shape its development. These trends include ultra-reliable low-latency communications (URLLC), massive machine-type communications (mMTC), enhanced Mobile Broadband (eMBB), enhanced spectral and energy efficiency, intelligent and autonomous networks, as well as ubiquitous connectivity. Each of these trends presents unique challenges and opportunities, demanding a reimagined architecture to support the diverse requirements of 6G networks [2], [3].

To explore the potential of 6G and its envisioned use cases for the year 2030, this research paper draws upon a comprehensive review of relevant literature, including research papers and industry reports. By synthesizing the findings and insights from these sources, we aim to provide a comprehensive understanding of the forthcoming advancements that will shape the future of wireless communication technology.

II. SOFTWARE REQUIREMENTS FOR 6G NETWORKS

A. Cloud Native and the use of Management and Orchestration tools

Requirements for 6G networks revolve around the implementation of cloud-based infrastructure that emphasizes virtualization and the separation of software network functions (NFs) from inflexible hardware as discovered from the work of the 5G-PPP working group [4]. The objective is to transform NFs into flexible building blocks that can be combined to create customizable network services, bringing together Virtualized Network Functions (VNFs) and Physical Network Functions (PNFs) to construct sophisticated network solutions. To effectively manage and coordinate this infrastructure, the telecommunications industry relies on the NFV ETSI Management and Orchestration (MANO) framework [5] depicted in Fig. 1.

The deployment of cloud-based infrastructure for 5G and 6G networks necessitates addressing various challenges. One such challenge is the requirement for multi-domain orchestration to synchronize and supervise network services across

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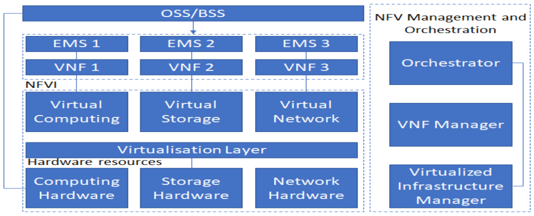

Fig. 1: ETSI NFV MANO Framework architecture [5]

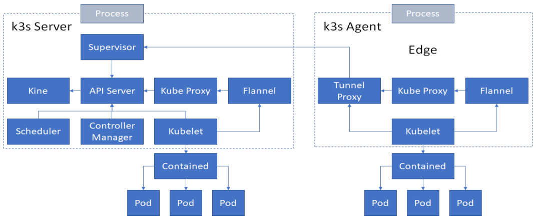

Fig. 2: Kubernetes k3s edge architecture [6]

different virtualized infrastructure managers (VIMs) or clouds. This capability enables the support of diverse use cases, such as situating the data plane in an edge cloud while the control plane resides in a public cloud. While OpenStack has been widely adopted for multi-cloud environments, Kubernetes is gaining popularity due to its ability to provide consistent orchestration across multiple clouds. Another challenge lies in managing virtualized network functions (VNFs) from multiple vendors in a unified manner. Although multi-vendor orchestration is feasible, most VNF managers (VNFM) are offered by the same companies that supply the VNFs, resulting in a dependency that limits the flexibility to mix and match components from different vendors. Furthermore, the challenge of building-to-order MANO involves integrating blocks from different suppliers at the implementation level, depending on specific use cases and orchestration systems.

The influence of hyperscale public cloud providers is a significant factor to consider. The support for containers in open-source communities like the Open Network Automation Platform (ONAP) and Open Source MANO (OSM) highlights the growing impact of these cloud providers on the telecommunications industry. Looking ahead, it seems like Kubernetes could become a fully capable VNF orchestrator. Kubernetes possesses features such as the Container Runtime Interface (CRI-O) and Custom Resource Definition (CRD) that make it a natural choice for orchestrating VNFs. Some experts believe that Kubernetes has the potential to become the default orchestrator for 5G networks, thereby driving the adoption of container network functions (CNFs) by network operators. Furthermore, Kubernetes' scalability enables its deployment at the network edge using lightweight versions like k3s [6], facilitating the deployment of 5G services reliant on multi-access Edge Computing (MEC) deployments as can be seen in Fig. 2.

Nevertheless, achieving a fully Cloud-Native Telco system still encounters certain barriers. Firstly, the novelty of Cloud-Native compared to other approaches and technologies presents a challenge. Established non-Cloud Native solutions have been available for a significant duration and offer shorter time-to-market, making them more appealing from a business perspective. Another obstacle is the lack of stringent standards in Cloud-Native technologies. While standards like ETSI GS NFV-IFA 013 [7] provide guidance for NFV architectures, Cloud-Native primarily relies on open-source software, which offers greater adaptability but fewer standardized practices. Efforts are being made to address this issue, such as the development of frameworks like service mesh and network service mesh, which provide features similar to Service Function Chaining and VNF Forwarding Graphs.

B. *Zero Touch Networks and the use of Machine Learning*

In today's highly complex and dynamic environments, manual management of networks is becoming increasingly challenging. In order to attain efficiency, and adaptability, there is an increasing demand to automate networks as a solution to this challenge. This has led to the development of zero touch networks (ZTNs), which leverage virtualized networks and software solutions instead of hardware-based ones. In contrast to partial automation, ZTN strives for complete automation of network operations, facilitating self-configuration, self-monitoring, self-healing, and self-optimization without requiring human intervention. ZTNs possess end-to-end network programmability and operate automatically through different application programming interfaces (APIs) [8]. They are particularly valuable in scenarios where network resources must be distributed to meet the specific needs of industries or individuals. With their components of data-driven decision-making and Machine Learning (ML), ZTNs have the potential to solve emerging problems in areas such as new business developments, vertical industry services, scaling, and enterprise solutions. They offer various autonomous services, heterogeneous infrastructures, and capabilities that unlock the full potential of current 5G and future 6G networks. This level of automation is crucial for analyzing and responding to customer-specific needs and ensuring the desired Quality of Experience (QoE) [9].

The significance of ML techniques in revolutionizing network management becomes evident in the extent of automation necessary for ZTNs to achieve self-adaptation and self-response within highly dynamic environments. Multiple Horizon 2020 research projects, such as SelfNet [10] and SliceNet [11], have been established to promote network automation. In 3GPP Release 17 a software-defined networking (SDN) approach has been introduced, through the network data analytics function (NWDAF), to facilitate network automation [12].

Zero-touch network and service management (ZSM) is an essential framework for network orchestration, utilizing ML and data analytics for end-to-end management. ZSM replaces tightly coupled management systems with flexible services and defines architectural blocks, as shown in Fig. 3 [13].

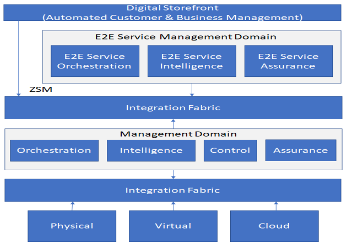

Fig. 3: Zero-touch network and service management architecture [14]

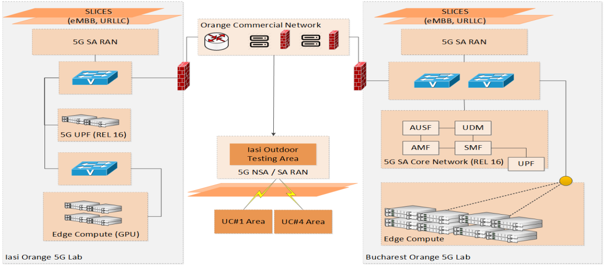

Fig. 4: Orange Testbed for future networks

C. Network Programability

With the emergence of B5G/6G networks, there will be a substantial increase in the number of connected devices. This development is anticipated to drive the complete digitalization of the physical world, leading to a substantial increase in data that requires processing. To address this, new technology enablers have been or will be introduced in three main areas:

- at the service provisioning level, the exposure of APIs from the network core and edge opens up new opportunities for third parties to interact with the network.
- at the network and resource management level, disruptive changes are taking place across various domains of service provisioning. Crucial factors driving these changes include the adoption of cloud-native methodologies by mobile network operators (MNOs) and the initiatives of the Open RAN alliance, aimed at achieving vendor-agnostic control of radio access components.
- at the network deployment level, the establishment of private networks is already clearly defined, and innovative concepts like the cell-free paradigm and the implementation of a connectivity mesh topology for end devices are anticipated to facilitate the realization of a remarkably adaptable access network. Consequently, novel architectural and service concepts are emerging, envisioning multi-connectivity arrangements and the integration of edge computing.

In order to realize these advancements, there is a need for the evolution and development of service abstractions, programmability features, as well as improved capabilities for application-to-network interaction and negotiation. Standardization organizations like 3GPP have already established native APIs and interfaces, such as the service-based architecture (SBA) and the Network Exposure Function (NEF), which enable indirect connections and interactions with network functions. To facilitate these interactions, various frameworks have been created to securely consume native APIs and access network nodes. These frameworks can leverage programming languages like the protocol-independent packet processor (P4) for data plane programming and utilize common data models like OPC UA information models, which cater to specific vertical industries. [15].

From a business standpoint, these programmability frameworks generate fresh prospects for the advancement of network applications. Network applications refer to external applications that engage with the network via standardized APIs, offering services tailored to the network or specific industries. These applications contribute to improving network operation and management or supporting specialized vertical applications. They establish communication with network functions and nodes using open and standardized interfaces across various planes (user, control, management) and domains (core, radio, transport).

Radio transmission advancements like terahertz frequencies, beamforming and massive MIMO technologies, that improve signal precision, coverage, and capacity, are also envisioned for future 6G networks, but will not be addressed in this paper because they are not in the scope of the presented research projects.

III. 6G EMULATION IN EXISTING 5G SA TESTBEDS

Orange Romania, with its participation in selected Horizon Europe projects related to 6G, referring mainly to TrialsNet [16] and ADROIT6G [17] for this paper, hopes to develop its infrastructure based on the novelties that are discovered during the research projects, pilot PoCs for emerging technologies and services that take advantage of the 5G, B5G and 6G networks and also create new professional services, based on the use cases that were investigated in the projects.

The Orange 5G Labs, from both Bucharest and Iasi, are the main places where Orange Romania will develop and test the features for the future B5G and 6G networks. The Bucharest 5G Lab is located inside the CAMPUS Research Center of the Polytechnic University from Bucharest (UPB) and currently implements a full 5G SA infrastructure, comprising 5G RAN, Core, Edge Computing and advanced SDN Network in the Datacenter. The Iasi 5G Lab is located inside the Iasi Technical University (TUIASI) and currently hosts only 5G SA RAN components. In the next months it will be prepared so that it will have similar edge-computing capabilities as the Bucharest laboratory. The testbed, represented in Fig. 4 and explained in the following subsections, is currently capable to provide multi-slices implementations, with QoS/QoE guarantee in the concurrent services implementation, as eMBB (1500Mbps DL/150MBps UL) or URLLC (E2E one way delay <4 ms), based in 3GPP NSSAI parameters.

*1) **5G SA RAN Implementation**:* For the deployment of the 5G SA gNodeBs (gNBs), Orange selected the radio N78 band (100MHz). Both the Bucharest and Iasi sites consist of

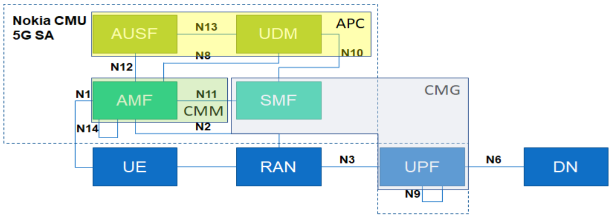

Fig. 5: Nokia 5G SA CN Service Based Architecture

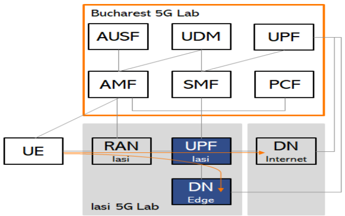

Fig. 6: ETSI MEC Architecture in Iasi

indoor NR cells, the Bucharest 5G Lab also having a cell placed in a semi-anechoic chamber for advanced experiments in a controlled environment.

*2) **5G SA Core Network Implementation**:* The Orange's future networks testbed currently employs the 5G SA Compact Mobility Unit (CMU) Core Network (CN) solution from Nokia, which operates on a virtualized infrastructure within the Orange Datacenter, on two high-performance servers for redundancy and load-balancing. The CN integrates three primary components: the Cloud Mobile Gateway (CMG), the Cloud Mobility Manager (CMM), and the Authentication and Policy Control (APC). These components implement the Network Functions (NFs) defined by the 3GPP for 5G SA, as depicted in Fig. 5.

*3) **Virtualized Infrastructure platform design**:* The testbed infrastructure is composed of various network and compute equipment, including open tools and technology ready to accommodate applications and services, using the following virtualization environment software tools: an Openstack Ussuri distributed cluster based on containers, an ESXi VMWare [18] cluster and a Kubernetes Container cluster.

*4) **Network and management functions**:* In Orange's testbed, OSMv12 [19] is the orchestrator of choice, being compliant with ETSI MANO architecture, integrating with our infrastructure controllers and being able to build different VNFs and Network Slices across all the platforms inside the lab. It can connect and communicate with VIMs for virtualized and containerized applications onboarding and will act as an umbrella configuration and management tool for different slices networking deployments. The automation backbone for provisioning and configuring applications is built using Ansible and Terraform, which are essential tools launched by CI/CD managers.

In the scope of the TrialsNet project, in order to improve the E2E system latency for the piloted Iasi use cases, the 5G network architecture will be further developed in a Distributed Cloud/MEC type of approach, close to what 6G proposes, with the deployment of a virtualized UPF in the Iasi 5G Lab Datacenter. This UPF will be integrated in the 5G SA CN from Bucharest (Control Plane), will be connected to the Iasi gNBs and the local edge-compute facility and will have direct access to several DNNs (including Internet), implementing the ETSI standard 5G SA MEC architecture [20], as it's shown in Fig. 6. External exposure to network features will be also approached during this project, by engaging with third-party applications developers and giving them access to the testbed APIs for resource management and performance monitoring.

The ADROIT6G project will take advantage of an advanced key component of the testbed, the Next-Generation SDN Data Centre that integrates the IPFABRIC concept, which is open to be orchestrated, dynamically configured and zero touch managed within the E2E network slicing and automated service deployment. Within this project network programaibility could be also addressed through the implementation of new P4 compliant equipment in the testbed.

IV. 6G USE CASES IN RESEARCH PROJECTS

*1) **TrialsNet use cases**:* The TrialsNet project aims to bring about positive changes in society by implementing advanced 5G and beyond applications. These applications will push the limits of current 5G networks and serve as examples for the transition to the next generation of mobile networks. TrialsNet will connect the digital world with the physical and natural realms through large-scale trials in three domains: Infrastructure, Transportation, Security & Safety; eHealth & Emergency; and Culture, Tourism & Entertainment. Within this project, there will be a total of 13 specific use cases covering the aforementioned domains. These use cases are being developed in four different countries and have already been described in the initial project deliverables [21]. In Romania, specifically in Iasi, Orange, in collaboration with the Technical University of Iasi, will host two of these use cases. One focuses on Smart Crowd Monitoring (UC#1), while the other involves the development of a Smart Traffic Management solution (UC#4).

The first use-case will take place in both Spain and Romania, albeit in different forms. In Romania, the trial will leverage 6G applications to enable Situation Awareness for key end-users in the city of Iași. It aims to integrate various data streams from sensors and cameras deployed throughout the city, utilizing reliable 5G and WiFi networks. The trial will provide real-time data-driven insights and actionable intelligence related to Public Safety Monitoring. Specifically, it will focus on the City Center area of Iași, particularly the Stefan cel Mare si Sfant Boulevard, and concentrate on public safety and crowd monitoring. This will involve the use of EDGE sensors, cellular mobility data, cameras, and computer vision capabilities to detect and notify incidents and threats that affect crowd safety, such as unauthorized vehicles entering restricted areas.

The second use-case involves designing, developing, and deploying tools that validate the concept of intelligent traffic management in large-scale environments. It aims to facilitate seamless interaction between humans and their surroundings by utilizing IoT sensors, computer vision, LiDAR Enhanced Vision, on-demand intelligent and autonomous drone surveillance, and cameras. The trial will take place in the Podu Roș Intersection Area, with a specific focus on traffic comfort and safety functions. It will monitor traffic flow to create predictive models and propose adaptive intersection rules to reduce congestion and enhance safety, particularly for vulnerable road users (VRUs). Additionally, the trial will collect data from IoT sensors to create a real-time dynamic mobility digital model and an air quality heat-map for environmental monitoring.

*2) **ADROIT6G use cases:*** The ADROIT6G project aims to showcase early-stage applications for the future 6G network using a novel cognitive approach based on distributed artificial intelligence. The project focuses on enhancing performance and control in digital service interactions and supporting innovative applications. This will be accomplished through the implementation of three use cases: Immersive eXtended Reality (XR), Industrial IoT (IIoT), and Collaborative robots (cobots) in construction. The Romanian cluster will be involved in the piloting of the last two use cases.

The first use-case implemented in Romania will focus on Industrial Internet-of-Things (IIoT) applications, utilizing both terrestrial 6G and Non-Terrestrial Networks (NTN) satellite technologies. IIoT heavily relies on reliable communication, which is typically available in urban areas or locations well-served by mobile and fixed communication networks. However, there are regions where terrestrial communication is limited or unavailable. In such cases, satellite-based communication can extend existing services and enable new global IIoT services with worldwide coverage, even in areas with sparse or no terrestrial communication. Proof of Concept 2a will simulate a scenario where multiple robots collaborate in an automotive manufacturing production line, requiring real-time supply chain optimization through extensive IIoT sensing and predictive analytics involving a large number of sensors and actuators. Proof of Concept 2b will validate the use of ADROIT6G in leveraging satellite-based communication to enhance terrestrial 6G networks in areas with weak or absent infrastructure. This will involve a hybrid system comprising an emulated satellite network and real end devices, creating a ”mixed reality” environment.

The second use-case simulates a construction scenario with multiple robots and drones. This scenario involves coordinating the actions of robots and drones at a construction site. Different types of autonomous robots and drones must synchronize and coordinate their movements, including tasks such as lifting, unloading, and loading construction materials between robot cranes, mobile robots, and drones. The coordination takes place in three dimensions to avoid collisions and enable collaboration among aerial robots like drones. In addition to coordination, real-time exchange of process data is necessary among the entities involved, requiring extreme synchronization, including clock synchronization. The system must meet requirements for reliability, functional safety, latency, and positioning, even when trajectories are blocked or need to be altered. Communication among robots and drones at the construction site relies on Device-to-Device (D2D) communication provided by 6G. This use-case aims to pave the way for smart construction sites that improve building efficiency and enhance worker safety.

V. KPIS AND CHALLENGES IN DEVELOPING 6G NETWORKS

*1) **TrialsNet:*** In order to work towards the project’s vision, TrialsNet will focus on specific technical objectives that will have a significant impact on the current 5G ecosystem. This will effectively pave the way for the upcoming B5G technology wave, which is expected to occur during the project’s duration. By doing so, TrialsNet will establish important requirements for the next generation of mobile networks, fostering a productive exchange among various stakeholders in the 5G ecosystem. Service providers will be able to leverage the widespread adoption of 5G technology to innovate and develop truly advanced 6G applications, ultimately enhancing people’s interactions with the urban environment in multiple ways. The large-scale trials conducted by TrialsNet will involve the implementation of various use cases utilizing both commercial and pre-commercial applications and devices. These use cases will be open to the public and aim to involve a minimum of 200 users or cover an average area of 2 square kilometers. The coverage will extend indoors to specific locations like museums, hospitals, and airports. To support these demanding use cases, TrialsNet will enforce several Key Performance Indicators (KPIs) provided by subsequent releases of standardized 3GPP technology. Table I provides a preliminary outline of the network KPIs that TrialsNet aims to achieve during the project. It is important to note that the final requirements will be defined throughout the project activities, and they will depend on the thorough Systems Analysis and Design of the different use cases.

*2) **ADROIT6G:*** ADROIT6G will validate its technological solution through three use cases that cover extreme scenarios, showcasing the capabilities of various service classes at extreme levels. These use cases include extreme eMBB for immersive XR (eXtended Reality), extreme URLLC for collaborative robots, and extreme mMTC for Industrial IIoT. The use cases will also demonstrate how NTN can interwork with terrestrial 6G networks, showcasing the seamless integration of these technologies. Table II presents a comprehensive overview of well-defined network-level Key Performance Indicators (KPIs) for 6G. It includes both the baseline values and the target values to be validated in the use cases. Since 6G is still in its early stages of development and largely undefined, the target 6G KPIs have been derived from previous experimental test trials conducted by 5G-PPP ICT-52-2020 projects, as well as from various 6G-related white papers [22], technical journals [23], the NetWorldEurope SRIA (Strategic Research and Innovation Agenda), and the expertise and experiences of consortium members involved in flagship 6G projects like the Finnish 6G Flagship and Hexa-X

TABLE I: TrialsNet initial network KPIs.

KPI	Target	Notes
Downlink throughput per user	200-500 Mbps	Achieved by the devices envisioned in the project
Uplink throughput per user	20-100 Mbps	
Downlink cell capacity	1.5 Gbps	
Uplink cell capacity	150 Mbps	
Application level latency	$\leq 100ms$	
Reliability	99%	In the targeted scenarios
Coverage	99%	
Service availability	99%	
Location accuracy	$\leq 5meters$	

TABLE II: ADROIT6G initial network KPIs.

Service class focus	All service classes	Extreme eMBB	Extreme mMTC + NTN	Extreme URLLC + Extreme mMTC
Network-level KPIs	5G KPIs	6G KPIs		
Peak throughput (Gbps)	≤ 20	≥ 1000	Not critical	Not critical
Experienced upload throughput (Gbps)	≤ 0.1	≥ 1000	Not critical	Not critical
Experienced download throughput (Gbps)	≤ 0.2	≥ 1000	Not critical	Not critical
Maximum bandwidth (GHz)	≤ 1	≤ 100	Not critical	Not critical
Application latency (ms)	≤ 10	≤ 1	Not critical	≤ 0.1
Jitter (us)	N/A	≤ 100	≤ 100	≤ 1
Energy efficiency (Tb/J)	N/A	nominal	high	nominal
Device density (devices/m2)	≤ 1	Not critical	≤ 10	≤ 10
Reliability (packet error rate)	$10^{-}5$	$10^{-}7$	$10^{-}6$	$10^{-}9$
Positioning accuracy (cm)	$\leq 50in2D$	Not critical	≤ 100	$\leq 1in3D$

VI. CONCLUSION

In conclusion, the development of the 6G network, as highlighted in the context above, holds immense potential to revolutionize communication and connectivity. Projects like ADROIT6G and TrialsNet are pushing the boundaries of technology, aiming to validate and showcase the capabilities of 6G through innovative use cases and technological solutions.

These initiatives recognize the need for advancements beyond 5G and emphasize the importance of addressing extreme use cases across different service classes. By targeting these extreme levels of performance, they are paving the way for a future network that can support diverse applications and services with unprecedented reliability, low latency, and massive connectivity. While the concept of 6G is still in its early stages, the development and validation of well-defined network-level KPIs through extensive research, experimentation, and collaboration are critical.

Overall, the ongoing efforts in the development of the 6G network highlight the collective ambition to transform our digital landscape and enable new possibilities for communication, connectivity, and interaction. As these projects progress, they contribute to the journey towards realizing the full potential of 6G, driving innovation and shaping a future where connectivity is more seamless, reliable, and transformative than ever before.

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