DEDICAT 6G - Dynamic Coverage Extension and Distributed Intelligence for Human Centric Applications with Assured Security, Privacy and Trust: from 5G to 6G

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***Abstract*—5G networks offer unparalleled data rates and features. However these are still far from what a hyperconnected society and industry needs. Future wireless connectivity Beyond 5G (B5G)/6G will require a smart and green platform that is ultra-fast, highly adaptive, and dependable to support innovative, human-centric applications securely. This is the focus of the EU-funded DEDICAT 6G project, the vision and methodology of which is presented in this paper. DEDICAT 6G investigates enablers for dynamic distribution of intelligence to improve task execution time, energy efficiency, and ultimately, reduce end-to-end latency. The project also examines solutions for dynamic coverage extensions utilizing robots, connected vehicles and drones. The scope also comprises methods for security, privacy, and trust assurance including enablers for novel interaction between humans and digital systems exploiting innovative interfaces and devices, like smart glasses. DEDICAT 6G focuses on four representative 6G use cases: Smart Warehousing, Enhanced Experience, Public Safety and Smart Highway. The developed solutions will be demonstrated and tested in these use cases through experiments in laboratory environments, and larger field evaluations utilizing diverse assets and testing facilities. The aim is to derive results that will showcase substantial improvements in terms of intelligent network load balancing and resource allocation, extended coverage, enhanced security, privacy and trust and human-machine applications.**

***Index Terms*—Smart connectivity; Coverage extension; Distributed Intelligence; Trust; Human centric applications**

I. Introduction

The sixth generation of mobile communication networks (6G) expands the scope of wireless communication networks to native artificial intelligence (AI) and a blockchain empowered smart connect-compute platform that is highly adaptive, ultra-fast, and dependable for supporting human-centric applications securely . This will enable 6G networks to combine the existing communication infrastructure with novel distribution of intelligence (data, processing, and storage) at the edge to allow not only flexible, but also energy efficient realisation of the envisaged real-time experience. The 6G network architecture will be based on efficient mechanisms fulfilling a larger panel of quality of service (QoS) requirements, dynamic connectivity for a versatile and adaptable network and elastic behaviors by opportunistically exploiting novel terminals and mobile client nodes (e.g., smart connected cars, robots and drones) as Mobile Access Points (MAPs). At the horizon of 2030, the evolution of today's 5G services incorporating natively new technologies to satisfy future needs will create the momentum for a radical new class of services that will bring the network performance beyond today's Shannon's theory [1] [2]. Vertical applications and related use cases will be more and more reliant on intelligent components, in accordance with the AI paradigm. New classes of semantic and goal-oriented services will appear [3] [1]. Connect-compute networking will provide extreme new performance at scale, providing the connection of billions of devices to supporting augmented and virtual reality (AR and VR). Dependability and connectivity resilience will require new stringent requirements not only on latency but also on its jitter in order to ensure deterministic service provision [4]. The new beyond fifth generation (B5G) framework will also need to include trustworthiness by design. As a consequence new challenging performance will be imposed to B5G networks to meet the requirements of the services and use cases [4]. The DEDICAT 6G project has identified the following four challenges for operational, sustainable and efficient inclusion of new technologies for achieving and maintaining dynamic connectivity and intelligent placement of computation in the mobile network.

Challenge 1 : *Dynamic and migratable distribution of intelligence and computation.* With the advent of XaaS (Everything as a Service), the performance of cloud-native applications will become increasingly critical. They have a wide range of requirements, including imperceptible latency, energy efficiency, optimized resource consumption in terms of computation/processing, communication, and/or storage. To achieve this aim, a key mechanism will be the dynamic distribution of intelligence between the devices, edge, and core or cloud, taking into account the vast heterogeneity of technologies used. In addition, the interplay with predictive caching expands the capabilities for reducing the end-to-end latency and the load of recurrent computation requests [5] [6].

Challenge 2 : *Dynamic coverage and connectivity extension.* It is important to ensure that equal opportunity is offered to citizens and businesses regardless of location with a dynamic and efficient expansion of the infrastructure. This flexible infrastructure will exploit access nodes delivering B5G/6G features, dynamically deployable, (e.g., car, robot or automated-guided-vehicle, and drone mounted base stations), which can deliver the required service at the needed area (e.g., as transitory network extensions during disasters and short-term events).

Challenge 3: *Trustworthiness.* Cyber security threats are never-ending even for traditional networks. The openness and pervasiveness of the Internet of Things (IoT) and human-centric applications introduce additional vulnerabilities that make security even more challenging. In this context, key issues include secure and trusted exchange of information and orchestration of decision-making logic among different, collaborating edge devices, cloud and fog computing components, network devices and infrastructure elements. Establishing ad-hoc communication and computation between available resources, systems, and stakeholders requires novel approaches for security, data protection, system integrity, and trust.

Challenge 4: *Human in the loop.* The combination of digitalization, AI, and ubiquitous communication is drastically increasing the intensity of human-machine interactions [7]. In addition to trustworthiness, smart networks and services need to ensure openness, reliability, and fast enough reactions to changes in the environment. Smooth communication between people and machines requires new ways of interaction based on new terminal types embedded in the daily environment.

DEDICAT 6G is motivated by the aforementioned challenges and trends, and aims to realise the vision of a smart connectivity platform based on the following main pillars: (i) Enablers for the dynamic distribution of intelligence, in conjunction with predictive caching; (ii) Enablers for the dynamic coverage and connectivity extension through the utilisation of diverse types of devices (e.g., drones, robots, connected cars, other mobile assets like fork-lifts in a warehouse, etc.); (iii) Security, privacy. and trust assurance especially for mobile edge services; (iv) Infrastructure enablers for supporting novel interactions between humans and digital systems.

The paper is organized as follows. Section II presents the envisioned system architecture. Section III analyses the use cases and Section IV gives an overview of the planned pilot activities. Section V concludes the paper.

II. System Architecture and New 6G Infrastructure Enablers

Fig. 1 provides a high-level view of the project concept while Fig. 2 depicts an overview of the DEDICAT 6G baseline functional architecture. The functional entity ”Goals, objectives, and policies” includes information on application, service and network goals and objectives to be achieved, as well as potential policies. The functional entity ”Capabilities of network elements, Mobile Access Points (MAPs) and edge devices” includes information on the capabilities of these entities in terms of communication networking (e.g., radio access technologies (RATs) and spectrum, capacity and coverage), physical movement, type of the MAP, computation capabilities, storage capabilities and available power. The functional entity ”Context and situation awareness” provides information and knowledge on the context that has to be handled in terms of computation tasks, power consumption requirements, a set of mobile nodes that need coverage, mobility and traffic profiles of the different nodes, radio quality experienced by client nodes, options for connecting to wide area networks, the locations of docking and charging stations for drone and robot MAPs and the current locations of the terminals, client node and MAPs elements. These three functional entities

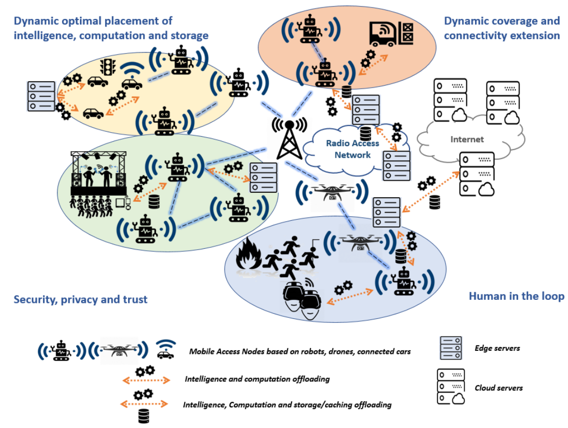

Fig. 1: DEDICAT 6G concept overview.

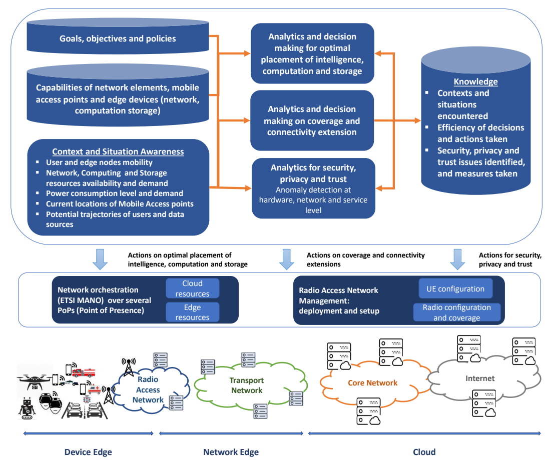

Fig. 2: DEDICAT 6G baseline functional architecture.

provide input to the key enablers of DEDICAT 6G described in more detail hereafter. The outcomes of the DEDICAT 6G key enablers are recorded by the Knowledge functional entity along with corresponding contexts and situations encountered (triggering those decisions), policies that were considered, the efficiency of the decisions and actions taken in terms of achieved power consumption, latency, QoS, cost, etc. Additional information stored by the Knowledge entity is related to security, privacy and trust issues identified and respective measures taken. Knowledge can be developed autonomously (e.g., by each MAP or edge node) and in a centralised, aggregated manner (in the “global” cloud). Knowledge can then also be exploited by the different key enablers providing insights on actions that have proven valuable in the past and thus speeding up the decision-making process. Actions on (i) optimal placement of intelligence, computation/processing and storage, (ii) coverage and connectivity extension and (iii) security, privacy and trust are then enforced on the Cloud and Edge resources and the Radio Access Network by utilising existing radio access network management and orchestration tools (e.g. ETSI OSM MANO).

A. Mechanisms for dynamic distribution of intelligence

In recent digital transformation process, proper positioning of computation and content with respect to the mobile users has been one major research topic in both academia and industry. Communication resources are further allocated to support the data traffic needs. These resources can be virtualized via sophisticated functions and the controlling of the resources can be separated from the data plane via softwarization approaches [8] so that the location of network control can also be adapted. Cloud computing has become a standard way to support digital services that are not appealing to be performed at user devices with limited performance and operation lifetimes [9]. On the other hand, edge computing (also cloudlet, fog computing) has recently emerged as one potential direction in solving some fundamental problems of cloud computing, essentially treating the communication challenges arising from high communication delay and network congestion due to long distance and bandwidth-intensive cloud applications [10]. The third emerging approach to boost intelligent computing is edge caching which aims to bring frequently requested digital service content to storage nodes closer to the users [11]. In parallel to networking concepts to distribute computing, in computer science, a number of scheduling methods have appeared balancing the workload of processor nodes [12]. In all cases, maintaining resource efficiency is imperative [13]. The proper distribution of computation and storage resources is also related to the deployment of AI functions as micro-services that can be deployed as re-usable components for executing specific tasks across various applications [14], [15]. Mechanisms that dynamically determine, based on the available resources across federated platforms and user mobility, which intelligence functions should be executed where, are an important technical challenge. Despite of recent developments on new edge computing approaches, there is still urgent need to find further improvements to fulfil the emerging service requirements of B5G/6G networks. In essence, user devices are executing more power-hungry, delay-sensitive, and immersive applications. Communication needs are more polarized in highly crowded areas and low-density, but hard-to-reach areas, resources become more limited and efficiency in all dimensions is vital, whereas service needs are more heterogeneous and time-varying.

While in the past the location and offloading of computation and content has been of central interest to be optimized, the timing and dynamic distribution mechanisms are gaining more importance to address the user mobility and changes in local computation and storage needs. Moreover, workload balancing within multicore processors has been mostly done in isolation with management of mobile edge networks which hinders global optimization processes. In light of aforementioned prevailing challenges and promising outlooks, DEDICAT 6G develops new mechanisms to dynamically co-distribute data, computation (i.e., data processing and analytics) and storage, based on network status information of both communication and computing loads. The dynamicity can come from different sources, namely share of elastic and inelastic on-demand services, user mobility, mobility of data sources, network resource consumption, and computing resource consumption to meet the requirements of real-time and ultra-low-delay sensitive innovative IoT applications. Since many of the required decision-making tasks are coupled, the effective distribution mechanisms must be able to jointly use the underlying reactive and proactive approaches for multicasting, computation offloading, and edge caching methods.

B. Mechanisms for dynamic coverage extension

First studies on the topic of coverage extension, using robots or drones, were targeted to the provision of adaptive sensor functionality in a dynamic environment. They take into account the dynamic coverage problem [16] or cooperative multiple mobile robot systems which have sensing, computation and communications capabilities [17]. The concept of moving base stations has been used, primarily in military, and also in civilian communications. The main objective was to reduce the number of base stations with improved network performance in a highly dynamic environment [18]. Operator governed opportunistic networks were addressed in [19]; temporary and local extensions of the infrastructure, are created at places and for the time they are needed to resolve cases of poor coverage or low capacity. The position optimization of MAPs was studied in [20] based on the pheromone feature of the ant colony optimization with the same objective. Drones or unmanned aerial vehicles (UAVs) will also be an important component of B5G cellular architectures that can potentially facilitate wireless broadcast or point-to-multi-point transmissions. The work in [21] investigates the feasibility of multi-tier drone network architecture over traditional single-tier drone networks and identifies scenarios in which drone networks can potentially complement traditional RF-based terrestrial networks.

DEDICAT 6G will build on the existing work to develop its dynamic coverage extension mechanisms that will rely on innovative devices (e.g., drones, robots, connected cars, other mobile assets like forklifts in a warehouse, etc.) to offer the most satisfactory QoS to users through MAPs-based opportunistic radio network. MAPs will be exploited for covering areas that cannot be easily reached (e.g., hard geo-morphology: cave forest, facilities) where infrastructure or additional capacity is required only for a finite, short time (e.g., moving hotspots: festivals) and where regular network infrastructure has been damaged (e.g., after an emergency: earthquake, fire terrorist attack). It includes addressing mobility aspects of client nodes to a greater extend and machine learning mechanisms for knowledge building to support the optimal configuration of the dynamic coverage extension through MAPs, application specific optimization of deployment, mobility, and operation of MAPs in a converged broadband wireless networking scenario and integration of MAPs computation and communication resources along with other resources.

C. Mechanisms for security, privacy, and trust

Security and trust aspects of IoT systems applied across different industrial domain are extensively researched. Special focus is put on application of AI techniques on improving security and data protection by employing predictive solutions capable of identifying threats and risks in a proactive way [22], [23]. DEDICAT 6G will leverage on results and best practices identified within various initiatives and H2020 projects such as SECURE IoT (general IoT security and data protection practices [24]), CREATE-IoT (security and data protection challenges in large scale pilots and cross-system interoperability [25]), CHARIOT (general IoT security and data protection practices [26]) and ICONET (application of blockchain for trust management [27]) projects. The DEDICAT 6G AI powered security management framework will provide mechanisms for realizing threat detection, classification, and risk mitigation in the context of highly dynamic and distributed communication and computation networks. In the scope of trust management, DEDICAT 6G will employ fast prototyping and validation of different blockchain and smart contract configurations to facilitate trust procedures. By validating these blockchain prototypes in real pilot deployments, the project will produce a set of best practices and templates (Hyperledger Fabric configurations, smart contract templates and chaincode configurations) to be used in 6G dynamic ad-hoc networks.

D. Human centric applications

Human centric applications have special requirements since they have a human in the loop [28], [29]. Haptic interfaces will complement the conventional audio-visual interfaces. In the most demanding applications, the sensations of sight and touch must have an end-to-end delay of 1 ms to avoid cybersickness. The requirements also include the delay variation. The Third Generation Partnership Project (3GPP) has specified the performance requirements for 5G systems [30].As part of the overall objective of the DEDICAT 6G project the solutions that will be developed contribute to improving the task execution time and energy efficiency of host edge devices and ultimately reducing the end-to-end latency for human-centric applications. DEDICAT 6G develops human-centric applications in the scope of the project use cases and showcases innovative interfaces and devices such as AR/VR equipment and smart glasses.

III. Analysis on Scenarios and Use Cases

DEDICAT 6G has identified four use cases (UCs) to investigate, engineer and prove the target performance enhances for 6G: (i) Smart Warehousing with strong emphasis on real-time human machine interaction, computation offloading, and security; (ii) Enhanced Experience, with emphasis on distributed intelligence, computation and caching offloading, and dynamic coverage extension; (iii) Public Safety (Public Protection and Disaster Relief, PPDR) with emphasis on distributed intelligence, dynamic coverage extension, security, and human in the loop; and (iv) Smart Highway with emphasis on distributed intelligence, computation and caching offloading, dynamic coverage extension, safety, and human in the loop.

A. Smart Warehousing

Upgrading or improving the digitization of relevant industry processes and embracing Information and Communication Technologies to increase productivity and efficiency is a key societal challenge and an economic target. This use case intends to demonstrate the feasibility and value of applying the distributed intelligence and computation offloading concepts in a Smart Warehousing context. The goal is to apply DEDICAT 6G technological concepts (B5G/6G connectivity, enhanced through coverage extension, jointly with the computation offloading) for: (i) AI based optimization of warehousing operations to increase performance and improved efficiency; (ii) assisting training and maintenance through application of 3D augmented reality; (iii) promoting human-robot interaction with 3D video-driven solutions; (iv) enhancing safety of personnel and goods; (v) remote inspection and diagnostics; (vi) identification and tracking of goods throughout value chains.

This will be achieved through an integrated state-of-the-art operational system based on automated guided vehicles (AGVs), drones and IoT systems with edge computation capabilities supporting configuration of high performance AI solutions and deployment of DEDICAT 6G enablers for distributed computing and opportunistic networking.

B. Enhanced Experience

The COVID-19 pandemic with its virtual meetings and conferences, lock-downs, and event cancellations has shown that real physical presence at public events is not always obvious. The event organizers, service providers, technology enablers, and application developers for music concerts, festivals, and sports events are forced to exploit the latest mobile networking technology to adapt against the tightened quality requirements by the paid users regardless of their location. The goal in the Enhanced Experience use case is to develop and showcase enhanced B5G technology that can be exploited both locally in public events as well as remotely defined as virtual participation. In such cases, live video streaming plays the essential part in the storyline. In the event area, there is a need for smart video applications and equipment, such as smart glasses, taking advantage of the latest streaming technology in ultra-fast B5G mobile networking with extremely low latency. In addition, dynamic edge processing and computation offloading with novel network algorithms enriched with intelligent exploitation of unicast-multicast streaming techniques can enhance the experience also for remote participants in terms of the selected Key Performance Indicators (KPIs), such as quality, latency, or consumed energy.

C. Public Safety

Communication capabilities are the cornerstone of Public Protection and Disaster Relief (PPDR) organizations procedures to coordinate First Responders in the field and with Command Centers, relying more than 30 years on Private Mobile Radio (PMR) legacy technologies, such as TETRA and TETRAPOL currently in use as they offer reliable voice communication. Facing more complex urban infrastructure and the necessity to maintain a non-urban presence for fast rescue, First Responders need to get more relevant information shared, starting from alert, during response management and until end of response: they need real-time situational awareness information which cannot be provided with such legacy systems. Mission Critical Services, standardized by the 3GPP, starting since the release 13 and continuously improved, leverage networks architecture and applications for real-time multimedia communication to facilitate voice communication and data with First Responders. Mission Critical services are enhanced with cloud based architecture and new features in order to make the multimedia communication more reliable and introduce the use of drone to get video from the disaster and reduce the injury of First Responders during the reconnaissance phase. DEDICAT 6G will support the transformation of First Responders towards digitalization by providing the Common Operational Picture and tools to plan and conduct public safety missions. DEDICAT 6G aims to demonstrate through a Public Safety use case the achievement in delivering reliable and efficient connectivity everywhere and anytime to drive digital transformation plan for Augmented First Responders. It will be demonstrated through two contexts: natural in non-urban and man-made in urban disasters. To achieve this goal, the project will achieve the integration of state-of-the-art operational systems: Mission-critical communications systems for (i) incident management structure, (ii) group management, (iii) automatic vehicle location (AVL), (iv) mapping Geographic Information System (GIS) engine, (v) integrated messaging, voice and video calls and (vi) real-time tactical situation sharing. Mission-critical communications systems will be implemented and integrated to benefit from DEDICAT 6G with distributed intelligence, dynamic coverage extension, security, and human in the loop.

D. Smart Highway

Connected and autonomous mobility is a use case that requires connectivity offering the smallest possible delay and ultra-reliability (i.e., nearly no packet loss), with more flexibility. Most importantly, when it comes to interactions with vulnerable road users (VRUs), "situation awareness" needs to be gained within milliseconds to be able to react to safety related threats or dangerous situations. To showcase the DEDICAT 6G concept, where decision making and context analysis mechanisms are pushed as far as possible into the radio network to further decrease delays and increase reliability, an example is considered, according to which a connected autonomous car exits the highway and meets an intersection at an urban area. At the intersection, cars can encounter VRUs such as cyclists and pedestrians. Through the connected environment, both the car driver and the cyclist can get alert warnings so that both can pass through the intersection safely. The required warning should be disseminated without delay in order to support scaling up to level 4 driving automation (latency within a few milliseconds and near 0 packet loss). While 5G ultra-reliable low-latency communications (URLLC) will support very low latency, edge processing to gain situation awareness and recognise events rapidly, and to exchange this knowledge between the different vehicles will be developed and deployed in this use case. In order to boost the speed of dissemination of alert warning notifications, the actors in this use case are assisted by a Road Side Unit (RSU) with edge capabilities for communication and high performance computing, e.g. for processing the status of the environment such as the location of the cars and bicycles. Additionally, in order to meet the safety requirements, the computational load will also be dynamically distributed within the edge devices based on the real time requirements and key performance indicators (KPIs). This will also be supported by having cars as both edge nodes and mobile access points to provide coverage extension.

IV. Pilots for 6G use cases

The four vertical pilots for the use cases described will demonstrate the four pillars of the project vision for a smart and flexible connectivity platform, facilitating the integration of the developed technology and innovative interfaces (smart glasses, connected cars and robots) and running-up the demonstration of human-centric applications during the project. The pilots will define a set of measurable key performance indicators (KPIs) and metrics that will permit the testing of the integrated platform, both in terms of technical

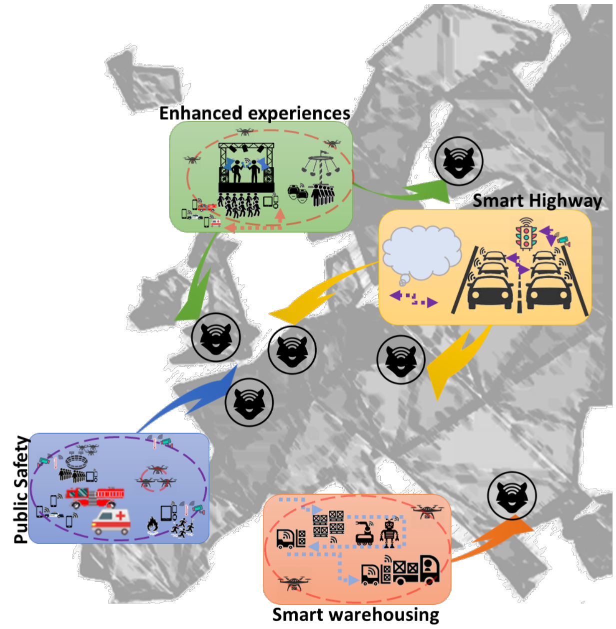

Fig. 3: DEDICAT 6G Use cases and Pilots Locations.

performance but also from the perspective of stakeholders' acceptance and non-technical validation (usability, relevance and other pertinent features of the developed solutions in each pilot). The Smart Warehousing pilot will take place in Diakinisis, Greece, led by Fondacia Vizlore Labs. It aims to demonstrate improved latency, reduced energy consumption and improved quality of experience that will play a key role in the demonstration of DEDICAT 6G technology. The Enhanced Experience pilot will take place in Surrey, UK and Public events in Oulu, Finland, led by Teknologian tutkimuskeskus VTT Oy. It will be on demonstrating the throughput to individual users, service availability (interrupts) and reliability (packet losses) and end-to-end latency. The Public Safety pilot will take place in Elancourt, France, led by Airbus DS SLC, and will concentrate its technical validation on improved latency, improved availability, reliability and response time, whereas the Smart Highway pilot [31] will take place in E313 highway, Antwerp, Belgium and B101, Ore Mountains, Germany, led by Interuniversitair Micro-Electronica Centrum. The last pilot will pay attention to the end-to-end latency, reliability (packet delivery rate), throughput and processing time. The use cases leaders will facilitate the integration and run-up of the demonstration of the technologies developed during the project. In the 4 cases, feedback contribution from the participation of relevant stakeholders, not only within the scientific but also in the relevant business fields, will play a key role in the validation of the technology and business cases, smoothing the market uptake after the project end. To strengthen the innovation and outcomes of the pilots, some of the demonstrations will be planned and run conjointly with on-going projects on specific research topics aligned with the DEDICAT 6G objectives like H2020 ICT-52, H2020 DRS-02, etc. Finally, as the experiments evolve, key lessons and observations will be used to produce a set of guidelines and best practices for implementation and deployment of the project solutions, as well as for the provision of feedback about the current level of 5G/B5G technology in supporting distribution of intelligence (data, computation, storage), dynamic coverage extension, security, privacy and trust, and human in the loop solutions in realistic environments. Partners with specialized skills and innovation potential are part of the consortium, all of them interested in drastically enhancing their offerings by optimizing latency and resource consumption, global coverage, advanced security, and human interfaces. DEDICAT 6G awareness and exploitation strategies will be designed to generate a significant impact on the business and related activities of all its partners and, by extension, on end users benefiting from the project's innovations.

V. Conclusions

This paper presented an overview of the DEDICAT 6G project vision. DEDICAT 6G will develop new mechanisms to dynamically co-distribute data, computation (i.e., data processing and analytics) and storage, based on network status information of both communication and computing loads. DEDICAT 6G will also develop dynamic coverage extension mechanisms that will rely on a combination of robots, drones and cars to offer the most satisfactory QoS to users through MAPs-based opportunistic radio network. The AI powered security management framework of DEDICAT 6G will leverage on state-of-the-art and best practices to innovate on mechanisms for threat detection, classification, and risk mitigation in the context of highly dynamic and distributed communication and computation networks. DEDICAT 6G trust management will be based on high performance and efficient private permissioned blockchain (Hyperledger Fabric). DEDICAT 6G focuses on four representative 6G use cases: Smart Warehousing, Enhanced Experience, Public Safety and Smart Highway. The developed solutions will be demonstrated and tested in these use cases through experiments in laboratory environments, and larger field evaluations utilizing diverse assets and testing facilities.

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