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5G and Beyond 5G Technologies Enabling Industry 5.0: Network Applications for Robotics

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Abstract

The convergence of cloud and edge computing, along with distributed AI and the latest 5G/6G communications, is revolutionizing collaboration, connectivity, and interaction. These digital advancements pave the way for a new era of AI-powered robots, enabling them to navigate unfamiliar scenarios and adapt in the long term by seamlessly engaging with the digital realm. Consequently, these innovative applications generate diverse, continuous, and rapidly evolving data transmission requirements that traditional network resource management struggles to satisfy in terms of Quality of Service (QoS). In this paper, we take a step beyond focusing solely on network-side traffic engineering efforts. Instead, we explore the potential of application-side traffic shaping within non-public networks to address these demanding transmission needs. Within the framework of optimizing Quality of Experience, we discuss on how the 5G-ERA project focuses on a multi-domain learning process for autonomous robotics using an intent-based networking approach for optimized resource management within the network validated by the use cases within the project enabling the transition from Industry 4.0 to Industry 5.0. Our central aim is to efficiently control and direct data traffic within the confines of the private network, ensuring it aligns with predefined objectives. While this methodology can be applied in various contexts, it is essential to establish precise intentions rooted in domain expertise. This innovative approach serves as a valuable complement to conventional network resource management methods typically employed at the network infrastructure level.

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1. Introduction

5G and its future iterations are widely acknowledged as critical enablers for industrial communications, playing a pivotal role in the digital transformation of the economy. In this context, networking will undergo a fundamental shift, transitioning from predominantly supporting end users to catering to specialized vertical applications. While 5G is still in its early developmental stages, its new architecture incorporating Software Defined Networks (SDNs) [1] and Network Functions Virtualization (NFV) [2] holds significant promise for this paradigm shift.

However, as we venture into supporting these vertical applications, certain challenges become apparent. One prominent issue is the increasing demand on networks to efficiently manage their resources, even with the advent of software-defined approaches. The primary concern revolves around the need to handle potentially bandwidth-intensive applications with varying and unpredictable transmission requirements, making resource allocation a complex and ever-changing task.

The proposed approach holds the potential to significantly enhance network applications, particularly in resource management, thereby elevating the Quality of Experience (QoE) [3]. An example of this improvement is seen in enabling 5G-Enhanced Robot Autonomy (5G-ERA) [4], achieved through the offloading of learning processes in a multi-domain multi-administration setting. This vertical-oriented approach not only enhances the support for intent-based deployment of future robotic applications within the 5G framework but also unlocks new possibilities for various sectors leveraging robotic technology.

Robotic applications stand out as one of the most promising verticals, finding applications across multiple industries. Leveraging 5G's Software Defined Networking (SDN) and Network Functions Virtualization (NFV) capabilities, the deployment of robots can now scale up their learning and knowledge sharing capabilities, revolutionizing their potential beyond what was feasible in the past. The specific robotic application addressed in this paper requires intensive data transmission and processing, setting it apart from other projects, such as H20202 5G-TOURS [5], and 5G-HEART [6], which have demonstrated initial proofs-of-concept in areas like smart/connected ambulances, museum tours, and healthcare utilizing virtual network slices.

In reality, deploying robotic applications on a large scale, or even achieving robust applications that respond effectively to real-world scenarios after deployment, remains a significant challenge. The key to deployable robotics lies in empowering robots with transparent knowledge, connected intelligence, and scalable skills, enabling them to operate autonomously and handle unexpected situations confidently. Presently, the capacity for robot deployment is hindered by fragmented intelligence and poor scalability, but formulating a paradigm based on these essential characteristics can unlock the potential for truly autonomous deployable robots in real-world environments.

From the perspective of robotics, the autonomy of robots holds immense importance in various 5G vertical sectors, playing a crucial role in automated mobility, Industry 4.0, and healthcare domains. In parallel, 5G technology itself offers significant potential for enhancing robot autonomy. This potential lies in its ability to facilitate the transfer of knowledge and learning from individual robots to a collective, thus fostering substantial advancements in robot autonomy.

To exploit the advantages of allowing third-party development of autonomous robotic applications across different vertical sectors, there is a pressing need to further develop and standardize experimentation facilities. These facilities serve as essential platforms for testing and refining the performance of robotic applications, ensuring their effectiveness and safety in real-world scenarios.

In the rapidly evolving realm of autonomous robotics, enabling third-party development of applications spanning diverse vertical sectors is paramount. To realise the potential of this approach, there is an urgent call to enhance and standardize experimentation facilities. These facilities serve as vital platforms for rigorously testing and fine-tuning the performance of autonomous robotic applications, guaranteeing their efficacy and safety when deployed in real-world scenarios. What makes this imperative even more compelling is its applicability across a wide array of industries, from manufacturing and healthcare to agriculture and logistics. The crux of the matter lies in the standardization of these facilities, ensuring consistency in capabilities and interfaces. This standardization not only promotes interoperability between various robotic systems but also fosters collaboration among developers and researchers, fostering innovation and advancing the field. Ultimately, the goal is to facilitate testing in environments that mirror actual operational conditions, ensuring that autonomous robotic applications excel in both performance and safety when faced with the complexities of the real world.

The deployment of 5G networks further accelerates progress in this domain. The high-speed, low-latency capabilities of 5G networks are instrumental in facilitating real-time communication between robots and their control systems. This not only enhances the efficiency of autonomous robotic operations but also enables remote monitoring and control, extending the scope of their applications.

As we embark on the journey towards Industry 5.0, the integration of these technologies becomes even more imperative. Industry 5.0 represents a paradigm shift, where humans and robots collaborate harmoniously in the workplace. The development of standardized experimentation facilities, the implementation of intent-based networking, and the deployment of 5G networks are fundamental steps toward realizing the full potential of Industry 5.0. It heralds an era where autonomous robotics becomes an integral part of our industrial landscape, enhancing productivity, safety, and innovation across industries, and reshaping the way we work and interact with machines.

Within the EU 5G-ERA project [4], our focus is on addressing challenges from both the application and network sides. We are actively engaged in developing middleware that plays a crucial role in facilitating vertical applications. This middleware acts as an intermediary layer, enhancing the interaction between the applications and the underlying network infrastructure, thus optimizing the overall performance and capabilities of robotic applications within the 5G ecosystem.

The paper is onwards split in the following sections: Section 2 introduces the concept of the 5G-ERA [4] project and the approaches followed for enabling autonomous robotics while Section 3 describes how 5G and Beyond 5G networks can enable Industry 5.0. We follow up with the validation of our approach through the use cases described in Section 4 also introducing the 5G-ERA platform and its potential in transitioning to Industry 5.0.

2. 5G-ERA concept

In the project, we will implement a reference cloud-native Network Application with two primary objectives. Firstly, it will showcase the composition of services in 5G-enhanced robot autonomy. Secondly, it will support continuous deployment and integration through a cloud-native application approach. To achieve the cloud-native design, we will implement generic vertical services using microservices. These services can be defined and accessed through a reference catalog service, ordered, and replicated using the reference order service. The applications within the library of generic vertical services are developed using a Robot Operating System (ROS) [7] directly.

To enable interpretability, low-level events obtained from testbeds will be propagated through an event bus and translated by a semantic interpretation engine to derive high-level meanings. This capability ensures a clear understanding of the events. Third-party vertical developers can benefit from reusing Virtual Network Functions (VNFs) and Knowledge Network Functions (KNFs) [8] of the generic vertical services with guaranteed compatibility from the testbeds. As a result, the experimental facilities are encapsulated for developers and ready to be expanded for use case-specific functions in the project, such as 5G-enhanced perceptions, detection, and planning in various vertical sectors.

To illustrate the concept, we present a simple scenario of an autonomous robot operating in an unstructured workspace, where the environment is only partially known, a common real-world application. For the robot to be truly autonomous, it needs to learn during its operational process. However, due to limited computing resources, safety constraints, and biased training data, the learning process will be shifted to the cloud using 5G technologies. The workflow of 5G-enhanced robot autonomy follows a Plan-Do-Check-Act (PDCA) model [9], where planning, doing, and checking are carried out virtually in the cloud, and the robot in the real workspace performs the actual actions (act).

This mechanism optimally utilizes the computing resources on the cloud, avoiding safety constraints by trialing virtually. The virtual environments are constantly updated with data from the real workspace, creating a "Digital Twin" of the robot, workspace, and operators. This Digital Twin serves for real-time warnings, feedback, what-if analysis, and decision support or optimization of the robot's operational environment. Through 5G technologies, cloud, and robots are closely linked together, enabling collective intelligence. The robot sends its sensing data to the cloud, updating the local decision model via the cloud. In this workflow, real-time communication is not always essential for autonomous robots due to their local intelligence. This autonomous approach leads to a high tolerance on the placement of service components, which is vital for ensuring resilience in applications.

Fig. 1 shows a typical workflow, which demonstrates the multi-domain learning process.

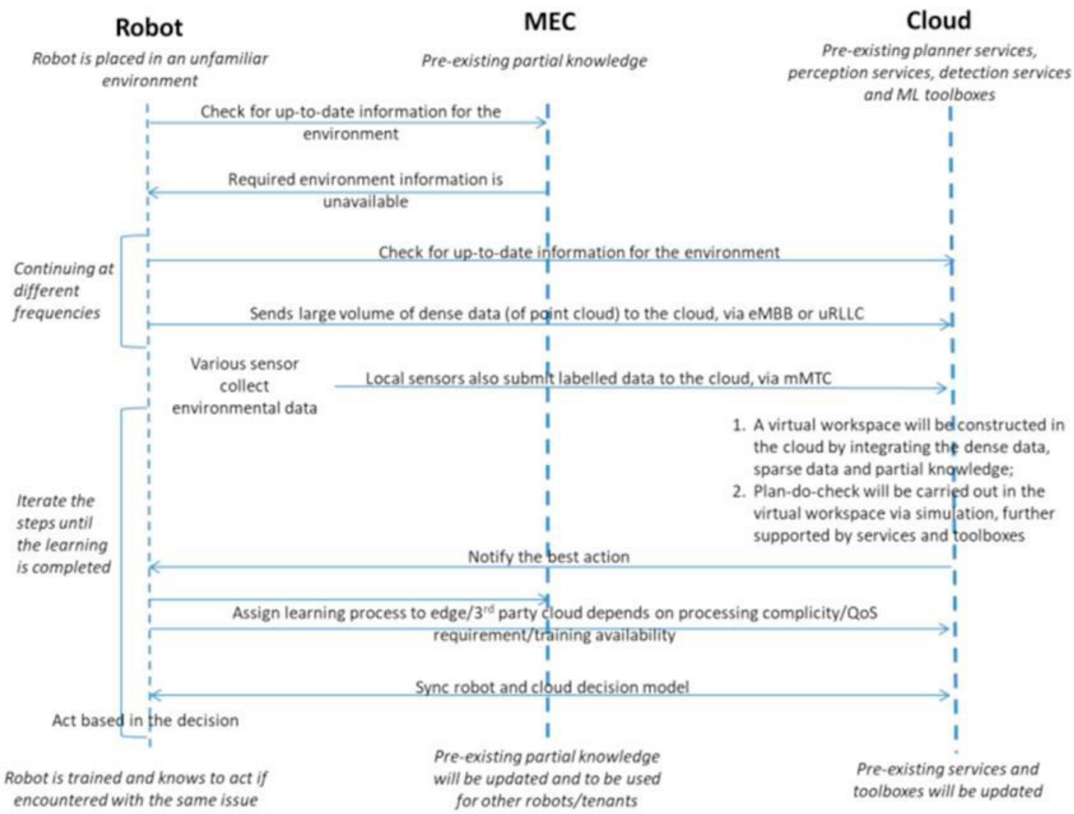

Fig. 1. Workflow of multi-domain learning process

From a 5G robotics perspective, the process of achieving autonomous robot capabilities with the assistance of 5G technology involves a well-coordinated workflow that seamlessly integrates cloud-based and edge-based functionalities. Local sensors and Internet of Things (IoT) devices play a crucial role in collecting data from the robot's surroundings. While they contribute valuable information, their submission to the cloud occurs at a lower frequency and with reduced data volume due to inherent limitations.

In this context, pre-existing partial knowledge resides in the edge, which serves as a valuable resource for the robot's decision-making process. To enable true autonomy, a virtual workspace is constructed in the cloud, integrating dense data, sparse data, and the pre-existing partial knowledge. This virtual workspace serves as a testing ground for the robot's actions, where planning, execution (do), and verification (check) occur via simulation. The simulation is executed rapidly to provide quick results, enabling the robot to navigate its virtual environment effectively. Essential cloud services such as planner services, perception services, detection services, and machine learning (ML) toolboxes contribute to the successful execution of the robot's actions.

Depending on the complexity of the task and the Quality of Service (QoS) requirements, the learning process may be offloaded to third-party cloud services specialized in various domains, such as AWS RobotMaker or Google Cloud

AI. This dynamic approach allows the robot to leverage specialized expertise and computational resources to optimize its learning process.

The synchronization of the robot's local decision model with the cloud model ensures that the robot acts in the physical workspace based on its local decision-making capabilities, drawing from the collective intelligence of the cloud. As the learning iterations progress, the robot gradually achieves a level of autonomy that allows it to operate independently and effectively in its environment.

The knowledge gained through these learning iterations is stored in data centers for future knowledge discovery and reuse. Additionally, the pre-existing partial knowledge on the edge is continuously updated and shared, enabling other robots or tenants visiting the same site to benefit from a rich pool of collective knowledge.

In the realm of 5G-enabled robotics, experience replay takes precedence over knowledge generalization on the cloud side of the training process. Experience replays consist of propositions that may be of uncertain authenticity, necessitating the generation of multiple predictions. These predictions are then subjected to verification by the robot during its planning, execution, and verification processes (plan, do, and check). This rigorous approach ensures the accuracy and reliability of the robot's actions, leading to improved performance and adaptability in real-world scenarios.

The primary objective of intent-based networking for autonomous robots in the context of 5G is to elevate the Quality of Experience (QoE) for vertical applications, specifically enhancing 5G orchestrators for individual autonomous robots. To achieve optimal performance, it is essential to efficiently specify and allocate resources required by the connected intelligence. The intent-based networking technique predicts the intelligence needs based on intents and defines policies for applications to ensure effective management, topology, placement, and resource optimization within the 5G and cloud environments. Connected intelligence, a critical component of autonomous use cases, necessitates dynamic and repeated shifting of computing and storage resources among robots, edge devices, and the central cloud. To facilitate this process, partial information will be replicated among Network Services (NSs) deployed in different locations [10]. Fig. 2 demonstrates the approach followed by the 5G-ERA project.

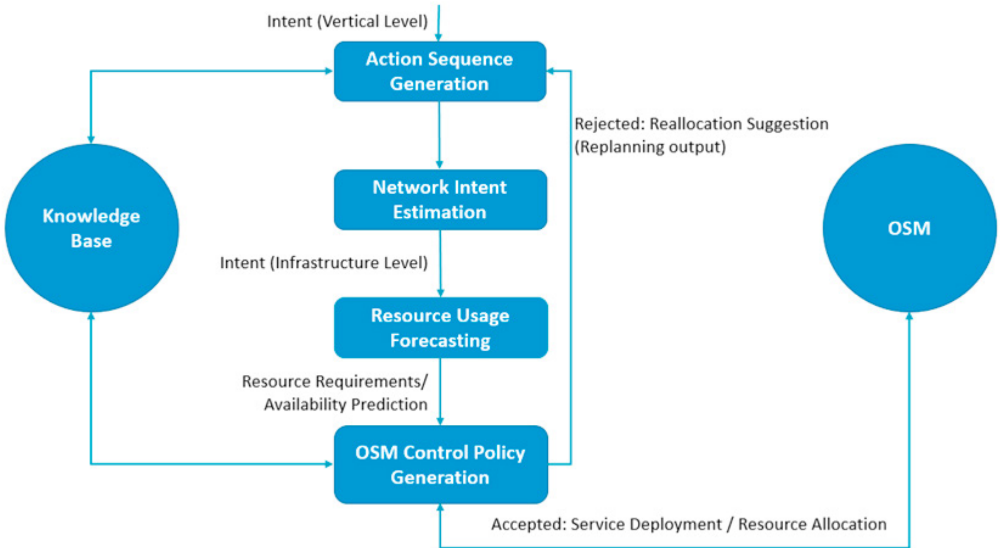

Fig. 2. Intent-based management in the context of the 5G-ERA project

Deploying robotic applications at scale with robust capabilities to respond to real-world scenarios poses a significant challenge. The concept of deployable robotics addresses this issue, aiming to enhance the effectiveness of robot deployment in real-world environments. Currently, fragmented robot intelligence and limited scalability hinder this ability. To overcome these limitations, a paradigm centered around transparent knowledge, connected intelligence, and scalable skills must be formulated. Key attributes of deployable robotics within this framework include autonomous operation and the capacity to handle unexpected situations effectively.

In the context of intent-based networking, different configurations of Virtual Network Functions (VNFs) and slices are required to tailor NSs effectively [[11]-[13]]. However, creating slices at the complexity level of use cases remains problematic for existing testbeds. As such, 5G experimental facilities need to adopt a cloud-native approach to efficiently deliver services for enhanced robot autonomy. Intent-based networking not only enhances existing NSs but also aligns them with cloud-native principles, ensuring scalability, availability, and feature velocity as expected by autonomous robots. Thus, the development of intent-based networking bridges the gap between the existing 5G product vision and the cloud-native deployment required for robot autonomy enhancement. This development significantly enriches the domain model supporting advanced orchestration of essential robotic capabilities.

Within 5G-enabled Non-Public Networks (NPNs), a middleware implemented through the Platform as a Service (PaaS) paradigm plays a vital role in facilitating intent-based networking. This middleware allows the creation of customized virtual network platforms tailored to specific vertical applications, rather than forcing vertical applications to conform to the network infrastructure. By adopting this approach, the management of network resources can be optimized, resulting in an enhanced QoE for users. For instance, this methodology proves beneficial for 5G-enhanced robot autonomy by enabling the offloading of learning tasks in a multi-domain multi-administration environment.

The vision of the 5G-ERA project includes the development of an intent-based networking dashboard (IBD) [14], which holds substantial benefits for users in effectively managing and optimizing their Network Applications. Our IBD offers a user-friendly interface that allows users to visualize and control their various Network Applications on the network infrastructure.

One of the primary advantages of the intent-based networking dashboard is its ability to provide users with a unified view of their Network Applications, independent of the underlying infrastructure. This simplifies the management of Network Applications, removing the burden of dealing with the complexities of the infrastructure. Users can effortlessly create, delete, or modify Network Applications and adjust QoS settings for each application without delving into the technical details of the network.

Beyond the aforementioned benefits, the intent-based networking dashboard offers several additional advantages. Firstly, it provides an intuitive and customizable interface, enabling users to interact with their Network Applications in a way that aligns with their preferences. The streamlined interface allows quick access to relevant information without navigating through complex menus. Moreover, the ability to customize the dashboard tailors it to the specific needs of users, thereby enhancing efficiency and productivity.

Secondly, the intent-based networking dashboard enables users to automate certain tasks related to managing Network Applications, further optimizing their operations. Thirdly, the dashboard provides valuable insights into the usage patterns of Network Applications [15]. This is particularly beneficial for organizations with multiple departments or locations utilizing the same network infrastructure. Through detailed analytics and reporting, the dashboard empowers users to identify usage trends, monitor resource utilization, and allocate resources more effectively.

In conclusion, our IBD will prove to be a valuable tool for users seeking to manage and optimize their Network Applications. By delivering a user-friendly interface, it empowers users to achieve their business objectives more efficiently and effectively. The seamless integration of intent-based networking principles into the dashboard simplifies the complexities of network management, making it a powerful solution for modern network administrators.

3. 5G/Beyond 5G testbeds enabling Industry 5.0

Industry 5.0, as an evolution and continuation of Industry 4.0, targets not only to improve the efficiency in manufacturing productivity and quality but also to provide safety in the working environment and environmental protection as well as supply chain optimization. Therefore, 5G and Beyond 5G (B5G) networks are not introduced to redesign the production line but to enable operating models with networking characteristics that enable added value services.

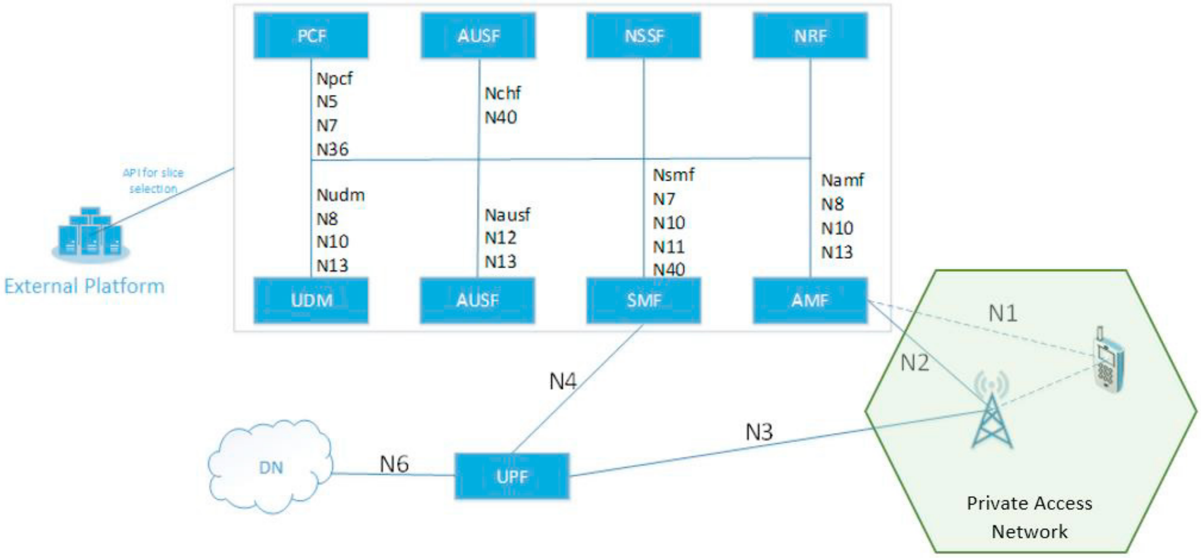

Fig. 3. Network architecture with private access network

Each industrial environment is expected to have its own special characteristics depending on the requirements of each business. For example, logistics companies require speed and precision in the storage and handling of goods, while a factory with high production requires high precision and synchronization of processes. For all these characteristics there are technological solutions and services. And they all converge on the following characteristic: they require a reliable telecommunications network, which will offer advanced features.

The implementation of private access networks (Fig. 3) can offer great flexibility in supporting specialized applications. Radio Access Networks can be installed in industries, and interconnected with the 5G/6G packet core, enabling the capabilities that new generation networks offer, as they are presented in Fig. 4. Moreover, due to the demanding environment, such a network implementation can easily provide complex, heterogeneous requirements, supporting personalized slices according to the user's needs. To achieve this, the creation of slices is chosen. Slices are partitions of the network, each of which can provide specific characteristics. For example, one slice could provide high bandwidth and be exploited by applications that require this feature (e.g., cameras that need to send a large amount of data), while another slice could support low latency and be exploited by corresponding applications. In this way, better utilization of network resources can be made, ensuring that the applications using it will always have the necessary resources.

A specific example of a slice mechanism is presented by the 5G-ERA project. A mechanism has designed focusing on the 5G Core slicing. Multiple slices have been pre-configured in the 5G SA Rel. 16 Core supporting all the available types of services [16]: mMTC (massive machine type communications), URLLC (ultra-reliable low-latency communication) and eMBB (enhanced mobile broadband).

In Fig. 5 we present the high-level architecture implemented. As shown in Fig. 5, two extra components are introduced, apart from the 5G SA architecture components: the Middleware, which is an external component, supports external processes and application hosting and access the user equipment, and the Slice Manager, which is a network component.

The Middleware, even though it is considered as an external component on the network architecture, it plays an important role as part of the overall infrastructure. It is the component which requests slices and allows robots to be connected with the packet core through the slice manager.

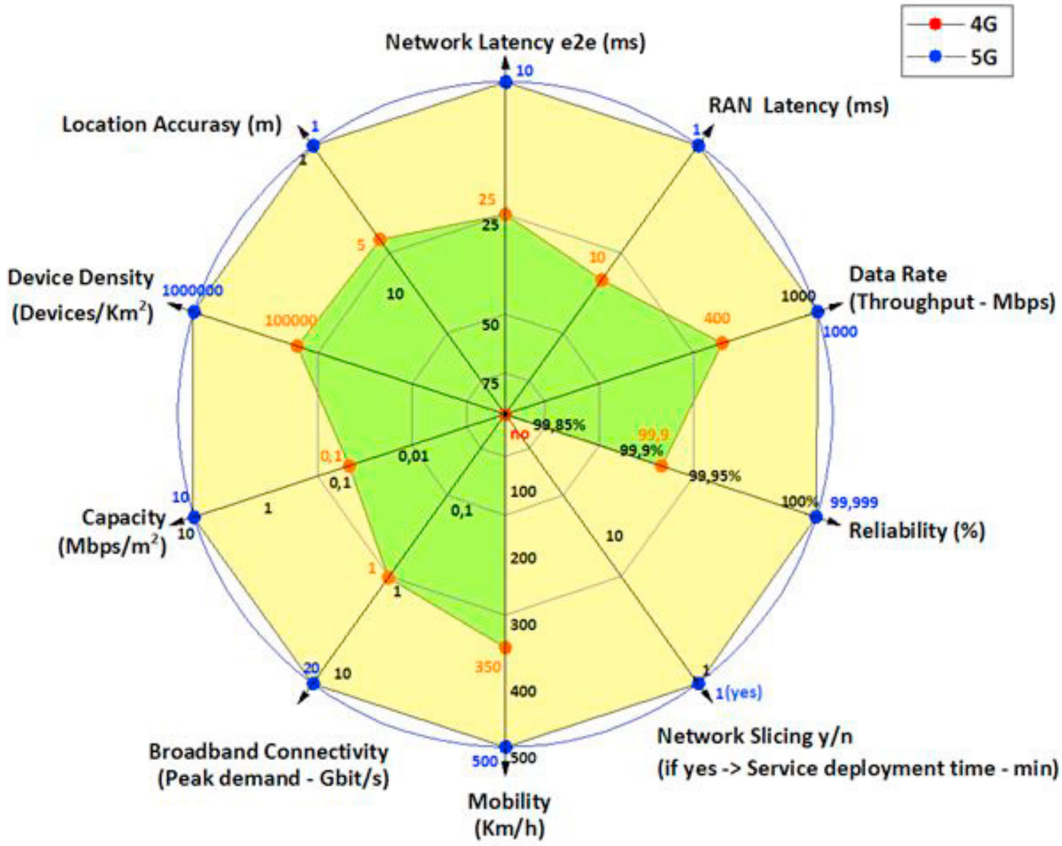

Fig. 4. 5G network characteristics compared with 4G networks

The Slice Manager is a translator, that allows an external component, like middleware, to talk with the packet core and at the same time increases the security level since it does not allow an external component to be interconnected directly to the network. The Slice Manager is a component directly connected to the 5G Core requesting slice changing and its southbound interface is used to interact with the slice plugins deployed in 5G testbed.

When a user equipment first registers to the network, it will use the default slice, which is defined in advance in the packet core. If the application that is used by the user equipment requires different network characteristics, the following steps will be followed:

1. The Middleware will send a message to the slice manager to get information about the available user profiles. The slice manager will send the request to the packet core and the packet core will respond with the list of user profiles which will be forwarded to the Middleware.
2. The Middleware will choose the proper user profile based on the needs of the robot for the specific use case and inform the slice manager.

3. The slice manager will then send a request to delete the user equipment from the default slice and re-register it in a new one.

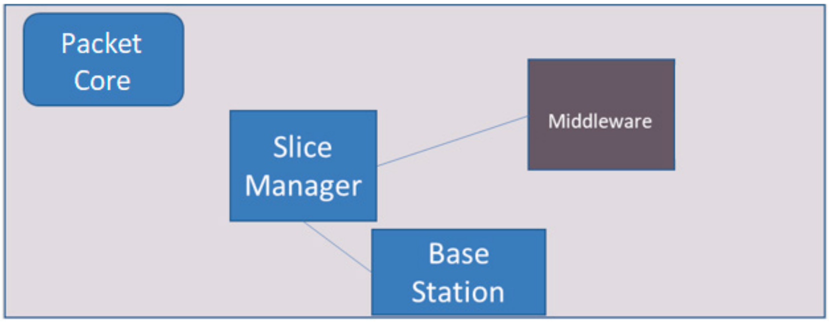

Fig. 5. 5G-ERA architecture for slicing support

Based on the above mechanism, it is shown that networks do not only offer connectivity and allow the data sharing, but also interact with user equipment. The network architecture and the components that are integrated allow the user equipment to request resources by slice changing.

4. 5G-ERA platform for connected robotics and Industry 5.0

Within the framework of the 5G-ERA project, we will develop and prototype relevant Network Applications tailored to each selected use case. Through these prototypes, we will demonstrate the project's experimental facilities' innovative capabilities and highlight the significant advancements made in 5G-Enhanced Robot Autonomy across diverse vertical sectors. To ensure comprehensive coverage, the project has identified four specific vertical sectors as the primary focus of its use cases: Public Protection and Disaster Relief (PPDR), transport, healthcare, and Industry 4.0 to help transition to Industry 5.0. By targeting these sectors, we aim to showcase the versatility and potential impact of our 5G-powered robotic applications in addressing crucial real-world challenges across different domains.

4.1. Use Case 1: Public Protection and Disaster Relief (PPDR)

As part of the 5G-ERA project, we are developing a novel Network Application explicitly designed to support autonomous Public Protection and Disaster Relief (PPDR) services in unstructured environments. This carefully chosen use case serves as a showcase for the technological advancements made possible by 5G communication solutions, demonstrating their potential as bridges between legacy technologies and cutting-edge communication solutions.

The primary objective of this use case is to enable close-to-seamless handover and switching capabilities between Edges (i.e., peripheral network elements) and Mobile Operators. To achieve this objective, we are working on robust communication solutions that can seamlessly integrate and switch between different network environments. This will ensure uninterrupted services to end users, empowering PPDR applications to operate effectively in dynamic and challenging scenarios. Through this use case, we aim to highlight the transformative capabilities of 5G communication solutions in addressing critical needs within the PPDR sector and showcasing their potential to revolutionize emergency response and disaster relief efforts.

4.2. Use Case 2: 5G enhanced semi-autonomous transport

The key objective of this use case is to empower robots to operate in teleoperated and semi-autonomous modes, leveraging the capabilities of 5G technology [25]. By harnessing 5G communication solutions, this use case serves as a compelling demonstration of the potential for efficient and reliable communication between robots and the transport infrastructure.

The ongoing development of the Network Application supports semi-autonomous transport operations, providing advanced real-time decision-making and navigation capabilities. Utilizing lightweight onboard unit virtualization techniques, we create a flexible and scalable fog environment capable of adapting to the evolving needs of the transport domain. The intent-based networking dashboard (IBD) plays a crucial role in supporting various data flows and ensuring Quality of Service (QoS) by mapping multiple data streams from sources like sensors and video streaming. Additionally, the IBD facilitates the security of Network Application endpoints, preserving the confidentiality and integrity of sensitive data.

This use case showcases how 5G technology can significantly reduce service creation time and enhance the transport sector's capabilities. By capitalizing on 5G communication solutions, the Network Application enables seamless communication and collaboration between robots and the transport infrastructure, resulting in more efficient and reliable transport operations. The transformative potential of this use case lies in its ability to enable smart and interconnected transport systems, leading to safer, more efficient, and sustainable transportation in the future.

4.3. Use Case 3: 5G enhanced healthcare robots

The 5G-ERA project includes a significant use case that revolves around designing and developing a novel Network Application, supporting diverse data flows with varying priorities and Quality of Service (QoS). The primary objective of this use case is to enable the seamless mapping of multiple data streams, encompassing sensor data, alerts, and video streaming. A crucial focus is also placed on demonstrating the robust security of Network Application endpoints and data streams, ensuring the protection of sensitive and confidential information.

The Network Application developed under this use case plays a vital role in enabling robots to carry supporting materials on behalf of healthcare workers, depending on the robots' level of autonomy. Leveraging 5G technology, this application facilitates efficient and reliable communication between the robots and the healthcare infrastructure, enabling the robots to execute their tasks safely and effectively.

Ensuring the security of Network Application endpoints and data streams is a central aspect of this use case. To achieve this, the Network Application leverages the capabilities of 5G technology, employing robust security measures to safeguard sensitive and confidential data at all times. The application also supports the mapping of data flows with varying priorities and QoS, ensuring optimal and effective communication between the robots and the healthcare infrastructure.

Moreover, the intent-based networking dashboard (IBD) plays a pivotal role in securing the Network Application endpoints while supporting the management of various data flows generated by sensors, video streaming, and other sources. The IBD prioritizes the mapping of data streams, optimizing communication efficiency within the system. Users can access local and task planning services through the IBD, facilitating task planning based on local information. Additionally, edge task planning services are utilized to plan tasks integrated with a smart environment. Finally, the central cloud planning service offered by the IBD facilitates the optimization of feature and semantic maps based on global knowledge and semantic-based task planning.

Through this use case, the 5G-ERA project aims to demonstrate how advanced 5G communication solutions can play a pivotal role in revolutionizing healthcare robotics. By effectively managing data flows and ensuring end-to-end security, the Network Application enables robots to perform essential tasks in healthcare settings, contributing to improved patient care and operational efficiency.

4.4. Use Case 4: 5G-remote assistance for manufacturing process

The 5G-ERA project includes a compelling use case focused on establishing an interface between the Robot Operating System - Industry (ROS-I) [7] and an industrial production cell. The primary objective of this use case is to leverage Industry 4.0 techniques and the 5G-ERA middleware to enable highly flexible and robust manufacturing capabilities for both small and medium-sized enterprises (SMEs) and large-scale fabricators.

To showcase the potential of this use case, the project employs a brazing cell, demonstrating how human-robot learning control algorithms [[17]-[18]] can be applied to collaborative output tasks. Through these algorithms, the use case effectively enables seamless communication between robots and human operators, resulting in a production cell that is remarkably flexible and responsive to dynamic demands.

A key advantage of this use case lies in its ability to deploy highly flexible and robust manufacturing solutions catering to both SMEs and large-scale fabricators. Leveraging Industry 4.0 techniques and the 5G-ERA middleware, the use case aims to establish a seamless interface between the production cell and the ROS-I [7] system. By doing so, the production cell becomes inherently adaptable and capable of swiftly responding to evolving requirements.

The intent-based networking dashboard (IBD) plays a pivotal role in supporting a variety of services associated with this use case. These services include brazing robot operation through task planning based on the brazing process specification, edge operation planning services, central cloud services responsible for optimizing features and semantic maps using global knowledge, and learning services tasked with proactive updating of dense and semantic maps, as well as the robot's skill set, thereby enhancing accuracy and autonomy levels.

Furthermore, the features of this use case are supported by an external dashboard located at the premises of the use case provider. This dashboard enables seamless connection and interaction with the production cell, further enhancing the control and visibility of the manufacturing processes.

Through this use case, the 5G-ERA project [4] aims to demonstrate how Industry 4.0 techniques, combined with the capabilities of the 5G-ERA middleware, can revolutionize manufacturing operations. By enabling highly flexible and responsive production cells, the project endeavors to bring substantial benefits to SMEs and large-scale fabricators alike, unlocking new levels of efficiency and adaptability in the manufacturing domain.

In addition to its contribution to the 5G-ERA project's goal of advancing 5G-Enhanced Robot Autonomy, this use case also establishes a significant connection to Industry 5.0. By showcasing the potential of Industry 4.0 techniques and the 5G-ERA middleware to enable highly flexible and robust manufacturing, this use case exemplifies how robots can seamlessly integrate into industrial production processes, fostering a human-centered approach.

Industry 5.0 builds upon the foundation of Industry 4.0, emphasizing the collaboration between humans and advanced automation technologies, including robots. In this context, the use case highlights the successful integration of robots into the production cell, enabling collaborative and adaptive manufacturing practices that enhance productivity and efficiency while maintaining a focus on human expertise and creativity.

By demonstrating how Industry 4.0 techniques and 5G-ERA solutions enable human-robot interactions in the manufacturing domain, this use case aligns with the principles of Industry 5.0, emphasizing the importance of human involvement and skills in conjunction with cutting-edge technologies. The seamless integration of robots into industrial production processes through this use case exemplifies how Industry 5.0 aims to foster a harmonious relationship between humans and machines, unlocking new possibilities for innovation and economic growth.

In conclusion, this use case not only contributes to the advancement of 5G-Enhanced Robot Autonomy within the 5G-ERA project but also establishes a strong connection to Industry 5.0 principles. By showcasing the potential of Industry 4.0 techniques and 5G-ERA solutions to create highly flexible and adaptive manufacturing environments, the use case exemplifies the shift towards human-centered and collaborative production practices envisioned in Industry 5.0.

4.5. Enabling Network Applications through the 5G-ERA Platform

The 5G-ERA project presents a versatile platform that plays a pivotal role in enabling the development and deployment of cutting-edge Network Applications. By leveraging intent-based networking principles, this platform facilitates seamless communication, efficient resource management, and intelligent decision-making across various vertical sectors. Through this platform, the Network Applications can harvest the full potential of 5G technology, transforming the way robots interact, collaborate, and operate within their respective domains.

4.5.1. Seamless Communication and Collaboration

The platform offers an intent-based networking dashboard (IBD) [14] that serves as a user-friendly interface, providing a unified view of Network Applications irrespective of the underlying infrastructure. By employing the IBD, users can effortlessly manage and control their Network Applications, enabling seamless communication between robots and various components of the network infrastructure. This close-to-seamless handover and switching capability between Edges and Mobile Operators ensures uninterrupted services and optimizes the exchange of data streams, including sensor data, alerts, and video streaming.

4.5.2. Efficient Resource Management

The intent-based networking dashboard also supports the mapping of data flows with different priorities and Quality of Service (QoS), ensuring efficient resource allocation and optimization within the network. By leveraging 5G communication solutions, the platform empowers Network Applications to adapt dynamically to changing demands, enabling highly flexible and responsive operations in diverse sectors such as healthcare, transport, and industry.

4.5.3. Robust Security and Compliance

A significant aspect of the platform is its focus on security and data protection. By implementing robust security measures, the platform safeguards sensitive and confidential data at all stages of communication and ensures compliance with industry regulations. This capability is critical for use cases such as healthcare, where the integration of robots demands stringent data security and privacy considerations.

4.5.4. Integration with Industry 4.0 and Beyond

The platform extends its capabilities to seamlessly interface with Industry 4.0 techniques, showcasing its alignment with the principles of Industry 5.0. By enabling robots to operate collaboratively with humans in manufacturing environments, the platform demonstrates how human-robot interactions can foster innovation and efficiency while maintaining a human-centered approach.

4.5.5. Future Scope and Advancements

As the 5G-ERA project progresses, the platform will undergo continuous testing and evaluation under various scenarios to provide further insights and recommendations. By refining and enhancing the platform, the project aims to unlock its full potential in optimizing traffic management, supporting intelligent decision-making, and enhancing Network Applications' performance across multiple vertical sectors.

In conclusion, the 5G-ERA platform acts as a powerful enabler for Network Applications developed in conjunction with intent-based networking. With its emphasis on seamless communication, efficient resource management, robust security, and alignment with Industry 4.0 and beyond, the platform marks a significant step towards realizing the vision of 5G-Enhanced Robot Autonomy and shaping the future of autonomous robotic applications across diverse industries.

5. Conclusions

This paper introduces our preliminary exploration of intent-based deployment for robot applications within a 5G-enabled non-public network. The primary objective is to effectively manage and shape traffic before it exits the private network. While the approach is applicable across different scenarios, the intentions must be clearly defined based on domain knowledge. This approach complements traditional network resource management techniques used at the network side.

Moving forward, we plan to conduct extensive testing and evaluation of this approach under various scenarios to obtain valuable insights and generate further recommendations. The aim is to refine and enhance the implementation to maximize its effectiveness and applicability in real-world scenarios. By continually iterating and improving the approach, we strive to unlock its full potential in optimizing traffic management and supporting efficient robotic applications within the 5G-enabled non-public network.

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