Remote Monitoring at Distribution Network of Dynamically Constrained Working Areas

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***Abstract*—Smart5Grid exploits the robustness and flexibility enabled by the 5-th generation (5G) mobile network technology to contribute an open and adaptable platform for reliable testing, validation, and operation of Network Applications (NetApps), addressing the challenges of the Renewable Energy Sources (RES) production and those of the operation of the active power distribution ecosystem, in particular. Smart5Grid aims to support current energy sector and future smart grid stakeholders through the adaptation of 5G networks and the support of the respective NetApps that will be developed and validated on real power grid facilities. Smart5Grid intends to provide a more secure, flexible, efficient, scalable and real-time communication framework for modern smart grids. Through remote inspection and control of automatically delimited working areas, the capabilities of the created Smart5Grid 5G platform will facilitate the improvement of working conditions for power grid maintenance crews and inspection workers. In this paper, we presented the methodology of the Smart5Grid project, which will enable remote inspections in high-risk areas and real-time execution by supporting various distribution network applications and providing accurate results and information on the operational condition of power grid assets via augmented reality. If maintenance work is undertaken, real-time control will be enabled to support working procedures remotely and automatically, without putting employees in potentially harmful conditions.**

***Index Terms*—smart grid, energy, netapp, 5G, network, virtualization,**

I. Introduction

More profound and quicker decarbonization is transforming the energy sector and creating new supply and demand concerns. The power sector will contribute significantly to the process. In this environment, the energy infrastructure must be upgraded and digitalized to accommodate the deployment of renewable sources, increased decentralization, and electrification of end-user and active customers while guaranteeing network stability, security, and resilience. Variable renewable energy output requires grids to manage power flows more quickly and effectively to maintain supply quality. Smart grids will promote resource-efficient economic growth and global and local pollution reduction by boosting Renewable Energy Sources (RES). A key development pillar is grid interoperability with distributed resources, such as tiny photovoltaics (PV) and local electricity storage, energy communities, and 'prosumers'. As demand and supply patterns shift toward decentralized generation (linked at medium and low voltage networks), congestion and multidirectional energy flows must be managed. Connecting smart metered consumers to the distribution system will allow them to provide flexible services in the energy market (demand response).

New types of energy demand in building, transport, and industry, such as charging electric vehicles, heat pumps, and other consumer-based devices, are transforming energy consumption patterns. Smart integration of electricity with ultimate uses will reduce greenhouse gas emissions and energy demand, delivering similar services with less energy and resources. In this regard, the Smart5Grid platform aims to support the energy transition by providing the needed digital layer for communication infrastructure's availability whenever needed. Smart grids are intricate networks that provide "more than the sum of their parts." Power systems incorporate interrelated and geographically dispersed components, both hardware and software, on the producers' and consumers' sides of power transmission and distribution systems, and retrieve their assets to produce higher functionalities such as active network management, for operational optimization through predictive maintenance, energy network remote reconfiguration, and restoration strategies activation covering nearly real-time.

This paper describes the Smart5Grid "Remote Inspection of Automatically Delimited Working Areas at Distribution Level", which aims to border the safety zone in a volumetric approach, dynamically assisting field technicians using 5G due to its ultra-reliable low-latency communications and increased mobile broadband and sensor technologies. Using wireless technologies and image processing (advances cameras with incorporated artificial intelligence (AI) software), the objective is to transfer expertise from the field, with real-time localization of persons and objects to the maintenance supervisor using a dedicated NetApp developed during the Smart5Grid project. The major goal is to enhance the safety of working environment for the workers in high voltage (HV) power stations. Based on the remarks mentioned above, the remainder of this paper is organized as follows. Section II provides the background and presents similar works and projects in this field. Section III describes the NetApp concept in the context of the Smart5Grid project, including the architectural design, the main components and their functionality and the development phases. Section IV presents an overview of the experimental results. Section V provides a brief description of the Validation and Verification framework used for the NetApps. Finally, Section VI concludes this work.

A. *Problem Statement*

Through virtual network functions (VNFs), software networks offer high flexibility. As demonstrated in the previous 5G PPP phases, VNFs can be linked across domains to develop NetApps suited to diverse needs of tenants. This necessitates open platforms that allow access to network resources, which can then be utilized to construct NetApps that serve unique vertical industry requirements and developments. The vertical energy domain has long been one of the most difficult to enter (i.e., which prevents new rivals from rapidly entering this vertical). Smart5Grid presents an open 5G platform for managing power grid resources by leveraging unique NetApps and VNFs built for the energy industry. The open-source NetApps will be created and tested on the Smart5Grid experimental facilities to meet the needs and development of modern power grids. Importantly, third-party developers, engineers, and small medium enterprises (SMEs) will be allowed to utilize the Smart5Grid platform, fostering openness and lowering the high hurdles to accessing expensive energy grid infrastructures. Finally, existing power grids will benefit from Smart5Grid NetApps because the project will improve communication, monitoring, operational, and maintenance conditions for the network tenants (i.e., Distribution System Operators (DSOs) and Transmission System Operators (TSOs) as critical participants in the energy ecosystem).

II. Background and State-of-the-Art

Smart5Grid uses 5G's robustness and flexibility to provide an open, customizable framework for testing, validating, and operating NetApps, addressing the RES production and vertical distribution environment in particular. The forthcoming 5G mobile cellular network, combined with ultra reliable low latency (URLLC), multiple machine type communication (mMTC), enhanced mobile broadband (eMBB), and the notion of mobile edge computing (MEC), which brings cloud computing to the network's edge, will provide a capable environment for distributed monitoring and control duties in Smart Grids. Smart5Grid enables cost-effective and efficient distributed State Estimation (SE) solutions based on advanced optimization algorithms. Smart grids will provide more frequent voltage and phase readings than standard measuring equipment. SE estimates the system status variables (voltage magnitude and angles) at all the electrical network's buses using remotely acquired measurements. The Smart5Grid open testing platform allows partners and third parties to construct and test VNFs and NetApps (i.e. entities outside the Smart5Grid consortium). This will create an experimental execution environment that increases the stability, availability, and maintainability of smart grid energy networks by using revolutionary 5G solutions.

Currently, DSOs charge substantial operational costs as examining and maintaining energy distribution grid assets is a challenging critical work [1]. Currently, human maintenance teams evaluate and maintain the assets of DSOs through visual examination. As a result, dedicated people are frequently exposed to hazardous working conditions, such as high heights for tower/pylon climbing inspections, challenging ground patrols, and electrical dangers (e.g., electric arcs that can cause electrocution) during substation visits [2] [3]. For employee safety, intentional power outages are scheduled during inspection and maintenance operations, reducing the capacity and availability of the distribution network regularly. Furthermore, when maintenance work is being done near essential distribution grid equipment, such as transformers, circuit breakers, switchgear, and so on, the working areas are limited and only authorized employees have access to them. As it is critical for DSOs to obtain an efficient and short-duration inspection and maintenance procedures from central offices in order to support risk prevention and assist field operators through the provision of advanced information and data, inspection and maintenance, and procedures of delimited working areas at the distribution level must be performed remotely without compromising quality.

The Smart5Grid NetApp allows developers to build vertical applications by integrating new and/or existing software components in VNFs. Separating the NetApp's functionality into decoupled VNFs facilitates the reuse of software functions. However, this is not a novel concept that NetApp introduces. The Smart5Grid NetApp concept seeks to provide a solution by shielding vertical application developers from network implementation and configuration complexity. Smart5Grid suggested that NetApp is a native cloud application. Therefore, it is composed of VNFs utilizing OS container technology. A Smart5Grid NetApp has the required components to provide a service as a software application for the energy vertical. This does not imply, however, that the service supplied by this vertical application cannot be used by other external or legacy apps, for example, via a north-facing API. A NetApp may provide other user interfaces, such as dashboards, for which

the developer may make design considerations.
NetApps can hold VNFs. Container-based NetApp VNFs can be deployed. NetApp takes advantage of cloud/edge infrastructure by dividing components whenever possible. In the case of a NetApp with two components, the function that requires low latency input or responses could be placed at the edge of the computing infrastructure, while the other function, which may be resource-intensive should be placed in a cloud datacenter where resources are not constrained.
Each NetApp structure is correctly defined in a NetApp descriptor, which includes information about its services, configuration, and performance requirements so that the infrastructure over which it is instantiated can perform its required purposes, such as MEC offloading, VNF scaling, and traffic policy enforcement via its management and orchestration (M and O) systems. This information allows M and O systems to generate end-to-end slices that meet these requirements, allowing engineers to create apps with comprehensive performance requirements without requiring network knowledge.
The authors in [4] are concerned with adapting 5G designs for future NetApps and verticals. They begin with a brief introduction to the existing and future environment of 5G and then discuss the 5G-Public-Private-Partnership (PPP) projects that contributed to the early deployment of a 5G testbed in Romania. They are centred on the NetApps and vertical context, as shown by the two 5G-PPP initiatives, VITAL-5G and 5GASP, the incremental evolution of the 5G network to serve all of these complex NetApps and vertical Use Cases (UCs). The 5G-EPICENTRE [5] platform will be based on an open Service Oriented Architecture (SOA) and supports open access to 5G network resources, serving as an open source repository (OSR) for Public Protection and Disaster Recovery (PPDR) 5G NetApps. The objective of the federated platform is to provide adequate resources to cover the full spectrum of the three ITU-defined service types (eMBB, mMTC, and URLLC) and to deliver secure interoperability capabilities that extend beyond vendor-specific implementation. Network Applications (NetApps) are gaining popularity, which will aid in implementing vertically-specific services and their smooth interaction with 5G networks and vertically-specific components. The authors in [6] describe the work of the EU-funded project VITAL-5G in deploying 5G Stand Alone (SA) testbeds in three real-world Transport Logistics facilities across Europe, the necessary 5G network extensions and architectural considerations, their integration with a cutting-edge experimentation platform, including the use of NetApps to enable the smooth implementation of 5G-enabled vertical services.

A. *NetApps State-of-the-Art*

The 5G PPP projects supported by European Commission under the Information and Communication Technology (e.g., ICT-41-2020 call for proposals), including Smart5Grid, promote NetApps as solutions for vertical issues. The main similarity of this grant is to enable experimentation facilities that help open new markets within the verticals and ease application developers' entry into these markets, thereby providing an appropriate workplace for SMEs and an exceptional ground for start-ups in the European ecosystem. The projects included in this program are outlined in Figure 1 [7]. The added value of the Smart5Grid is realized through remote inspection and control of the automatically defined working areas. The capabilities of the created Smart5Grid 5G platform will provide a solution for improving working conditions for power grid maintenance crews and inspection workers. The 5G eMBB features will enable high bandwidth communication between power grid monitoring equipment (existing permanent and manual sensors, as well as high-resolution cameras of various types) and the cloud-based inspection platform to achieve an automated evaluation of equipment position as well as automated delimitation of working areas during remote inspection. By supporting a variety of distribution NetApps and giving precise results and information on the operational health of power grid assets, the Smart5Grid project will enable remote inspections in high-risk locations and real-time execution. Real-time control will be enabled in the case of maintenance work to help the working procedures remotely and automatically without exposing the supervisor employees to harmful conditions.

B. *Expected Benefits*

The expected benefits of the Smart5Grid UC on the remote monitoring at distribution network UC are the following:

- Economic: To save expenses by enhancing worker safety. If there is an accident at the primary substation, the network could fail, affecting many customers.
- Social: To reduce workplace accidents and enhance workplace safety. The new system will also enhance the company's social image, as the company will be perceived as one that places a premium on the well-being of its employees. Moreover, if an accident occurs at the primary substation, there may be a network failure, and many customers may experience a loss of power supply, which would significantly harm the company's reputation as a consistent and uninterrupted service.
- Business: As part of the UC, the company's workforce management systems will incorporate a new bespoke digital system to enhance the safety of primary substation workers. It is anticipated that this will enhance the current network operation methods.

III. NETAPP CONCEPT IN SMART5GRID

Smart5Grid will use a private 5G network to showcase the possibilities of the created 5G platform and NetApp for remote inspection of automatically demarcated functional areas at the distribution level. The developed NetApp will (i) generate a detailed 3D volumetric model of the setup of the electric grid resources where the work will be performed, (ii) instantly define the working areas and the authorized personnel, (iii) allow real-time communication of big data generated from the existing permanent and manual sensors and cameras within the working area, and (iv) allow real-time remote control of the

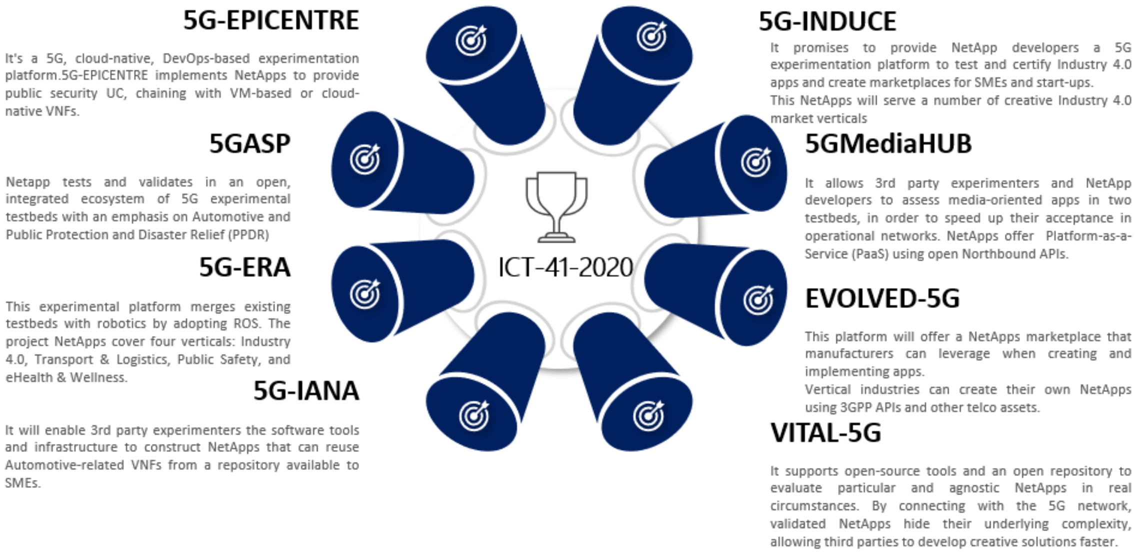

Fig. 1. 5G PPP projects funded under ICT-41-2020 [8]

work and identify the movement. The developed 5G private network is predicted to have a peak data rate of 10 Gbps. This UC presents a method that identifies the exposure of personnel and their equipment when they reach a restricted area while working in an EcoGarraf substation. In a high-risk environment where the voltage exceeds 66kV, the safety of those who work at electrical stations is of paramount significance to any energy provider. The safety requirements will be of the most outstanding quality, with continual updates incorporating recent technical developments. In the context of Smart5Grid, developing various NetApps with 5G capabilities will strengthen safety measures and create a safer working environment. The current infrastructure employs two safety systems: a camera software with integrated image recognition that provides an overview of the workers physically located in the substation and a UWB (Ultra-Wideband) that provides basic location information via tags and anchors. Merging data from various sources, processing it, and implementing communication channels utilizing 5G technology constitutes a technological leap beyond the current infrastructure.

A. Architecture design

The design for the architecture that will be created for this UC is depicted in Figure 2. The UWB unit (tag and anchor) transmits data to the synchronization (sync) switch, which transfers the data over 5G to the NetApp's virtualized function. The camera unit (camera device and image processing unit) transmits the output to the NetApp via an industrial type switch (model IP68 switch) and 5G. The synchronization NetApp takes the data from the two sensors, assesses it, and notifies the on-site personnel if they or their equipment have entered a restricted area, activating the vibration mechanism in the UWB tag and the alarm unit.

B. Components

The conceptual design is split into two separate designs: the overall pilot demonstration design, and the NetApp software components design. The pilot demonstration design includes the overview of all the components that will take place during the demonstration to provide a better level of worker safety than the current safety installation. The NetApp design consists of the software for the deployed camera sensors, the Ultra Wide Band (UWB) software for the wearable sensors, and the Synchronisation NetApp. Specifically,

1) The camera sensor software receives the image from the camera and incorporates a neural network that can identify the worker and tool presence within site.
2) UWB sensor software collects data from deployed wearable sensors. As workers move across space, their actions are detected by sensors and transmitted to the Synchronisation NetApp.
3) The Synchronisation NetApp receives and combines the information from the primary components, assess and validate it, and, if necessary, activate the alarm system.

Figure 3 depicts the NetApp UC architecture at a high level. Both input/output and intercommunication between the software mentioned above components are depicted in the image. The cameras' software receives input from the deployed cameras, and the UWB sensor software receives the traffic recognized by the field sensors. Synchro NetApp then synchronizes the input from the installed software and generates the corresponding information and alarms. On the other hand, the NetApp software components design consists of the camera data analysis component, the wearable sensor data analysis component, the data streaming software, the area delimiting alarming component, and the Key Performance Indicators (KPIs) collection component, the front-end adminis-

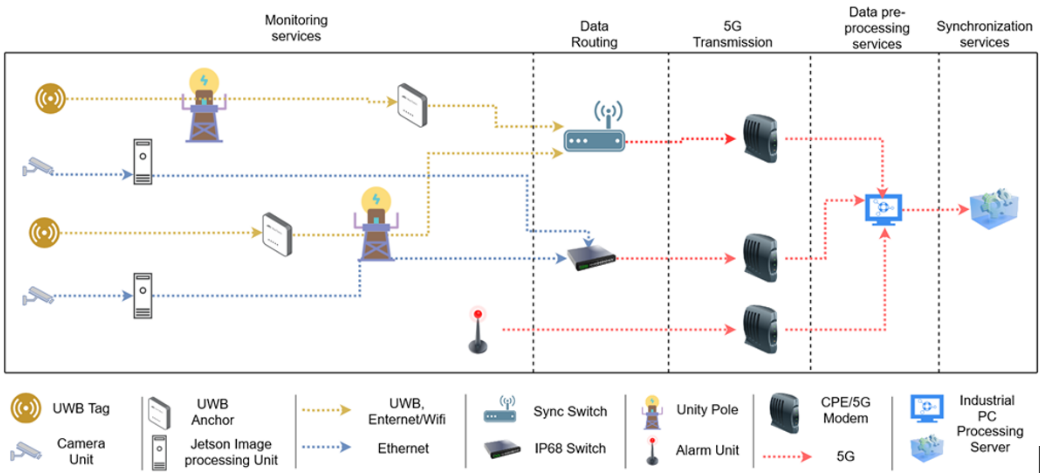

Fig. 2. Use case-based Smarrt5Grid architecture

tration application and the Synchronization component. Below we will present each software component's role within the Synchronisaiton NetApp. To be more specific:

1) The front-end administration application is responsible for illustrating the volumetric safety area, enabling the safety manager to designate prohibited zones before the beginning of every maintenance activity.
2) The camera data analysis component receives the position of a worker and/or a tool, as detected by the deployed camera incorporates a set of spatial transformations that can identify the worker's and tool's actual position within the pilot site.
3) The UWB wearable sensor data analysis component collects data from deployed wearable sensors. As workers move, their actions are detected by sensors and transmitted to this component for input normalisation.
4) The Synchronisation component receives the pre-processed incoming information from each deployed sensor and combine the information to assess and validate the worker and/or tools position and, if necessary, activate the alarm system.
5) The data streaming component is responsible for acting as a middleware asset for the incoming and pre-processed information to flow towards the synchronisation component.
6) The KPI component gathers the area violations detected by the synchronisation component and calculates the functional KPIs for administrative purposes.
7) Finally, the alarm component will be triggered by the synchronisation component once an area violation is detected, and it will provide optical, acoustical and haptic feedback for the worker to be aware of any potential area violation.

C. Functionality

The Remote Inspection of Automatically Delimited Working Areas at Distribution Level pilot demonstration will be carried out at a Barcelona, Spain, urban Spanish primary substation with open-air busbars. Figure 5 depicts the proposed private 5G network on the left side. In the significant substation, a MEC platform with virtualization capabilities will be installed. Depending on the 5G deployment strategy chosen, this cluster will support a virtualized mobile core network, such as a virtual 5G Core, as well as the Remote Inspection of Automatically Delimited Working Areas NetApp, that will be developed to serve this UC.

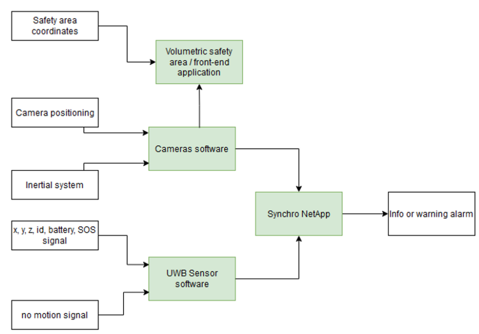

Fig. 3. Use Case based NetApp Architecture

For maximum capacity and low latency, a hybrid RAN integrating 5GNR and WiFi6 will be deployed. The spectrum necessary to deploy the 5G network will be in the 3.5 GHz band, and the 5GNR radio access will be supplemented by a set of Wi-Fi 6 access points radiating in the ISM 5 GHz band, utilizing either an 80 MHz or a 160 MHz configuration, providing complementary capacity to the 5G network. Standalone and non-standalone modes will be evaluated. 5G multi Wireless Access Technology (WAT) Customer Premise Equipment (CPE) will be explored to connect the infrastructure's cameras and position sensors to the 5G network. This CPE will be able to dynamically aggregate the capacity of the 5GNR and WiFi6 radio access networks into a single "wireless pipe" that will deliver increased capacity, lower latency, and increased reliability through packet steering and duplication. The ”Advanced Traffic Steering, Switching, and Splitting” (AT3S) system specified in 3GPP Release 16 [9] will be the fundamental technology to support the multi WAT CPE. Finally, personnel will be outfitted with wearable position sensors that will provide cm-level positioning based on position anchors installed in substation facilities. The positional anchor technology will be selected during the project, although during the proposal preparation phase, Ultra-Wide Band (IEEE 802.15.4a) has been recognized as a potential appropriate candidate. A 3D model of the substation's configuration has already been developed for validation reasons. Different substation parts and equipment will be used to confirm the automatic delimitation of working areas, and real-world tests will be conducted using existing wearable position sensors.

D. NetApp Development Phases

During the component design of the proposed NetApp, it was apparent a methodology including a set of steps, had to be defined and act as a guide for the software development. The proposed NetApp software component architecture is shown in Figure 4. The following development steps describe our approach to designing, developing, and finally deploying the NetApp:

1) At first, the technology stack had to be decided. For the proposed solution, Python [10] was chosen as the primary programming language for the more significant part of the code base. Redis [11] for the data streaming component for its simplicity, reliability and speed. Finally, for the front-end administrative application, Django [12].
2) Every software component has to be containerized. Docker [13] was utilized for the containerization.
3) For the deployment of the NetApp to the demonstration pilot site, cluster management software was required. In order to fulfil the need for cluster management, the well-known open-source management tool, Kubernetes [14], was selected. Based on the Kubernetes proposed approach, corresponding Kubernetes descriptor files were developed to dictate the deployment and communication between all the software components within the NetApp.
4) The final step on the deployment of the NetApp had to include a Kubernetes deployment manager software. For this purpose, the first choice was Helm [15]. By deploying an application as a Helm chart, developers have the freedom to deploy, upgrade and manage even the most complex Kubernetes application.

IV. Experimental results overview

A. Experiment design

The NetApp that will be designed based on UC takes data from two distinct sources, motion sensors and cameras, processes the received data, enables the synchronization mechanism, and alerts security personnel if they have entered a restricted area. This UC addresses two scenarios: in the first, the worker enters the primary substation and stays within the prescribed area without triggering an alarm; in the second, the worker crosses the safety area and activates the alarm. Figure 5 depicts a sequence diagram encompassing both instances. In the first phase, the coordinates are transmitted to the NetApp receiver subcomponent by the motion sensors and cameras mounted to the workers' uniforms. The input data are then translated into the unified data flow and sent to the NetApp computing subcomponent, which performs the required pre-processing to normalize the various inputs and export the harmonized data flow, which is then sent to the NetApp synchronization subcomponent. Eventually, the final choice regarding whether or not to activate the alarm is made, and the worker is warned if he has entered the restricted area. The 5G KPIs of the demonstration include increasing the average service deployment cycle time to 90 minutes, with an end-to-end delay of 50-100 milliseconds, and 99 per cent network availability/reliability. The 5G services that will be demonstrated include (i) 5G Core with a User Plain Function at the edge to enable local breakout and (ii) 5G Stand Alone network with dedicated capacity for UC services.

B. Testing scenarios

Workers will receive a personal locator through UWB with a unique identifier. There will be a database on the back-end where all IDs will be saved. API will be used to supply the data. All possible back-end operations must be specified in advance. Optionally, we develop a front-end application that administrators can add/remove/modify individual IDs and generate a dynamic list of IDs with access permissions. A reader device will be installed on the gateway and connected to the 5G module, which will query the server to determine if the employee ID is in the database and if entry is permitted.

V. Validation and Verification Framework for NetApps

The Smart5Grid Validation and Verification Cycle (VV Cycle) will include several components that will aid in developing, validating, and verifying NetApp workflows that can be implemented on the Smart5Grid platform. Furthermore, Smart5Grid will embrace the DevOps paradigm for providing access to the Smart5Grid open platform, enabling faster and continuous software delivery, less complexity to manage, and faster resolution of possible vulnerabilities and problems, resulting in NetApps that are more reliable and take less time to produce. The project's proposed DevOps approach will be used for flexible configuration, performance, and fault management in the open Smart5Grid platform and involve engineers, developers, SMEs, and third parties in obtaining, operating, and validating their own energy-oriented NetApps and services.

VI. Conclusion

This paper's primary objective was to outline the Smart5Grid NetApp idea followed by the UC on ”Remote Inspection of Automatically Delimited Working Areas at Distribution Level”, including the platform architecture, its

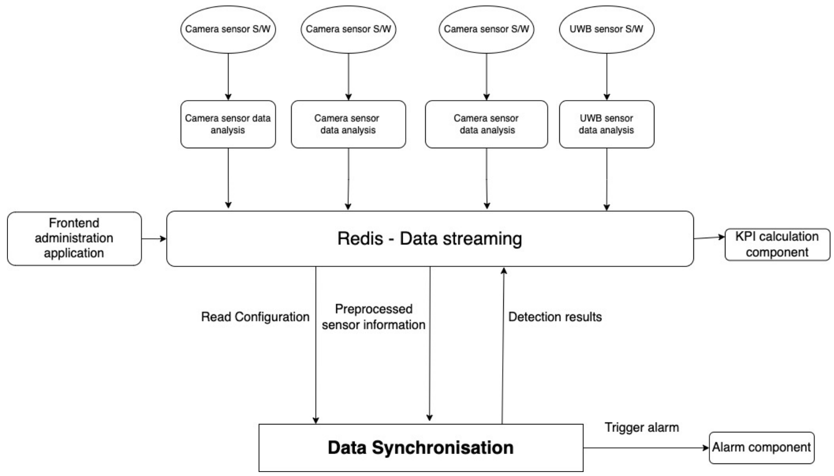

Fig. 4. NetApp Software Component Architecture

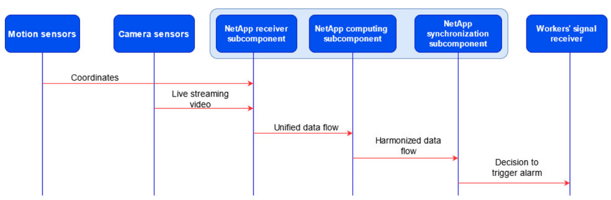

Fig. 5. NetApp flow of information

components, and their interconnections. The state of the art and other initiatives pertinent to the project was given to provide a solid foundation for the subsequent design and specification work. Smart5Grid will enable an environment where cloud-native NetApps may actualize the integration between the energy vertical and 5G networks, emphasising installations that employ edge infrastructure. Numerous 5G PPP initiatives from previous phases have published results that serve as a starting point for Smart5Grid, and the results of more recent projects will be actively watched to ensure a strong alignment with those results. This study emphasizes the need to reduce the difficulties vertical application developers have while working with 5G networks by shielding them from the intricacies of the most recent generation of telecommunications networks. Regarding the services supported by the described UC, the subdivision must be accomplished in real-time, and the data processing and warning signal must be transmitted as quickly as possible. This will be achieved due to the usage of a 5G New Radio (NR) private network with edge computing capabilities, which will provide low latency and high data transmission capacity

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