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Towards Unified Automation Platform for Industry 4.0 realization using Private 5G Networks

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Abstract: - Private 5G had become de-facto technology for realizing Industry 4.0 to have a whole new user experience for industries interconnecting all the objects, machines, and humans to realize the use cases covering factory floors and supply chain warehouses. The automation developed to realize Industry 4.0 heavily depends on communication technology, the applications such as augmented or virtual reality require incredibly high data rates, motion control/robotics have rigorous requirements in terms of reliability/ latency, and wireless sensor devices require more massive machine-type connectivity. Private 5G networks are an essential means of achieving high speed, reliability, low latency, and secured connections for realizing Industry 4.0/5.0. However, the complexity of commissioning private 5G Networks, technical skills and expertise required to manage the Private 5G network and integrate them with the legacy systems and networks are the barriers to deploying private 5G networks for industries. The most common approach for enterprise to private 5G adoption is to look for one-stop solution providers who can provide a common platform for end-to-end industry 4.0/5.0 automation covering the industrial devices, edge platforms, Private 5G and vertical industry applications that could be deployed on-premises in the Edge and as well in the cloud. This paper is concerned with studying and doing a comparative analysis of the existing Industry 4.0 automation solutions using private 5G which provides end-to-end industry 4.0/5.0 automation and assessing the gaps in existing solutions and identifying the concepts to develop a unified automation platform.

Keywords: Industry 4.0, Private 5G, 5G Non-Public Networks, OPC UA

I. INTRODUCTION

Industry 4.0 has revolutionized the manufacturing sector by interconnecting machines, devices and computer applications to promote the production of innovative products through process automation and creating an intelligent supply chain. Industry 4.0 isolated the workforce from automated industries focusing more on large-scale productivity and interconnecting industrial devices and applications. While Industry 4.0 ignored the human and environmental impact aspects, Industry 5.0 standards ensure the sustainability of civilization beyond jobs and growth by reducing waste generation, making production respect the boundaries of our planet and leading to a pollution-free environment [1]. The fifth industrial revolution complements Industry 4.0 with a primary focus on intelligent manufacturing by having human intelligence to co-work with machines on the production floor by enabling sophisticated industrial devices to collaborate with humans, thus augmenting human intelligence and creativity for industrial automation. The automation developed to realize Industry 4.0/5.0 heavily depends on communication technology [2]. With the advent of Private 5G, the top hyperscalers such as AWS, Azure, and Google are also working towards simplifying the commissioning and management of Private 5G networks along with their customized cloud offerings for vertical industries. The background section elaborates on the importance of a private 5G network in industrial automation based on detailed literature reviews. In the subsequent section, the authors compare various vertical industry offerings and private 5G network initiatives by hyperscalers. Further sections identify the gaps and challenges in deploying the Private 5G solutions for industry 4.0/5.0 automation and hence the need for Unified automation platform architecture.

II. BACKGROUND

The following section provides a detailed review of the literature on technologies that enable Industry 4.0/5.0, the importance of wireless communication technologies, particularly private 5G and the challenges in deploying the private 5G network in enterprises.

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A. Industry 4.0/5.0 Enabling Key Technologies

Industry 4.0 uses vital enabling technologies: Big data and analytics, AI, ML, Autonomous robots, Industrial Internet of Things(IIoT), Cyber-Physical Systems (CPS), Cloud and Edge Computing, Additive Manufacturing, Virtual and Augmented reality (VR/AR). On top of these, Industry 5.0 identified a few other enabling technologies, namely Human-machine interaction technology, Bio-inspired technologies, Digital Twins, and technologies for energy efficiency.

Industry 4.0/5.0 standards aim to transform industries into smart and resilient factories by integrating all the entities from end-users to production floors to suppliers using digital technologies as shown in Fig. 1. Realizing both Industry 4.0 and 5.0 standards using automation requires a large amount of data to be collected at the source and transported to the cloud for processing [4].

Fig. 1 Industry 4.0 and 5.0 Key enabling technologies [1][3]

The availability of different edge cloud computing platforms enabled the industries to move their factories near to the location where the raw material is available and use centralized cloud computing platforms along with AR/VR/tactile internet technologies to control the machines and the operations of the plants from a remote location [5]. The applications deployed in edge cloud platforms enable low latency, data security, and privacy by reducing the amount of data sent to a centralized cloud [6]. All things and humans interconnect as part of this industrial revolution will require hi-speed, high reliability, low latency, and secure communications to bridge the physical and digital worlds and blur the lines between them [8].

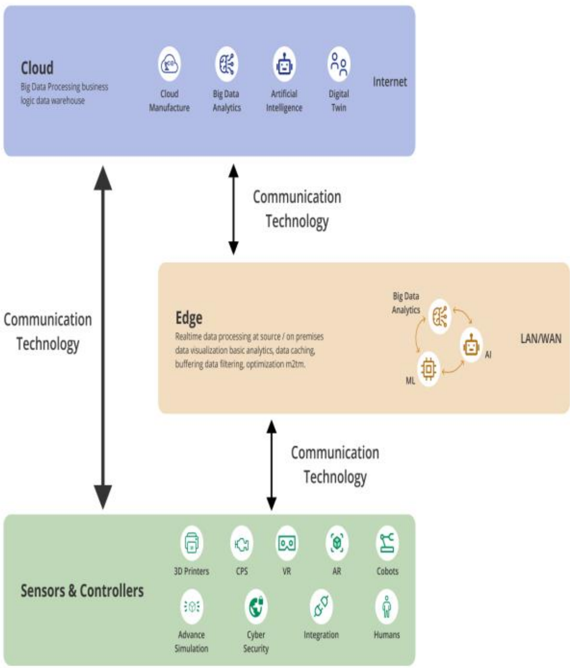

Fig. 2 Need for reliable communication infrastructure in hierarchical architecture [7].

As smart factories become more dynamic, wireless communication with low latency, high speed, and increased network bandwidth is essential for the devices roaming on the factory floor to communicate seamlessly with the digital technologies on Edge and cloud. Moving production assets with network cables attached to them require frequent cable replacement, causing downtime to impact production [9]. Communication technology is a crucial driver for Industry 4.0/5.0 realization [10].

B. Private 5G Networks

3GPP Release 14 defines Non-Standalone deployment (NSA) of 5G cellular networks, deployed along with 4G LTE technology as an interim solution [12]. 5G more specifically Private 5G Network shall empower the manufacturing industries to leverage more and more cyber-physical systems and mobile applications based on mobile phones/tablets to realize its use cases covering factories, plant floors, supply chains, and warehouses. As shown in Fig. 3, 5G supports enhanced mobile broadband (eMBB) with a peak download rate of 20 Gb/s and download speed of 2,560 MB/s, and a peak upload rate of 10 Gb/s and upload speed of 1280 MB/s, thereby enabling a rich experience for VR and AR covering various industrial use cases [11]. 5G architecture shall enable massive machine-type communications (mMTC) for autonomous devices (industrial sensors, actuators, machines) and other types of machinery [13]. Ultra-reliable low latency communications (URLLC) support end-to-end network communication latency from factory locations to edge cloud applications to be lower than 1 ms and provide high reliability for machinery data communications [13].

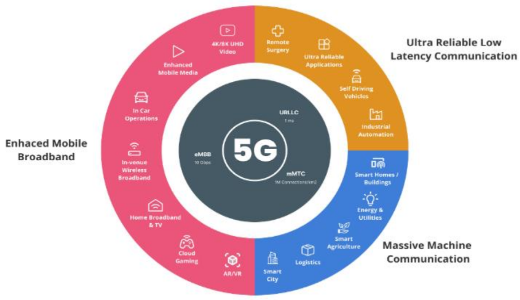

Fig. 3 Three usage classes of 5G [14]

A Private 5G network, refers to a 5G cellular network deployed exclusively in the industry premises to serve a more extensive factory with custom SIM, dedicated 5G Radio (5G NR), Virtualized Control Unit (CU), Distributed Unit (DU), 5G Core (5GC), Virtual Software Defined Networking (SDN) and other time-sensitive industry applications [15]-[18]. The main concerns or challenges for industries using public 5G networks owned and operated by mobile network operators are reliability, low latency, service quality, security, and compliance[19]. Large and technology-centric industrial companies prefer to use locally stored data on their premises and apply customized security policies to prevent data breaches and cyber-attacks [20]-[22]. In contrast, operator-owned public 5G networks do not provide this flexibility [23]. Compared to public mobile networks, Private 5G Networks in Industry 4.0/5.0 use cases offers Guaranteed coverage [20] and Complete network control over data privacy [24]. The use of dedicated radio access network equipment in factories allows it to be independent of traffic congestion compared to the mobile operator-owned public network, where there are possibilities of weak coverage in remote areas or locations unfavourable to RF conditions [20]. The private 5G network is tailor-made and under the enterprise's complete control as all the control plane and data plane traffic flows within the enterprise premises and can be independently managed by its owner, who can control every aspect of the network covering resource assignment, security, prioritized and data privacy [24].

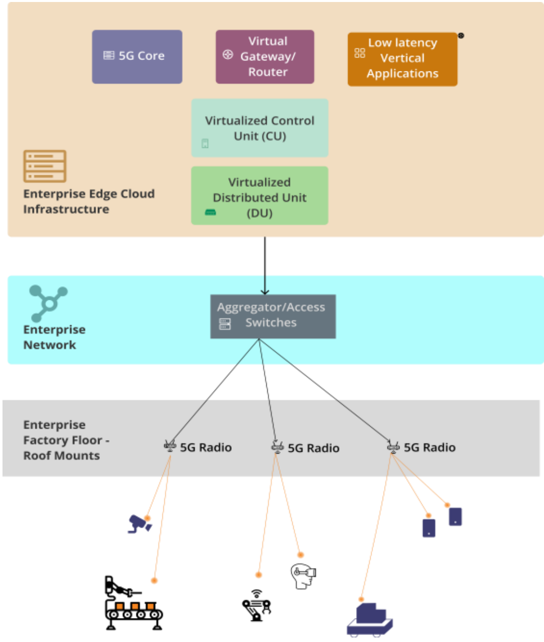

Fig. 4 On-premises private 5G deployment

C. Challenges in deploying Private 5G Networks

Private 5G networks have attracted significant interest, offering compelling benefits to industry 4.0/5.0 use cases leading many manufacturing industries, other operational technology, and neutral host providers to look for integrated solutions. Some industries have used out-of-the-box or do-it-yourself approaches, and this might be an alternative to Wi-Fi suitable for small deployments with some limited use cases. However, planning and deploying a best-in-class private 5G network involves choosing the correct deployment scenario/architecture comprising heterogeneous building blocks [25][26]. The building blocks such as Edge/Fog/Cloud, the 5G Next Generation Radios, virtualized CU & DU, 5G Core, switches, routers, SDWAN, MPLS VPN for site-to-site connectivity and vertical industry applications are usually from different vendors [21]. It requires close collaboration across the enterprise between all systems, communication technologies and manufacturing technologies to maximize the capabilities inherent in 5G [27]. Radio Frequency (RF) engineering and network planning are critical for ensuring complete and efficient radio coverage on factory floors so that there are no gaps and interferences in radio coverage [28]. Ensuring end-to-end quality of service (QoS) with reliable and highly available private 5G coverage with regular monitoring and maintenance of 5G infrastructure with zero downtime is critical for business continuity in the industries [29]. The top barriers to deploying private 5G networks are 1) integrating 5G technology with legacy systems and networks, 2) Complexity in initial commissioning and management of private 5G network elements, and 3) a Significant learning curve in acquiring technical skills and expertise for existing employees to the manage the 5G networks [30] 4) Overcoming the security challenges in deploying private 5G along with IoT Devices/Distributed clouds/virtualization/multiple technologies [31]. The mobile network operators (MNO), in addition to supporting public 5G networks, also started offering private 5G networks for enterprises. MNO has to make a few enhancements to their operating procedures, considering the different stakeholders involved and the challenges in commissioning and maintaining the Private 5G network [32]. Even though most industries already possess an IT team, due to the complexities of RAN Architecture and the lack of knowledge, they cannot bring up the private networks by themselves, as deploying private 5G networks has been challenging, confusing and expensive [33].

III. Comparison Of Existing Solutions For Industry 4.0/5.0 Realization

The top Hyperscale cloud providers such as AWS, Microsoft Azure, and Google have been dominating the public cloud offerings related to Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and Software as a Service (SaaS) [34]. These cloud providers also started expanding their offerings into the cloud continuum

[35][36] and numerous vertical industries, mainly focused on industry 4.0/5.0 automation platforms which significantly reduces the management overhead for IT operations for vertical Industries.

A. IaaS Offerings For Industry Automation

Table 1. tabulates the different IaaS platforms offered by hyperscalers that industries could leverage for deploying Industry 4.0/5.0 technologies in Cloud Continuum.

TABLE I

IAAS CLOUD PLATFORMS [37]-[39]

Cloud Platforms	**IaaS Cloud Platform**		
	AWS	**Azure**	**Google**
Hyperscaler Managed Local Cloud	AWS Local Zones	Azure Edge Zones	Google Network Edge
Multi-Access Edge Cloud Platform on Carrier Data Center	AWS Wavelength with Verizon	Azure Edge Zones with AT&T	Global Mobile Edge Cloud with AT&T
On-premises Private Edge Cloud-based on an appliance	AWS Snow Family, AWS OutPosts	Azure PMEC, Azure Stack Edge	Anthos for Telecom
Cloud Platform SW Stack deployed in the enterprise data centre using Customer H/W	Not available	Azure Stack	Google Distributed Cloud

B. SaaS Offerings For Industry Automation

The hyperscalers have extended the Software as a Service model for Industry 4.0/5.0 automation by simplifying the application bring up and providing cost-effective, fully managed, reliable, highly available, and scalable applications. Table II. Tabulates the managed SaaS solutions that industries could leverage for Industry 4.0/5.0 automation.

TABLE II

SAAS OFFERINGS FOR INDUSTRY 4.0/5.0 AUTOMATION [40]-[42]

Industry 4.0/5.0 Technology	**SaaS Platform**		
	AWS	**Azure**	**Google**
Autonomous Robots	Amazon Robotics & Amazon Robo maker	-	Intrinsic
Industrial Automated Guided Vehicle	AWS IoT RoboRunner	Automated guided vehicles fleet control	-

		architecture based on Azure IoT Stacks	
Computer/Machine Vision	AWS Panorama,Amazon Rekognition	Azure Percept,Azure Video Analyser	Vision Inspection
Industrial Sensors	Amazon Monitron, AWS IoT GreenGrass, AWS IoT Core, AWS IoT Device Management	Azure IoT Central, Azure IoT Edge,Azure IoT Hub	GC IoT Core
XR(VR/AR)	Amazon Sumerian	Unity, Unreal, HoloLens 2	AR Core Cloud
AI/ML/Big Data Analytics	AWS AI Services (AWS Lookout), AWS ML Services (AWS SageMaker, Augmented AI), AWS EMR, AWS Kinesis	Azure AI, Azure ML, Azure Synapse Analytics and Azure DataBricks	Vertex AI, AutoML, Google Big Data Services
Digital Twin	AWS IoT TwinMaker	Azure Digital Twin	Supply Chain Twin

C. Private 5g As A Service

The hyperscalers, in addition to offering IaaS/SaaS solutions covering the vertical industry are now engaging in providing the Private 5G network with a standard set of tools that are tailored services ready to use out of the box for Industry 4.0/5.0 automation. The hyperscalers, in collaboration with global telecommunications partners, have created a cost-effective Private 5G network solution with carrier-grade core network functions, Operations Support System/Business Support System (OSS/BSS), and Vertical industry applications, all running in different cloud hierarchies as well as on-premises. The following table lists the different Private 5G Solutions offered by hyperscalers.

TABLE III
PRIVATE 5G NETWORK OFFERINGS [43]-[49]

Private 5G Network Components	**Private 5G Offerings**		
	AWS	**Azure**	**Google**

5G NR	Fully Integrated hardware and Software delivered as AWS Managed Service model.	Partner Provided	Mobile Network Operator Provided/ Partner Provided
5G CU/DU		Partner Provided	
5G Core		Azure 5G Core	
5G SIM		Partner Provided	
Orchestrator		Azure Network Function Manager	
RAN Management System		Partner Provided	
Spectrum Access System(SAS)	Partner Provided	Third-party	Google SAS

IV. Research Discussion

The most common approach for enterprise to private 5G adoption is to look for one-stop solution providers who can provide a common platform for end-to-end industry 4.0/5.0 automation covering the industrial devices, edge platforms, Private 5G and vertical industry applications that could be deployed on-premises in the Edge and as well in the cloud. Hyperscaler-based solutions analysed above are the only possible option for one-stop solutions covering end-to-end industry 4.0 realization however following gaps still exist in those solutions which impede enterprises for Industry 4.0/5.0 realization.

A. Gaps in existing solutions/architectures

- The solutions offered by hyperscalers are still disjoint covering Factory floor IIoT automation to Private 5G infrastructure to Edge/Fog Cloud infrastructures to Central cloud vertical applications.
- Enterprises must still incur significant IT/OT effort to integrate all these different layers to realize industry automation.
- Hyperscalers solutions out of the box don't provide a unified user interface for enterprises to automate, manage and monitor factory devices, Private 5G communication infrastructure and vertical applications. Enterprises must access different interfaces and manually correlate the relationships between different layers.
- In case of any anomaly or failures or production defects, there is no straightforward way to identify the root cause i.e. whether the issue is caused by factory automation devices or latency incurred by 5G communication medium or misconfigurations in vertical applications.
- Enterprises must incur significant effort to integrate data streams from different layers to create a different insight for operational and environmental efficiencies/predictive maintenance.
- User/Role management as well gets complicated and results in an involved effort to integrate different layers.
- Using a single hyperscaler solution for all layers creates vendor lock-in thereby compromising on solutions, as the enterprise must use only the tools/features supported by the vendor.

V. Ongoing research

From the study it is imperative that using a one-stop solution by a single vendor is not the right approach for enterprises due to the various drawbacks mentioned above and is essential to have a framework which could provide a single pane of the interface as shown in Fig. 5. for end-to-end industry 4.0/5.0 automation with following capabilities:

- Support integrating the legacy systems covering the enterprise factory floor IoT Systems, Private 5G Networks and industry vertical applications from multiple vendors behind the scenes and thereby hiding all the complexities to the enterprises.
- Support flexible and simplified deployment models hiding the deployment complexities of Private 5G components
- Support lifecycle management across Industrial IoT Devices, Time Sensitive Networks (TSN), Private 5G Networks and Vertical applications as a unified solution.
- Support Fault, Configuration, Auditing, Performance and Security management for all layers
- Supporting OT/IT use cases across all layers
- New Product or Process introduction with unified automation across all layers

The ongoing research work on Unified Automation Platform architecture leverages dimensions defined in the Reference Architecture Model for Industry 4.0 (RAMI 4.0) [50] to provide different user persona-based user interfaces for realizing the Industry 4.0 automation in the enterprises as shown in Fig. 5. The architecture shall provide unified user experience to the enterprise existing OT/IT teams without the need to gain in-depth 5G skills to manage the automation platform. The platform extends Open platform communication Unified Architecture OPC-UA [51] to connectivity to Private 5G components covering 5G RAN (CU, DU, NR) and 5G Core to support NetConf and other protocols. The architecture shall be based on the federation layer to provision and manage different entities seamlessly. The Unified Automation Platform enables Enterprises to focus on manufacturing process optimization, targeting defect minimization and significant energy reduction and also concentrates on predictive maintenance of the machining tools which can also greatly contribute to OPEX reduction and equipment effectiveness.

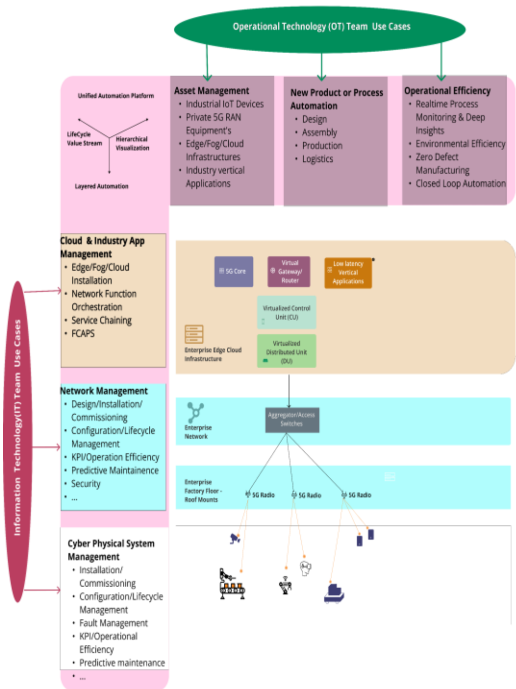

Fig. 5 Unified Automation Platform

Conclusions

The digital factory is a crucial enabler for Industries to continuously innovate to create new revenue streams, reduce costs, increase efficiency and build eco-friendly industries. It is critical to have a robust wireless communication medium that can transfer data at a high rate and low latency for interconnecting intelligent devices, applications, and humans in a digital factory. Private 5G is an essential enabler of this digital transformation. Existing literature extensively covers industry 4.0/5.0, private 5G networks and their applicability to industry 4.0/5.0. For the first time in this paper, the authors summarize the comparisons between different hyper scalers solutions for private 5G networks and their industrial automation solutions which will provide good insight for enterprises to leverage these solutions. This paper outlines ongoing work on the architecture, design and implementation of unified automation platform concepts which addresses the gaps identified in single-vendor solutions. The architecture presented in this paper also leaves room for detailed design and solving problems at further granular levels which are under study. For example, simplifying the Radio Planning in Industrial environments using AI based Path loss propagation algorithms, simplifying the management of Private 5G RAN like WiFi equipment's so that the deployment of Private 5G can be carried out by enterprises existing OT/IT teams without dependency to third party system integrations..

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