Network Slicing Strategies for Smart Industry Applications

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***Abstract*—The dawn of smart industries will utilize myriads of interconnected machines, devices, and sensors in factory environments to perform intelligent operations. This paradigm demands satisfying diverse communication requirements through strong network connectivity and services. Network Slicing (NS) in the fifth-generation (5G) and beyond networks is a pragmatic technology that can be utilized to satisfy the communication requirements of smart industries. This paper provides a comprehensive insight on how different NS strategies can be utilized to realize smart industry applications. Furthermore, we simulate a smart factory environment to evaluate the performance of different slicing strategies under two network statistics: bandwidth utilization and the number of connected clients, along with different base station arrangements.**

***Index Terms*—Network Slicing, 5G, L5GO, MNO, Smart Industry**

I. Introduction

Smart Industries mark a new era of industrial revolution that relies rigorously on inter-connectivity, automation, real-time data processing, and new trends such as big data and machine learning towards transforming industrial manufacturing systems into intelligent cyber-physical systems [1]. This paradigm is also referred to as Industrial Internet of Things or smart manufacturing and comes into play with Industry 4.0. Manufacturing or a supply chain management environment with automated guided vehicles, mobile robots or collaborative robots supporting automation, and uninterrupted workflows with real-time data collection and manipulation in a better-connected ecosystem is the expected smart industry revolution from Industry 4.0 and beyond [2]. Industrial networks should have revolutionary alterations to accomplish these requirements.

The number of connected devices in factory environments increases rapidly, and they will interact with cloud services continuously to make intelligent services [3]. Moreover, different industrial applications will have diverse network requirements such as security, privacy, latency, and reliability. Facilitating these requirements over traditional telecommunication networks is a cumbersome operation. Therefore, the 5G architecture and beyond networks with their advent technologies should be carefully designed to accomplish these requirements.

The traditional Mobile Network Operators (MNO) consider serving the heterogeneous network requirements of a specific application in a high-level manner. Addressing the custom requirements demanded by the different use cases at a specific geographical location intensifies the requirement of a local network management entity. Local 5G Operator (L5GO) is one of the promising advents in 5G, which serves as a private network for specific applications like hospitals, industries, schools, etc. [4]. L5GO networks satisfy the aspect of catering the network services based on the demand of the users while improving the efficiency of the communication system and ensuring their Quality of Service requirements. Hence, L5GO is becoming an area where researchers pay more interest to investigate.

NS is an innovative technology in 5G and beyond networks due to its ability in dividing the physical network into multiple logical networks that are specified for facilitating diverse network requirements of different applications [5]. NS supports the realization of the smart industries by allocating dedicated slices with different network properties for industrial applications. NS utilization for industrial applications has been discussed in the existing literature. In [3], [6], Anders et al. consider NS as a mechanism to facilitate diverse network requirements of industrial networks. Network slice management with possible slicing strategies is extensively investigated in [7]. However, the impact of different slicing strategies on different network statistics is rarely investigated, considering industry environments.

Our Contribution: This paper mainly focuses on network performance based on network ownership (L5GO and MNO) under different slicing strategies in a smart industry environment. We provide insight into different NS deployment scenarios: L5GO based, MNO based, static, dynamic, vertical and horizontal in industry applications. Later, we confine our discussion to two main scenarios of NS based on slice ownership: L5GO and MNO. We further demonstrate how static, dynamic, vertical and horizontal slicing deployments cater the user-specific network requirements under different L5GO environments and how MNO environments behave with static and dynamic slicing deployments.

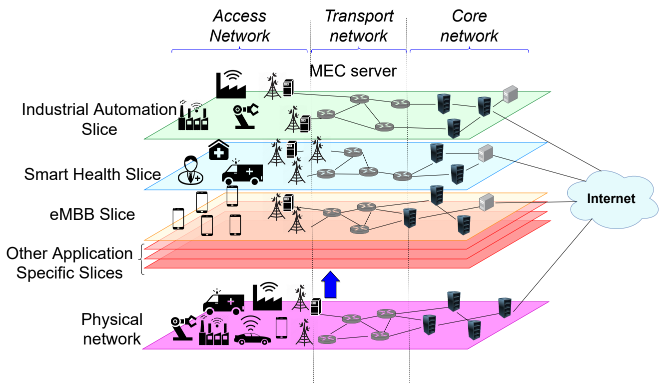


Fig. 1: Network Slicing architecture

The remainder of the paper is organized as follows. Section II gives an insight on NS, the different classifications of NS, and how the environments are classified under different slicing strategies. Section III presents the experiment setup and configurations with the justifications of the experimental parameters. Section IV discusses the obtained results for the different slicing techniques under varying network configurations for L5GO and the static and dynamic slicing deployments for MNO operated factory. Finally, section V concludes the paper and presents the future research directions of our research.

II. Network Slicing Deployment for Smart Industry

This section introduces the network slicing concept, the smart industry use cases, and the slicing strategies in an industry environment.

A. Network Slicing

NS is the method of dividing the physical network into multiple logical networks specified for specific applications. Figure 1 illustrates the concept of NS. Altering the composition of network functions in network slices leads the way to induce different network characteristics. NS is an End-to-End (E2E) technology that spans over Radio Access Network (RAN) to the core network. Primary service areas in the 5G architecture, enhanced Mobile Broadband (eMBB), Ultra Reliable Low Latency Communications (URLLC), and massive Machine Type Communications (mMTC), can be realized using NS.

B. Smart Industry Use Cases

3GPP has categorized factory use cases into five broad categories; Factory Automation, Process Automation, Human-Machine Interaction and Production IT, Logistics and Warehousing, and Monitoring and Maintenance [8]. Each category demands its requirements depending on latency, data volume, mobility patterns and operation areas specifications. Considering the case-specific communication and operating requirements, the stated categories are defined under four use cases: Augmented Reality (AR), Mobile Robots, Machinery, and Wireless Sensor Networks.

1) AR Assisted Devices

Identifying production flows, real-time monitoring and assistance in carrying out pre-defined tasks mainly lists down the role of AR devices in a smart factory environment. As the functionality, AR device captures images and transmits them to an image processing server where the images are processed, and processed information or control signals are then sent back to the AR device for display purposes. The network requirements for AR assisted devices are low latency, high data volume, high data rates and these demand AR devices to have a separate slice defined for AR [9].

2) Mobile Robots

Mobile Robots are programmable machines for miscellaneous operations. These can be either Automated Guided Vehicles/ Devices or automatic/ remotely controlled machines. Industry 5.0 introduces robots who can work collaboratively with humans in the production lines. They are assigned to dedicated tasks such as assembly of parts, providing assistance to humans, and transporting semi or fully finished products within the factory environment. The advantages of faster reaction ability and more exact movement patterns and orientation capabilities are the key reasons in introducing the robots co-work within factories. These robots should operate with a very low latency of 1ms - 500ms depending on the robot type [7].

3) Machinery

This is the use case of the machines, devices, appliances, apparatus and tools used in the factory environment. These are accessed and maintained remotely and exhibit very low mobility patterns and low data rates, and data volume.

4) Wireless Sensor Networks

The sensor network in a factory premise monitors the environment variables such as temperature, humidity, pressure, etc. The continuous monitoring of these parameters is crucial in ensuring that the desired conditions within the environment are maintained and to detect and alert any malfunctioning of the systems to take any precautionary measures in mitigating the upcoming failures of the environment. The condition monitoring sensors need to operate with very low latency, and some other sensors demand latency around 1s [7].

In addition to these defined use cases, factory workers, products and general services are considered under a general use case. For this use case, the latency is not critical and may not demand very high data rates.

C. Network Slicing Classification

The operators can deploy network slices in different ways to fulfil the network requirements for each use case and application. Classification of NS can be considered under three categories: Based on ownership, Based on dynamicity and Based on application.

1) Classification based on ownership

This classification is based on the role of creating slices, managing configurations and slice management in the network. **L5GO Slicing:** Local 5G Operator is a novel concept that enables the deployment of local cellular networks for facilitating specific network requirements of a particular vertical within a locally restricted region [10]. For instance, smart hospitals, factories, and universities are verticals that a specific local network can serve. The attention towards the L5GO concept increases rapidly due to the ability to fulfil the case-specific or location-specific services of a particular vertical than the conventional MNO concept as it is heavily serving to masses [9]. From the slicing deployment perspective, the local network can be further sliced to facilitate network requirements of specific use cases. In this slicing category, slice ownership is maintained by the local operator. The slicing arrangement in the local network is not visible to the MNO. In this smart industry vertical, the slice configuration can be done considering the different use cases. A dedicated network slice can be allocated for each discussed use case: slice for AR applications, slice for mobile robots, slice for machinery, slice for wireless sensor networks. Additionally, a separate general slice can be allocated to fulfil the general network requirements of the users.

MNO Slicing: The traditional NS paradigm belongs to this slicing category. The MNO manages the slice life-cycle, which includes slice creation, operation, modification and termination. As the Network Operator has to handle many applications and use cases, the slice arrangement is designed at a very high level. MNOs create slices considering the verticals that the operator has to facilitate. For instance, MNOs allocate one slice for industries, and for autonomous vehicles, a separate slice is created. The particular slice provides the demanded network requirements for all the use cases of the vertical. AR assisted devices, mobile robots, wireless sensor networks, and machinery use the general industry slice to accomplish their network requirements for the smart industry vertical discussed in this paper. In addition, other industries also use the industry slice created by the network operator, and the performance of all industries collectively impact the performance of the industry slice [7].

2) Classification based on dynamicity

Allocation of resources for the slices in the network considering the demand for each slice is considered in this classification. The allocation can be dedicated or varying depending on the strategy. This subsection discusses the static slicing and dynamic slicing techniques.

Static Slicing: Static slicing deployment allocates a predefined set of slices with a constant amount of network resources. In the smart industry scenario, the defined use cases are allocated to dedicated network slices: Slice for AR assisted devices; Slice for mobile robots; Slice for Machinery; Slice for wireless sensor networks; Slice for general user communication services within the factory. As the name implies, the capacity of each network slice remains consistent the whole time. The connectivity of the users happens with the availability of the resources. Hence, defining the slices and capacity for each slice needs to be performed precisely to ensure uninterrupted connectivity for clients. The decisions can be either based on historical traffic data or as per the tenant's requirements [11].

Dynamic Slicing: NS needs to facilitate diverse applications within the network and the heterogeneous network requirements of its services and clients. Dynamic deployment of network slices enables operators to establish different configurations on a shared network infrastructure [12]. Dynamically designed slices can be deployed and customized as per the network's service requirements and resource availability. Dynamic slicing makes the resource utilization in the network more efficient by allocating idle resources to congested slices. In contrast to a network with static slicing, the resource allocation of the slices in a network with dynamic slice deployment tends to show variations over time. The challenge in dynamic slicing lies in maintaining the expected QoS requirements. In the smart industry environment, the slicing arrangement is the same as in a static scenario, but the slice parameters and bandwidth (BW) utilization change dynamically based on the traffic flow [13].

3) Classification based on application

The slice creation and deployment can be done based on the applications in the environment or the service requirements within the network. Hence, a slicing strategy can be classified as either vertical or horizontal by the technique of defining the slices for the network.

Vertical Slicing: For the vertical slicing strategy, the slice allocation is based on the use cases in the system [14]. For smart industry use cases, five slices can be defined for vertical slicing deployment: Slice for AR assisted devices; Slice for mobile robots; Slice for Machinery; Slice for wireless sensor networks; Slice for general user communication services. The slice configurations can be defined based on the specific network and service requirements for each use case.

Horizontal Slicing: Horizontal slicing strategy focuses on the service requirements that need to facilitate in the particular environment rather than the use cases. A particular application may demand one or more services. Hence for a specific application, the network may need to facilitate multiple services [15]. For this slicing scenario, the slice arrangement in smart industry environment needs to cater four services with different service requirements. AR assisted devices demand three slices: AR services, video streaming and control signal communication. For massive wireless sensor networks, control signal communication is necessary. Machines and mobile

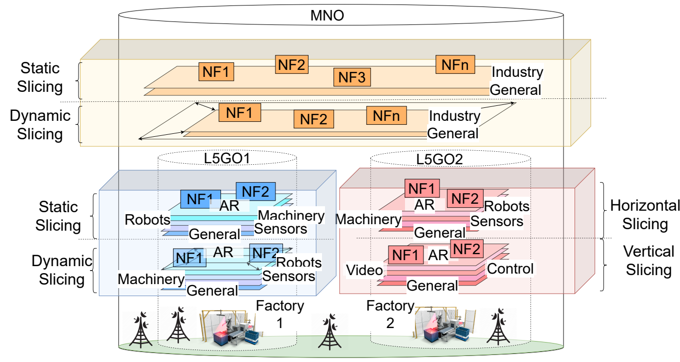


Fig. 2: Slicing strategies in smart industries

robots demand a video streaming service and control signal communication. Therefore, for an industry ecosystem, four slices can be arranged: Slice for AR services, Slice for video streaming, Slice for control signal transmission, Slice for general communication. For instance, AR assisted devices need to connect to three slices in the system to accomplish network requirements. These three slices can be of the same BS or different BSs.

L5GO and MNO strategies, classified based on ownership, are identified to gain more attention on smart industry applications [7]. Therefore, the other two slicing classification schemes are considered under these two categories. However, since the MNO slicing arrangements cannot be customized based on the applications, vertical and horizontal slicing techniques are discussed only for L5GO based ecosystem.

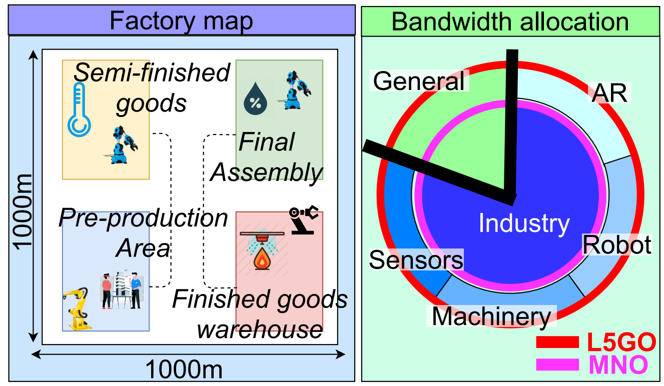
Figure 2 shows the deployment of network slices in a smart industry environment under different slicing strategies. Network requirements for factories in L5GO networks are facilitated by five slices, and the slices can be allocated and managed based on static, dynamic, horizontal and vertical strategies. In contrast, slice allocation in MNO networks are based on static and dynamic, and the slices are shared by all the factories covered by the particular MNO network.

III. Simulation setup

This section presents the experimental setup and configurations used in evaluating L5GO and MNO slicing strategies.The experiment has two parts; one for L5GO and the other for MNO network environment. Each setup runs for the identified NS strategies considering the factory environment with the discussed use cases.

Slicesim [16] tool is used as the base of the slicing simulation for the experiment. The tool provides a simulation suite for a network consisting of BSs and clients and models the intended environment with desired configurations. For our experiment, we modified the functionality of the tool to simulate different NS slicing strategies. Though the conventional slicesim tool simulates the static slicing scenario only, the modified tool is designed to simulate static, dynamic, horizontal and vertical strategies in both L5GO and MNO environments.

The geographical area in the industry environment is considered to be 1km * 1km. This area consists of a pre-production area, semi-finished goods area, final assembly area and a finished goods warehouse. In addition to these sub-areas, there are few defined routes for mobile robots. AR, Mobile Robots, Machinery, Sensor networks and general users demand communication services within the considered environment. The BS configurations for L5GO and MNO networks are decided based on typical and feasible conditions. The slices in the BSs are defined based on the users and the slicing strategy. The user distribution proportions within the factory environment are decided after considering real industry environments but not limited to a specific industry application. Each user is given mobility in each second according to the defined mobility patterns as shown in Figure 3, within one or more sub-areas within the factory premises. The mobility patterns are defined considering the existing standard values for each use case [7]. The geographical layout of the considered factory environment and BW allocation for each slice, along with client configurations, are depicted in Figure 3.



Client configurations

User type	Number of users	Mobility pattern	Data rate
AR	50	randint, [-1,1]	High
Machinery	200	randint, [-1,1]	Medium
Mobile Robots	150	randint, [-3,3]	High
Wireless Sensors	550	stationary	Low
General users	50	randint, [-2,2]	Medium
Total Users	1000		

Fig. 3: Experimental configurations

The BS distribution and the slice allocation in each BS are different in the two setups. For L5GO, the static, dynamic and vertical scenarios are configured with five slices, and for the horizontal scenario, each BS has four slices for AR, video, control and general. The MNO environment can only be configured for static and dynamic strategies. The same user distribution is considered for all the cases to discuss a clear comparison between the two environments with different slicing strategies. To increase the comprehensiveness of the simulation, the number of BSs in L5GO setups is varied. The results are obtained for L5GO factory environments with 4, 9, 16, 25 and 36 BSs when all slicing strategies are deployed separately. The MNO environment is kept constant with 4 BSs, and results are obtained for static and dynamic slicing strategies. All the BSs in the environment have been distributed symmetrically to cover the whole area. The simulation was executed for 500s, and the simulations were repeated 10 times with different random seeds to obtain more accurate results.

For the analysis, two network statistics are considered.

Number of connected users: This is the average number of connected users for each experiment during the entire simulation period.

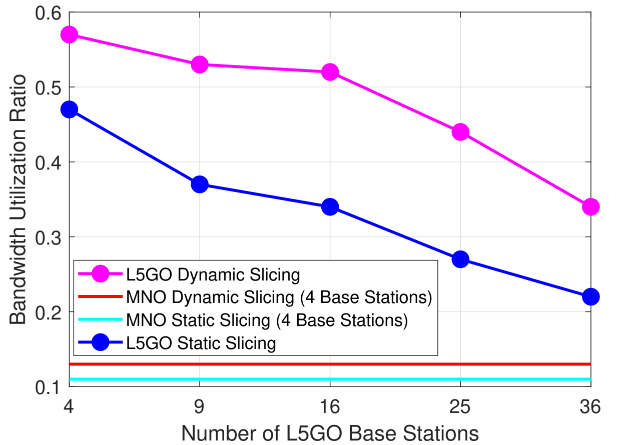


Fig. 4: Static vs Dynamic - Bandwidth Utilization Ratio

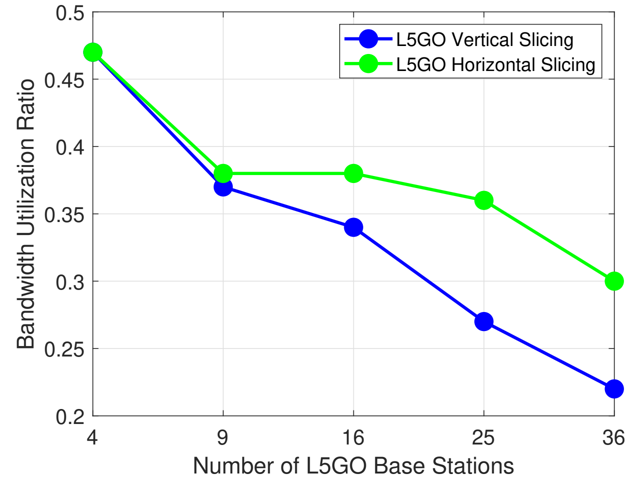


Fig. 5: Vertical vs Horizontal - Bandwidth Utilization Ratio

Bandwidth Utilization Ratio: This is the proportion of utilized BW to the total allocated BW amount.

$$\begin{aligned}&Bandwidth\ Utilization\ Ratio\\&=\frac{Used\ Bandwidth\ of\ all\ base\ stations}{Total\ Bandwidth\ of\ all\ base\ stations}\end{aligned} \quad (1)$$

IV. Results and Discussion

This section discusses the results of the experiment and the performance comparison of the different slicing strategies. The number of connected clients vs the number of BSs for L5GO-static, L5GO-dynamic, L5GO-vertical, L5GO-horizontal are compared. The same parameter is compared for MNO-static and MNO-dynamic scenarios. The same scenarios are considered for the BW usage ratio and the results are presented graphically.

A. Bandwidth Utilization Ratio for Static and Dynamic slicing

BW utilization for static and dynamic slicing deployments in both L5GO and MNO environments are depicted in figure 4. For all the considered cases, the BW utilization is higher for dynamic slicing than static instances. For a particular case, the users can retain connected or connect to the required slice in a new BS due to the dynamic nature of slice resource allocations according to the demand. The ratio decreases for all L5GO scenarios due to the redundant resources available. The BW utilization is most efficient when the environment is configured with four BSs.

In MNO based system, the BW utilization ratio holds low values for both static and dynamic deployments compared with L5GO systems. Low slicing arrangement (users have to connect to the common industry and general slices provided by the operator) in a MNO based system is the reason for this observation.

B. Bandwidth Utilization Ratio for Vertical and Horizontal slicing

BW utilization for vertical and horizontal slicing deployments in different L5GO environments are depicted in figure

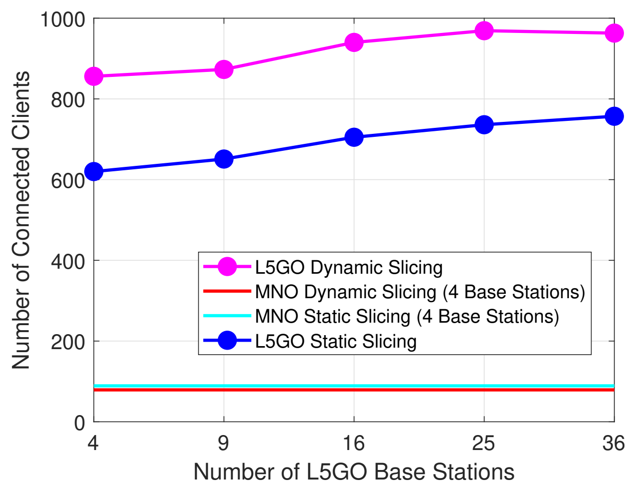


Fig. 6: Static vs Dynamic - Number of connected users

5. The BW utilization ratio decreases when the number of BSs increases. This is due to the total available BW increases with the increasing number of BSs, and hence, the surplus of resources increases. The efficiency in horizontal slicing deployment is greater than vertical slicing deployment due to its well structured slice arrangement considering the services.

C. Number of connected users for Static and Dynamic slicing

The average count of connected users for static and dynamic slicing deployments in both L5GO and MNO environments are depicted in figure 6. The resource availability increases when the number of BSs increases. Due to this, number of connected clients increases. Also, due to the dynamic resource allocation, more clients can connect in dynamic slicing.

D. Number of connected users for Vertical and Horizontal slicing

The average count of connected users for horizontal and vertical slicing deployments in both L5GO and MNO envi-

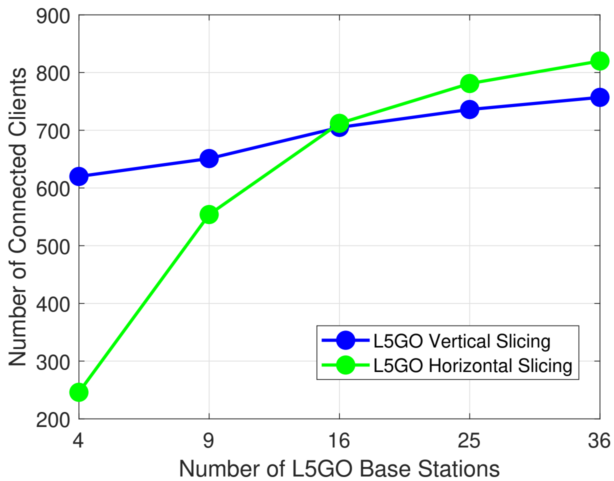


Fig. 7: Vertical vs Horizontal - Number of connected users

ronments are depicted in figure 7. Horizontal slicing shows a significant increase in the number of connected clients than vertical slicing. Also, with higher number of BSs, horizontal slicing caters requirements for more users than vertical slicing.

According to the results, L5GO has outperformed the MNO slicing environment. The efficiency in utilizing the available resources in the considered factory ecosystem decreases with the number of BSs. The best efficiency is shown at 4 BSs, and the value drastically falls after 16 BSs. In comparison, when the number of BSs increases, the network can facilitate more clients. The number of connected clients shows a considerable increment until 16 BSs. Therefore, for the considered industry environment in this paper, L5GO based system with 16 base stations with dynamic slicing deployment is the best strategy.

V. Conclusion and Future Work

This paper discusses how different NS strategies can be employed in smart industry environments. Several NS strategies have been discussed, elaborating slice configurations and characterizations. The paper mainly focuses on the network slice deployment for L5GO and MNO environments. For this, we use other slicing strategies to discuss how well each strategy supports the deployment. In addition, we discuss how the NS strategies in the L5GO environment differs with increasing resource availability. According to the results, the L5GO network with dynamic slicing performs well for a single-site factory environment. Consequently, the insights obtained through this comprehensive simulation study is expected to facilitate the development of NS technologies in 5G and beyond networks towards facilitating large scale and multi-site industry applications. For future telecommunication networks, L5GO will play a significant role for smart industries.

As future work, the study can be further extended towards a hybrid mechanism of L5GO and MNO. Also, research on deploying different NS strategies for a wide range of environments like large scale and multi-site factories can be conducted. Another future research direction would be to consider a federated network, where multiple operators facilitate the network requirements.

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