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Network Slicing for IoT Ecosystem in 5G Networks

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Abstract: The Internet of Things (IoT) is a new technology that improves the quality of people's lives by dominating a wide range of applications and service sectors. Fifth-generation (5G) wireless networks will soon be able to link this IoT ecosystem. It has been thoughtfully created to support the IoT industry's explosive development. One of the essential technologies in the 5G architecture, network slicing allows for dividing the physical network into several logical networks (i.e., slices) with various network properties. As a result, network slicing is a crucial driver of IoT in 5G. Through dedicated slices, network slicing can meet the different networking needs of heterogeneous IoT applications. We thoroughly review network slicing's use in IoT realization in this study. We cover network slicing in various IoT application scenarios and the technical problems that can be resolved using network slicing. This paper also discusses open research issues and integration challenges linked to network slicing in the IoT ecosystem.

Keywords: Network slicing, IoT, 5G, SDN, NFV, network architecture, latency, reliability.

I. INTRODUCTION

Over the past forty years, the Internet has developed from basic peer-to-peer networks to a cutting-edge IoT environment. The widespread use of IoTs has made everything around us smarter. With network access, it is possible to link people and objects at any time and from any location to receive information about them, use them, or even a combination of the two to improve humankind's quality of life. Devices that are linked are multiplying exponentially. By 2024, there will likely be 27 billion connected devices. These IoT applications will become more diverse, ranging from straightforward smart house solutions to vital healthcare systems [1].

These application scenarios demand numerous performance criteria, including low latency, extreme reliability, high security, and high data rates. Network slicing divides the physical network into logical pieces. Each slice can give specific network capabilities and characteristics [2]. Enhanced Mobile Broadband (eMBB), Massive Machine Type Communications (mMTC), and Ultra-Reliable Low-Latency Communications (URLLC) are the three primary basic service classes that the 5G network architecture is intended to support [2]. There are various network needs for each service class. An E2E network slice must be created for each service scenario to distribute the necessary resources to meet these requirements. Similar to this, various IoT applications necessitate various networking needs; For mission-critical communication IoT use cases, for example, less than 1 ms E2E latency and more than 99.99% reliability level are needed, Factory automation apps need an E2E latency range of 250 s to 10 ms and a 109-packet loss rate [3]. Allocating a dedicated E2E network slice for each application will allow for fulfilling such varied needs of various IoT applications, is shown in Figure 1.

Operators can design customized network slices for their clients to the Network Slice as a Service (NSlaaS) idea. Mobile Network Operators (MNOs) can create a new business strategy [4]. Additionally, an E2E network slicing framework that supports vertical industry apps and can horizontally slice computation and communication resources was suggested in [5]. Network slicing boosts resource utilization efficiency by dynamically adjusting network resources between the segments. Autonomous systems can be implemented for such resource distributions and dynamic resource adjustment.

Future IoT apps can be made more scalable by using this technique. Slice isolation provides high security and privacy for healthcare IoT apps. Ni et al. offered a secure service-oriented authentication framework for 5G fog computing and network slicing to enable IoT services [6]. Since IoT devices are generally resource-constraint, they are highly vulnerable to attacks. IoT devices' rapid growth and pervasiveness draw many attackers [7]. An adversary can control IoT devices and cause network DDoS attacks. Network-slicing IoT apps reduce the severity of these attacks. Also, the dynamic allocation of idle resources to the victimized network slice can keep the service without degradation during an attack.

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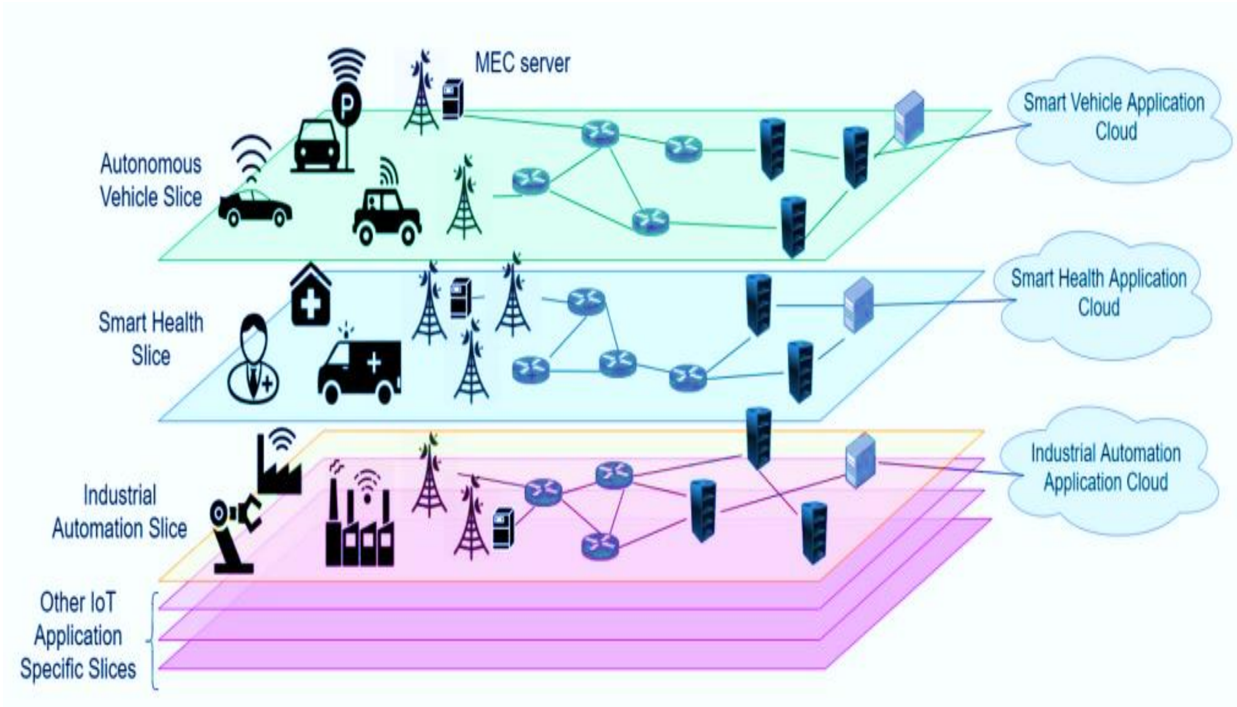

Fig 1: E2E Network Slicing

II. NETWORK SLICING

Due to the extensive range of new networking services, mobile networks in the future will have heterogeneous service needs. Consequently, the idea of "one size suits all" networking is usable up to and including 5G. The Next Generation Mobile Network (NGMN) Alliance presented the network slicing idea in 2015 to solve the problem. Network slicing is regarded as a crucial component of 5G networks by the Third Generation Partnership Project (3GPP) [8].

Network slicing is the idea of segmenting the physical network into numerous logical networks (networks), each of which can be specialized to provide particular network powers and characteristics for a particular use case. 3GPP describes network slicing as a "technology that allows the provider to design networks that are tailored to offer optimal solutions.".

Network Slicing Architecture: As stated by NGMN, network slicing architecture consists of three layers: infrastructure layer, network slice instance layer, and service instance layer.

1. The infrastructure layer provides physical or virtual resources such as storage, computing, and connectivity.
2. Network slice instance layer runs over the infrastructure layer and consists of NSIs, which form E2E logical network slices.
3. Service instance layer, which runs over all other layers, represents end-user and business services. The network operator or a third party will provide these services via service instances.

A functional network slice consists of two sub-slices: the RAN sub-slice, specific to Next-Generation Radio Access Network (NG RAN), and the core sub-slice, specific to the core network. It mainly consists of four segments: RAN sub-slice, slice-paring functions, core sub-slice, and the NSM. Fully data flow of some particular applications throughout the network is shown in Figure 2. A fully functional network slice can route and control a particular packet over the network without influencing other slices.

Different Types of Network Slices: Network slices can be categorized using vertical and horizontal models, static and dynamic, and RAN and core. RAN and core slicing have been discussed earlier.

1. Vertical network slicing: This is the network division into use-case-based segments while streamlining the conventional QoS issue. Here, each network area will be divided into slices, then paired using slice pairing functions to form the whole slice.

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2. Horizontal network slicing: A large amount of traffic is generated at the very edge of the network. Through edge computing and computation offloading, the generated traffic flow can be made non-uniform. This scenario can be identified as horizontal network slicing.
3. Static network slicing: Here, network slices will be pre-instantiated, and devices need to select the slice to which it will have the connection.
4. Dynamic network slicing: Operators can dynamically design, deploy, customize, and optimize the slices according to the service requirements or conditions in the network. It encourages the emergence of the novel concept known as Network Slice as a Service (NSaaS).

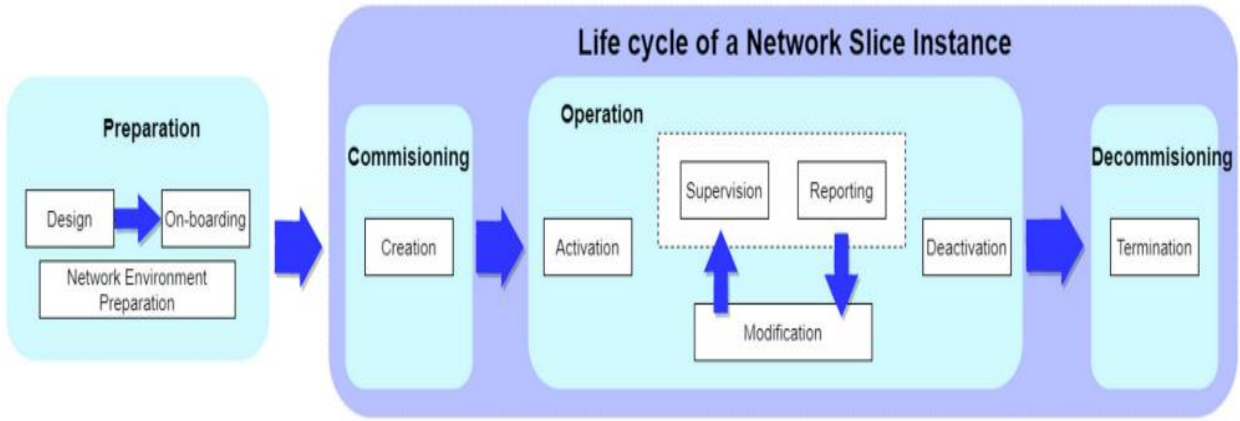

Fig. 2: Network Slicing Life Cycle

Network Slice Life Cycle: NSI life cycle can be divided into four phases: preparation, commissioning, operation, and decommissioning.

The phase of preparation: preparation phase of the life cycle is where NSI does not occur. The following tasks are involved in this stage.
1. The development and validation of NST.
2. Setting up the essential network infrastructure used to support the NSI life cycle.
3. Planning the network slice's capacity.
4. Accepting NSTs.
5. A review of the network segment specifications.
6. Setting up any additional network needs.

The commissioning phase: During this stage, the NST will be converted into the NSI. Here are the tasks:
1. Allocating the necessary network resources - Making the necessary settings to accommodate the slice needs. After this step, the network slice will be prepared for operation.
2. Operation phase: This phase comprises various network slice-related subtasks.
3. Decommissioning phase: – Reclamation of dedicated resources. – Reclamation of configurations from the shared/dependent resources.

III. THE ROLE OF NETWORK SLICING IN THE IOT ECOSYSTEM

This section concentrates on the technical elements that can be enhanced for network slicing's IoT realization. This article discusses how network slicing can enhance scaling, dynamicity, security, privacy, QoS, and E2E orchestration.

1. Improved Scalability Network slicing has been identified by 3GPP as a technology to improve the flexibility and scalability in networking systems, including IoT networks. Software-based network functions in network slices allow deploying of network functions according to the network traffic to achieve scalability. The amount of IoT traffic flow through the network is not always the same. Due to the energy-saving communication links, IoT

2. Improving Dynamicity Dynamism is the quality of something constantly altering. Network slicing can help networks become dynamic by removing their static character. Network slicing offers two methods for enhancing the dynamicity of networks: dynamic slice allocation for heterogeneous IoT apps and dynamic resource allocation between slices.

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3. Improving Quality of Service (QoS) QoS can be defined as a form of traffic control mechanism that guarantees the ability to run high-priority applications and traffic under limited network capacity. Network slicing facilitates QoS requirements of different IoT applications by allocating dedicated slices for each use case. Dynamic resource allocation between slices allows us to accomplish QoS requirements in congestion situations.

4. Providing End-to-End Orchestration Every time a service is enabled in a network, its lifetime must be managed for appropriate performance. The provision, administration, and optimization of resources for that specific network service are the duties of the service End-to-End orchestrator. By breaking the network into smaller, more manageable pieces, network slicing offers a remedy for this problem. It supports a wide range of customers' and operators' requirements by allowing them to execute required configuration changes at run time to their slices.

5. Better Resource Allocation and Prioritization Network resources used by IoT networks include processing, storage, and networking resources. To maximize resource utilization, it is necessary to distribute these resources effectively. The best solution to meet the various network requirements of 5G IoT applications is network slicing, which denotes resource allocation. The fundamental notion of network slicing is comparable to that of Infrastructure as a Service (IaaS) in cloud computing, which allows tenants to share computing, storage, and networking resources.

Additionally, by dynamically adjusting the resources allotted to each slice via automated slice manager functions, the problem of the varying nature of the necessary resource amount for a specific IoT use case can be resolved. The table below shows some IoT applications, their network-slicing-based solutions, and their advantages.

Table: IoT Application, network Slicing based Solution and their advantages

IoT Application	**Network Slicing-Based Solution**	**Advantages of Using Network Slicing**
Smart Cities	Dedicated network slices for different services such as traffic management, waste management, and public safety	Enables efficient use of network resources and better quality of service for each service
Healthcare	Network slices for critical applications such as telemedicine and remote patient monitoring, with guaranteed bandwidth and low latency	Ensures reliable and secure connectivity for critical applications
Autonomous Vehicles	Dedicated network slices for vehicle-to-vehicle communication and vehicle-to-infrastructure communication, with low latency and high reliability	Enables real-time communication between vehicles and infrastructure, improving safety and efficiency
Industrial IoT	Network slices for different applications such as predictive maintenance and asset tracking, with varying requirements for bandwidth, latency, and reliability	Enables efficient use of network resources and tailored services for different applications
Smart Grid	Dedicated network slices for smart metering, distribution automation, and grid management, with guaranteed bandwidth and low latency	Enables efficient and reliable communication between devices in the smart grid

IV. CONCLUSION

In conclusion, network slicing is a critical technology for enabling the full potential of the IoT ecosystem in 5G networks. By creating multiple virtual networks on top of a single physical infrastructure, network slicing allows IoT applications to be isolated from other network traffic and ensures the quality of service. This is particularly important for critical applications such as healthcare and autonomous vehicles, which require low latency and high reliability.

Moreover, network slicing enables network operators to provide tailored services to their IoT customers, offering different service levels and charging models based on usage patterns and requirements. As 5G networks continue to evolve and more IoT devices are connected, network slicing will play an increasingly important role in optimizing network performance and meeting the diverse requirements of IoT applications.

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