

A Comprehensive View of State-of-Art of 5G Network Slicing

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Abstract: Network Slicing is a concept that creates multiple virtual networks that serve the purpose of various service requirements. These logical networks created on top of the same physical network infrastructure are called “network slices”. Each slice of the network acts as an isolated network that is end-to-end and customized to achieve the requirements as expected by the application. This network slicing is one of the driving aspects in the 5G networks, which promises to provide various services as per the user requirement. A study is made on Network Function Virtualization (NFV) and Software Defined Networks (SDN) which forms the driving aspects for network Slicing in 5G networks. Also, the state of art developments in the field of network slicing has been studied and explained. The paper presents the benefits of 5G network slicing from the technical point of view and later describes different vertical segments that make use of slicing of 5G networks. It can be stated that network slicing in 5G networks offers to improve the efficiency of the 5G networks and also helps to achieve the expected and promised performance of the 5G in the coming future.

Keywords: 5G Networks, 5G Network slicing, Network as a service, Network slicing.

I. INTRODUCTION

The history of slicing the network is traced back to the 1980s where the concept of the “slice” in the networking field was introduced. The first kind of network slicing was provided by the overlay networks where the different types of network resources were combined to form a virtual network upon a common physical infrastructure.

5G Network slicing is an architecture that allows the multiplexing of the independent and virtualized logical networks on the same physical infrastructure. Each slice of the network acts as an isolated network that is end-to-end and customized to achieve the requirements as expected by the application (Fig. 1). Due to this advantage, the technology forms a central

aspect that supports the 5G networks that are mainly designed to encompass many services with a difference in service levels. This service-oriented view realization for the networks is influenced by the concepts of software-defined networking (SDN) and the network function virtualization (NFV). These concepts help in the implementation of the scalable and flexible slices of networks upon a common physical network infrastructure.

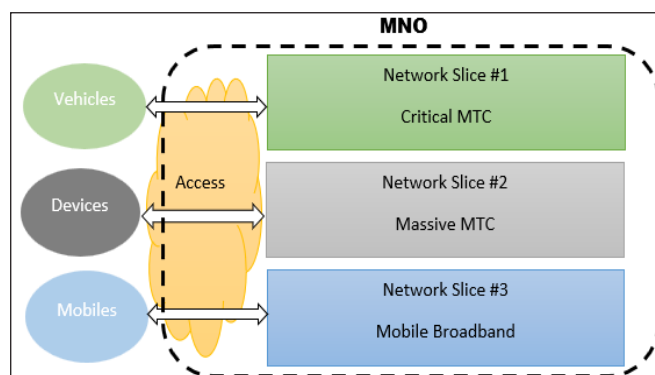


Fig. 1: Service-Based Network Slicing in 5G Networks

Each slice of the network is monitored by the mobile virtual network operator (MVNO) from the business perspective. The physical resources that share the underlying network are taken for lease by the MVNOs from the infrastructure providers. As per the resource availability, the network slices are autonomously deployed by the MVNOs which are customized according to the user requirement.

The network paradigm “one size fits all” which was employed by the previous mobile networks such as 2G, 3G and 4G are not sufficient to address the market model consisting of different services like ultra-reliable low latency communications, machine type communication, and enhanced mobile broadband delivery. To accommodate such different application requirements by using a single physical network platform, network slicing emerges as a necessary technique.

The principal concept is to “slice” the original physical network infrastructure into multiple independent and logical networks that efficiently meet the necessary service requirements. To realize

the concept of network slicing, the techniques employed are:

- *Network Functions*: These network functions detail the basic network functionalities that can be used as “building blocks” for creating each network slice.
- *Virtualization*: Virtualization provides the abstraction of the underlying physical resources with a homogenous and unified sense. Also, it supports a scalable slice deployment strategy that depends on NFV and allows to decouple each slice from its network hardware
- *Orchestration*: Orchestration is a process that enables the coordination of all different network resources which are involved in the network slice lifecycle. In this view, SDN is used to help enable the flexible and dynamic slice configuration.

Network slicing enables an operator for creating specific virtualized networks that yield to different clients and their requirements. Some applications such as machine-to-machine communications, mobile broadband applications or even smart automotive will profit from various aspects of 5G technology. Clients may have various types of requirements such as higher speeds, lower processing latency, even some may need to gain access to the edge processing resources. In 5G, by building individual slices that will prioritize specific requirements and resources, the operator can offer smooth solutions to specific industries. Few sources also insist that this will make a revolution in industries such as augmented reality, mobile gaming, and marketing.

Network slicing also improvises the service continuity by providing enhanced handoffs across various networks, by designing a logical virtual network that runs on the physical network infrastructure that enables the spanning of a large number of local or national networks.

The paper is structured in the following way: Section II gives the details of the research work carried out recently in the field of network slicing technology in 5G networks. Section III gives the generalized architecture that depicts the technology of network slicing which is followed by Section IV which provides the details of the major concepts that are used in slicing of the 5G networks. Section V gives the detailing of the state-of-art developments in the area of network slicing. Section VI and Section VII detail the advantages of slicing from a technical perspective and its applications respectively. In the end, Section VIII provides the conclusion of the study that has been carried out on the topic.

II. LITERATURE REVIEW

This section describes the work of various researchers following the network slicing in 5G networks.

In paper [1], the authors describe network slicing to be the backbone of the 5G technology that is the verge of rapid evolution. The historical view of network slicing, its principal

concepts, and technologies along with the standardization efforts that being carried out are identified in an end-to-end perspective by the authors. The paper provides the details solution for slicing each part of the 5G system. The authors also identify various research challenges and recommendations regarding the concept.

The authors of the papers [2] say that 5G network slicing must contain the core domain, radio access as well as transport domain. The authors specify that the support for the differences in the performances of mMTC, uRLLC, and eMBB slices cannot be provided only by virtualizing the core network. They also propose a control framework that forms the middle layer between the infrastructure and the orchestrator in order of achieving the real-time response in runtime. The control elements are flexibly combined to provide scalability and compatibility. The concepts of the radio spectrum, as well as network breathing, are explained in the context of network slicing. The authors also provide a brief demonstration of the proposed control framework.

With the evolution of 5G, the mobile network business model is now having a paradigm shift to a more open system from a network-oriented point of view. In this regard, the intermediate role between the resource provider and the service provided is played by the network slice provider. For the deployment of a network slice, the slice provider needs a brokering mechanism which helps in leasing the resource from various other providers in a secure fashion. The authors of the paper [3], provide a Blockchain technology-based brokering scheme that ensures the secure and anonymous transactions.

In paper [4], the authors elaborate that due to the flexibility, optimized resource allocation schemes and efficiency in the management of cloud-based networks, SDN plays a major role in faster development and deployment of the 5G networks. The authors also focus on the use of NFV and SDN concepts in 5G that helps in tackling the complex issues and also how the existing solutions can be improvised. The paper also gives a brief overview of the testbeds that are set up to carry out experiments and simulations for NFV/SDN for 5G across the world. The paper also discusses various technologies such as mmWave, MEC, and VLC communications for 5G cellular technology.

The paper [5] explores the various ways to use Artificial Intelligence (AI) and Machine Learning (ML) for the enhancement of deployment and operations of 5G networks. The authors in their research try to decode the demands of the 5G network by analyzing the specific requirements in the fields of network planning, operations, and optimizations. They also have discussed various strategical views for the MNOs to utilize the applications of AI in 5G.

Network slicing allows an infrastructure provider to have different 5G services to be working on the common shared platform. As the network becomes operative, the deployed slices can be scaled up/down as per the requirement of the

configured services. The paper [6] presents the reinforcement learning-based slice admission technique which allocates the network slices based on their service priorities. The policy proposed here will learn the priority of the services based on their potential of fetching higher profit and thus accepts such services.

Many applications in 5G networks are provided with flexible and on-demand solutions with the help of network slicing. The main challenges for network slicing are end-to-end delay guarantee for a slice and isolation of each of the functions (intra slice isolation). The optimal slice allocation in the 5G core networks is addressed by the authors by also tackling these two challenges. The authors have created a model that overcomes the above-mentioned constraints within the components of the slice for reliability [7].

Even though the 5G networks are still on the verge of evolution with new ideas, the architectures proposed for this are about to reach the forming phase. Keeping this in mind, the authors of the paper [8] try to evaluate the isolation abilities and the approaches selected to realize the network slicing concept. From the perspective of the end-to-end security of each slice, there is a need to address the requirements regarding the operation of isolated slices and their management. Hence, the paper presents the improvements regarding the slice isolation strategies as well as some challenges to be addressed.

The architecture representing the autonomic slice networking has been presented by the authors of the paper [9]. The authors present that the external nodes are used to make the local decisions and are placed closer to the network devices, whereas the centralized systems organize and transport the data to customer controllers which provide the customized and isolated data analytics process. The authors have experimentally demonstrated the proposed architecture with the help of the complex use case for an MPLS-over optical network with multiple domains.

III. GENERALIZED ARCHITECTURE

This section gives details about the generalized architecture used to represent network slicing in 5G networks.

Even though there are different architectural proposals for network slicing, a general architecture that represents the most common components for each solution can be defined. In a high-level context, architecture can be divided into two major blocks in which one is used for the slice implementation and the other is used for the configuration and management. The generalized architecture for network slicing is shown in Fig. 2. Initially, the first block is designed with multiple sublayers such as the infrastructure layer, network function layer, and the service layer. These sublayers help in defining and deploying with the specific services. The next block is the centralized entity, which is called as the controller, that manages various functionalities within the three sublayers for the efficient coordination of the multiple deployed slices.

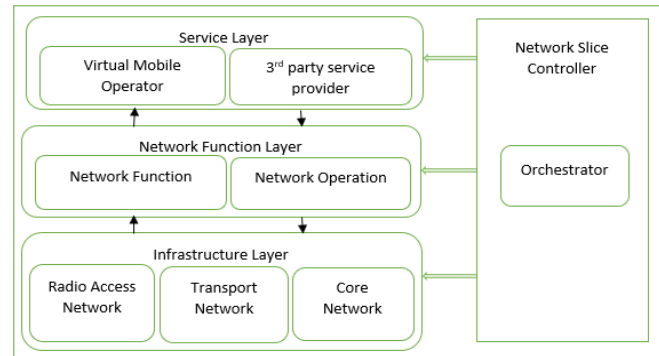


Fig. 2: Generic 5G Network Slicing Framework

Service Layer: The various business units are directly interfaced with the service layer which shares the common physical network platform providing the integrated vision for different services necessities. Here, each service is represented by a service instance that adds the required network features in the way of SLA requirements that are satisfied by creating a suitable network slice.

Network Function Layer: The development of the network slice as per the service instance requests from the above layers is taken care of by the network function layer. The network function layer comprises various network functions that include different interfaces. Different network functions are added upon the underlying virtual network infrastructure and are combined to generate an instance of the end-to-end slice which reflects various features that were requested by a service instance. A group of network operations manages the network function configuration that enables the management of the slice lifecycle.

To increase the efficiency of resource usage, different slices share the same network functionality, but with the cost of complexity rise in the management of operations. On the contrary, the mapping of the network function with the network slice helps in the easy configuration process. Though, this may lead to the inefficient usage of the resources.

Infrastructure Layer: The underlying physical network topology is represented by the infrastructure layer. Upon this layer, each deployed slice is multiplexed. The layer also provides a different set of physical resource that helps in hosting various network functionalities that forms up each slice. The different sets of network resources include data centers, network-connected devices such as routers and bandwidth resources such as base stations.

Network Slice Controller: The Slice controller is defined as the network orchestrator that allows different functionalities of each sublayer to accomplish the slice request from the service instance. The advantage of this entity is that it allows the creation of a slice flexibly and efficiently which can further be reconfigured in different stages of its lifecycle. Some of the functions of the network slice controller that helps in coordinating between the sublayers are:

- *Managing End-to-End Service*: This involves mapping the network functionalities that satisfies the various service constraints with that of the suitable service instances in the form of SLA requirements.
- *Defining the Virtual Resources*: The physical network resources are virtualized for simplifying the management operation of the resources that are carried out for allocating the network operations.
- *Management of the Slice Lifecycle*: This function includes the monitoring of the performance of the slices across the different sublayers which helps in the dynamic reconfiguration of each slice to perform SLA requirement changes. As the complexity of the operations performed by different slices increases, the controller can include multiple orchestrators that can individually monitor the functionality of the sublayers.

IV. IMPORTANT CONCEPTS RELATED TO NETWORK SLICING

Software-defined network (SDN) and the network function virtualization (NFV) are key concepts that support the implementation of the network slicing in 5G networks.

A. Software-Defined Networks

A software-defined network is the type of architecture that makes the network programmable. It separates the data and the control planes of the network devices, control and schedule the traffic in the network, and help in realization of the network intelligence. The architecture of the SDN consists of three different layers namely, infrastructure layer, control layer, and the applications layer. The infrastructure layer comprises multiple network devices required for the basic functionality and is mainly involves the forwarding of the data that is received from the control layer. The main layer of the SDN architecture is the control layer. It forms the core of the entire structure and is involved in resource arrangement for data forwarding, controlling the network topology, collection of information, etc. The last layer of the architecture is the application layer. It contains several application services that access the underlying resources through northbound interfaces. The control layer which lies in between the application layer and the infrastructure layer interfaces with both layers using the northbound and southbound interfaces respectively.

B. Network Function Virtualization

The technology of Network Function Virtualization (NFV) is based on the topics of virtualization, data centers, data, and control forwarding separations and the SDN controller. The main aim of this technology is to generate a various dynamic

of the network elements and provide the virtualized resources to separate the hardware and the software of the conventional telecommunication devices. The network device functionality is abstracted into virtualized resources that are equivalent to the physical resource with the help of the virtualization technique and does not rely on the particular hardware platform. With the help of this virtualization technology, the IT resources can be shared fully and flexibly, which helps in the high-speed development and deployment of the businesses. This also helps in achieving the elastic expansion of the business, automatic deployment of the applications, isolation of the faulty devices, and accordingly working on the required business needs. The main purpose of network function virtualization is to implement virtual network devices and the virtual network, ensuring that it only changes the network construction and organization and not the performance of the physical network.

C. SDN & NFV Working Together

Along with the various controllers and virtual network functions in different levels of the network slicing architecture, ETSI also adds some SDN controllers for efficient coordination of the layers. Every new SDN controller that is added will try to centralize the control plane functionalities and will offer an abstraction of the different network connectivity devices that the controller manages. The newly included controllers for the architecture are:

- *Infrastructure Controller (IC)*: The infrastructure controller is mainly to set up the underlying network resources that provide the necessary network connectivity for different VNFs and manage them. This controller which is managed by the Virtual Infrastructure Manager (VIM) is allowed to modify the behavior of the underlying infrastructure as per the tenant requirements.
- *Tenant Controller (TC)*: This tenant controller is initialized in the tenant domain in the form of a virtual network function or as a part of the network management system. The controller will dynamically monitor the VNFs that are used to implement the network services for the tenant. The virtual network functions are nothing, but the resources used in the forwarding plane of the TC. The applications that run upon this controller are responsible for triggering the operation and management that are required to be carried out by the TC.
- These controllers with the help of their programmable southbound interfaces will manage the resources specified to them. The protocols such as NETCONF and OpenFlow are implemented at these controllers. These controllers provide a separate level of abstraction at each layer. To support the development, deployment, and connectivity of the virtual network functions, the infrastructure controller provides an underlay and the

tenant controller provides the overlay that includes the virtual network functions which are composed properly, defines the various services which help the tenant to individually manage its network slices.

Even though the infrastructure controller and the tenant controller are used for different functions, the deployment also has some consequences in the way in which they work. Though IC is used to monitor the connectivity functions, it will not be aware of the count of slices that use the VNFs. The TC which is used to monitor the network services on each VNFs does not know how the VNFs are deployed because of the underlying abstraction. Despite the abstraction levels, both the controllers are needed to synchronize with their workflow.

V. STATE OF ART DEVELOPMENTS IN NETWORK SLICING

The main goal of network slicing is to identify a dedicated virtual network for every type of service which is supported and guaranteed by 5G networks (Fig. 3(a)). The idea of the network slicing is different from that of the traditional network view (Fig. 3(b)) in which all the networking elements that support different services are provided with the same quality of service (QoS). To achieve the goal of network slicing the three major areas must be researched. These areas include:

- The necessary infrastructure of the network slicing.
- The definition of each network function.
- Managing the deployment and communication service.

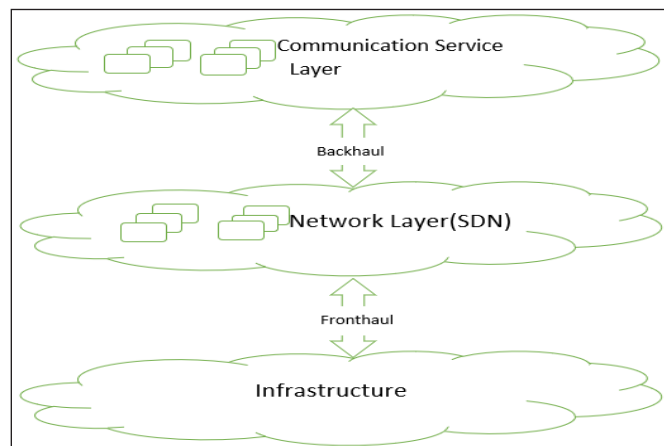


Fig. 3(a): Mobile Network Architecture - Traditional View

The research work that is being carried out in the area of infrastructure requirement emphasizes two major concepts: the organization of the necessary infrastructure and its virtualization. Some papers regarding the organization of the infrastructure concentrate on Infrastructure as a Service (IaaS) [10] scenario in which the generalized processing elements would support the whole system. Even though some of these solutions appear to be effective for the underlying core network, few authors propose the infrastructure with the edge computing solutions and fog computing solutions [11] for supporting the access network as well as latency requirements of various network slices [12]. The research is also carried out

on the virtualization of the underlying infrastructure which mainly emphasizes the Core network. Here the authors propose the ideas mainly concentrated on the Kernel-based VMs and the Linux containers [13].

The investigative works regarding the definition of the required network functions and their deployment are mainly related to Network Function Virtualization (NFV) and the Software Defined Networks (SDN). Currently, research is being carried out on the VNFs that is available in the market, along with the requirements for their deployments are also being studied [14]. For example, the research reports regarding virtualizing the LTE Enhanced Packet Core [15] are being accepted.

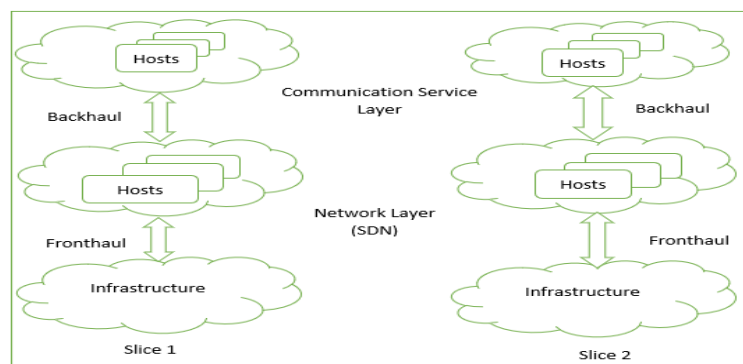


Fig. 3(b): Mobile Network Architecture - Network Slicing

The research studies regarding the management of the communication service are very rare nowadays. Some research papers provide the details concerning the services that match the network components ensuring that all the services will get the required resources.

VI. ADVANTAGES OF NETWORK SLICING IN TECHNICAL PERSPECTIVE

This section describes some of the advantages of the implementation of network slicing in 5G networks from a Technical perspective.

With the help of network slicing in 5G networks, the network operators can assign the proper amount of the resources to a particular network slice. For example, the network slice that facilitates the Internet of Things service could offer a particular delay, high availability, security, and specified data rate. Also, at the same time, another network slice that serves different network services could provide greater throughput, higher data speeds along with lower latency.

The network slicing is expected to be the basis of the 5G logical architecture. The network slicing technology allows the operators to offer services differentiated as per their requirements in the RAN access network layers. Though the slicing allows the division of the core networks, it can also be used in RAN for resource pooling. It involves the process of portioning and abstracting the virtual logical network segments from the underlying physical resources.

The solutions of the Management of network slices help the carries to implement the slice lifecycle management while preparing for the 5G networks. However, the motivation that keeps the technology moving forward is its capability to offer the network on the service basis, which helps in minimizing the expenses and reduce the capital expenditure, which increases the efficiency of the operations and improvises time-to-market.

The authors of [16] claim through the experimental evaluation that with the virtualization technique of network slicing the spectrum efficiency is increased to 91.40% and the packet loss ratio is reduced to 0.27% in the 5G cellular networks. In paper [17], the authors show that even in the congested 5G cellular networks the packet loss rate is reduced to 10% and the delay is ensured to be less than 700 ms for VoIP and video streaming applications with a bit rate of 5 mbps.

The authors of [18] detail the simulations conducted in the grid networks with 16 and 100 nodes and a random topology with 200 nodes. After the experimental evaluation, the authors claim that the proposed slice management method improves the throughput of slices up to 6%, 13%, and 7% respectively. They also show that the average delay of the slices reduced to 14%, 15%, and 11% respectively.

Paper [19] shows that for a network slice dedicated to massiveIoT (mIoT) communications the control plane signaling

is reduced up to 60% in 5G networks when compared to the baseline LTE/EPC system.

VII. APPLICATIONS OF NETWORK SLICING IN VARIOUS INDUSTRY SEGMENTS

Network Slicing in 5G networks helps in creating the virtual logical networks upon the shared physical infrastructure. These created logical networks are optimized to support different use cases, various service types that provide for various business models. For allowing the vertical industries to deploy their specific services upon the customized logical end-to-end networks, “Network as a Service” acts as the necessary tool. The different vertical industries have different requirements to be dedicated as per the provided service characteristics. One example where the services that require high reliability and lower latency are augmented reality, industrial control, and autonomous vehicles. Some industry verticals that use network slicing are:

- Automotive Industry
 - Connected traveler with the telematics and autonomous driving facilities.
 - Varying commuter habits and car sharing.
 - Decreased battery costs for electric mobility with the green agenda.
 - Digitalized vehicle ecosystem.
- Healthcare Segment
 - Increased attention of consumers on well being.
 - Growing expenditures to fit with changing social demographics.
 - Increased demand for the safety of patients, quality of treatment, and improved data storage regarding the patient’s health history.
- Entertainment and Telecommunication Vertical
 - Making the consumer as the co-creator for the content of media.
 - Extension of the digital media services through various news platforms and proving video on demand options by various new market players.
- Public Safety
 - Increase in public surveillance with a large number of CCTV and the wearable cameras.
 - Connected citizens, knows as “Internet of Public Safety”.

VIII. CONCLUSION

Network slicing is an architecture that allows the multiplexing of the independent and virtualized logical networks on the same physical infrastructure. Each slice of the network acts as an isolated network that is end-to-end and customized to achieve

the requirements as expected by the application. This network slicing is one of the driving aspects in the 5G networks, as it allows the creation of customized logical networks as per the business requirement.

A brief study is made on the various architecture of the network slicing that has been looked upon by many researchers from a technical point of view. The generalized architecture is given and explained briefly. Software-Defined Networking (SDN) and Network Function Virtualization (NFV) which form the basic foundation of the 5G network slicing has been discussed. The state of art developments that are being made on the topic of network slicing had been explained. Further, a brief study on the advantages of network slicing from a technical perspective is also made.

It can be said that the implementation of network slicing in 5G networks makes a drastic improvement in achieving the expected performance of the 5G. Further, it also helps in sustainable technological developments with a positive impact on the environment.

REFERENCES

- [1] I. Afolabi, T. Taleb, K. Samdanis, A. Ksentini, and H. Flinck, "Network slicing & softwarization: A survey on principles, enabling technologies & solutions," *IEEE Communications Surveys & Tutorials*, vol. 20, no. 3, pp. 2429-2453, 2018, doi: 10.1109/COMST.2018.2815638.
- [2] R. Ni, X. Li, J. Chen, S. Chen, E. Wang, M. Zhu, and W. Zhang, "An end-to-end demonstration for 5G network slicing," *IEEE Access, Wireless Technology Laboratory, Huawei*, 2019, doi: 10.1109/vtcspring.2019.8746569.
- [3] B. Nour, A. Ksentini, N. Herbaut, H. Moun gla, and P. A. Frangoudis, "A blockchain-based network slice broker for 5G services," *IEEE Networking Letters*, vol. 1, no. 3, pp. 99-102, 2019, doi: 10.1109/LNET.2019.2915117.
- [4] A. Hegde, and Vishalakshi Prabhu H., "Review of state of art of software-defined networking in 5G," *Journal of Network and Information Security*, vol. 7, no. 2, pp. 1-8, 2019.
- [5] C. B. Anuradha, and P. Sharma, "Empowering the future 5G networks: An AI based approach," *Telecom Business Review*, vol. 10, no. 1, pp. 53-59, 2017.
- [6] Muhd. R. Raza, C. Natalino, P. Öhlen, and L. Wosinska, "Reinforcement learning for slicing in a 5G flexible RAN," *IEEE Journal of Lightwave Technology*, vol. 37, no. 20, pp. 5161-5169, 2019, doi: 10.1109/JLT.2019.2924345.
- [7] D. Sattar, and A. Matrawy, "Optimal slice allocation in 5G core networks," *IEEE Networking Letters*, vol. 1, no. 2, pp. 48-51, 2019, doi: 10.1109/LNET.2019.2908351.
- [8] Z. Kotulski, T. W. Nowak, M. Sepczuk, M. Tunia, R. Artych, K. Bocianiak, T. Osko, and J.-P. Wary, "Towards constructive approach to end-to-end slice isolation in 5G networks," *EURASIP Journal on Information Security*, vol. 2018, article no. 2, 2018.
- [9] R. Wen, G. Feng, J. Tang, T. Q. S. Quek, G. Wang, W. Tan, and S. Qin, "On robustness of network slicing for next generation mobile networks," *IEEE Transactions on Communications*, vol. 67, no. 1, pp. 430-444, 2019, doi 10.1109/TCOMM.2018.2868652.
- [10] A. Gran, S.-C. Lin, and I. F. Akyildiz, "Towards wireless infrastructure-as-a-service (WlaaS) for 5G software-defined cellular systems," *2017 IEEE Conference on Communications (ICC)*, Paris, France, 2017, doi: 10.1109/ICC.2017.7996597.
- [11] B. Shah, and H. Bhavsar, "An approach towards the fog computing: Stretching cloud computing and internet of things," *International Journal of Distributed and Cloud Computing*, vol. 6, no. 2, pp. 5-11, 2018.
- [12] J. Gracia-Morales, M. C. Lucas-Estan, and J. Gosalvez, "Latency-sensitive 5G RAN slicing for industry 4.0," *IEEE Access*, vol. 7, pp. 143139-143159, 2019.
- [13] D. Huang, and H. Wu, "Level virtualization: An overview," *IEEE Conference on Mobile Cloud Computing*, 2018.
- [14] V. Q. Rodriguez, and F. Guillemin, "VNF modeling towards the cloud-RAN implementation," *2017 IEEE Conference on Networked Systems (NetSys)*, Gottingen, Germany, 2017, doi: 10.1109/NetSys.2017.7903950.
- [15] A. Basta, W. Kellerer, M. Hoffmann, K. Hoffmann, and E.-D. Schmidt, "A virtual SDN-enabled LTE EPC architecture: A case study for S-/P-gateways functions," *2013 IEEE SDN for Future Networks and Services (SDN4FNS)*, Trento, Italy, 2013, doi: 10.1109/SDN4FNS.2013.6702532.
- [16] J. Feng, Q. Zhang, G. Dong, P. Cao, and Z. Feng, "An approach to 5G wireless network virtualization: Architecture and trial environment," *2017 IEEE Wireless Communications and Networking Conference (WCNC)*, San Francisco, CA, USA, 2017, doi: 10.1109/WCNC.2017.7925592.
- [17] K. S. Ibarra-Lancheros, G. Puerto-Leguizamón, and C. Suárez-Fajardo, "Quality of service evaluation based on network slicing for software-defined 5G systems," *TecnoLógicas*, vol. 21, no. 43, pp. 27-41, 2018.
- [18] N. An, Y. Kim, J. Park, D.-H. Kwon, and H. Lim, "Slice management for quality of service differentiation in wireless network slicing," *Sensors (Basel)*, vol. 19, no. 12, pp. 27-45, 2019, doi: 10.3390/s19122745.
- [19] R. Trivisonno, M. Condoluci, X. An, and T. Mahmoodi, "mIoT Slice for 5G systems: Design and performance evaluation," *Sensors*, vol. 2018, no. 2, 2018, doi: 10.3390/s18020635.