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Algorithmics and Modeling Aspects of Network Slicing in 5G and Beyonds Network: Survey

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ABSTRACT One of the key goals of future 5G networks is to incorporate many different services into a single physical network, where each service has its logical network isolated from other networks. Besides, Network Slicing (NS) is considered as the key technology for meeting the service requirements of diverse application domains. Recently, NS faces several algorithmic challenges for 5G networks. This paper provides a review related to NS architecture with a focus on relevant Management and Orchestration (MANO) architecture across multiple domains. In addition, this survey paper delivers a deep analysis and a taxonomy of NS algorithmic aspects. Finally, this paper highlights some of the open issues and future directions.

INDEX TERMS Network slicing, next-generation networking, 5G mobile communication, quality of service, multi-domain, management and orchestration, resource allocation.

I. INTRODUCTION

A. CONTEXT AND MOTIVATION

The high volume of generated traffics from smart systems [1] and Internet of Everything applications [2] complicates the networking activities and management of current and next-generation mobile networks. Therefore, network models [3], should be invented to find a solution that enables managers to carry out management operations without needs to configure the devices. In this context, the Fifth-Generation (5G) is emerging with the rapid development and advancement in cellular networking technology as a completely new era for mobile communications. 5G networks are intended to provide a full connection between communities that can overcome the constraints of time and space as well as the creation of whole dimensional interconnections between people and things [4]. Also, the 5G network has to support several services [5], business models [6], and multiple slices sharing the same infrastructure to attain complete resource usage, finest level of granularity, and satisfy the distinct scenarios. Backing all these demands in the same infrastructure necessitates re-engineering of the network architecture beyond the present 3rd Generation Partnership Project [7]-Long Term Evolution [8] (3GPP-LTE) extensions.

Respectively, Network Slicing (NS) is one of the most promising solutions to such network re-engineering [3]. NS [9] allows the creation of several Fully-fledged virtual networks (core, access, and transport networks) over the same infrastructure while maintaining the isolation among slices. The FIGURE 1 shows the way different slices are isolated. Each slice integrates a specific use case that supports diverse verticals such as remote surgery, safety, automotive infrastructure, home management, etc. When a failure or an inaccuracy has occurred in one slice it does not affect the

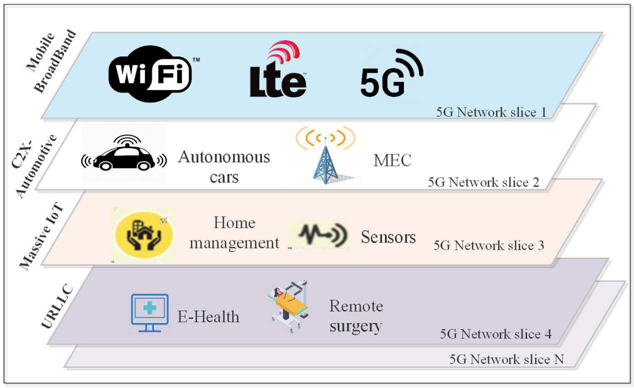

FIGURE 1. 5G network slicing.

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other slices. NS will be employed to realize certain relevant key features of 5G such as the guarantee of a heterogeneous performance, the coexistence of diverse business model and use cases, as well as the rapid launch of services and applications [10]. Several elements must be provided to support the NS paradigm in mobile networks such as the framework of NS aware orchestration, a flexible control system for the network functions, a persistent framework of Quality of Service (QoS)/Quality of Experience (QoE) management, and an enhanced management algorithm [11]. The basic idea of NS is closely linked to the cloud computing Infrastructure as a Service (IaaS) [12]. IaaS shares computing, networking resources, and storage between various tenants and afford entirely functional Virtual Network (VN) powered by Network Function Virtualization (NFV) and Software Defined Network (SDN) [13]. Furthermore, NS requires a rising degree of resilience that has only been made by the recent emergence of NFV and SDN. SDN is based on the separation of the Control Plane (CP) and the Data Plane (DP) in each network. In this paradigm, the routing operations are determined by a centralized controller that manages the different network components. NFV allows each network function called the Virtual Network Function (VNF), to reduce the cost of deployment that runs on general-purpose hardware. Hence, NS presents an integration of several VNFs. Consequently, the NS provides not only a scalable, flexible, and programmable service but also minimizes Operating Expenditure (OPEX) and Capital Expenditure (CAPEX) by efficiently managing and orchestrating VNFs [14]. In fact, the VN slice is implemented on top of the physical network in a manner that gives the illusion to slice tenants for running their own physical network [15]. On all physical links that constitute the path, a virtual link among virtual nodes can be performed as a physical multihop path with reserved bandwidth, where the virtual links can be efficiently created through SDN routers. It is possible to implement virtual nodes as VNFs operating on general-purpose hardware that forms a cloud infrastructure. To explain the flexibility offered by NS, we present various indicative applications (IoT, video service and broadband) in FIGURE 2 which illustrates the essential VNFs specific for each application and the corresponding network domains where it could be placed.

IoT services are implemented with a simplified CP, for example, the service of smart meter monitors the energy consumption of houses without using the functionalities of mobility management. Broadband and traditional voice services require hard functionalities of CP such as authentication placed at the core cloud and mobility management. Video delivery services can be improved if caching functionality and User Plane (UP) are available in the edge cloud, reducing back-haul traffic and improving User Experience (UE).

B. STRUCTURE AND ORGANIZATION OF THE PAPER

This paper is organized as follows: The scope of the paper and the contribution are provided in section II. Section III presents the NS architecture. The taxonomy of NS Algorithmics Aspects are discussed in section IV. Section V presents the open issues and future directions. Finally, conclusions are drawn in section VI.

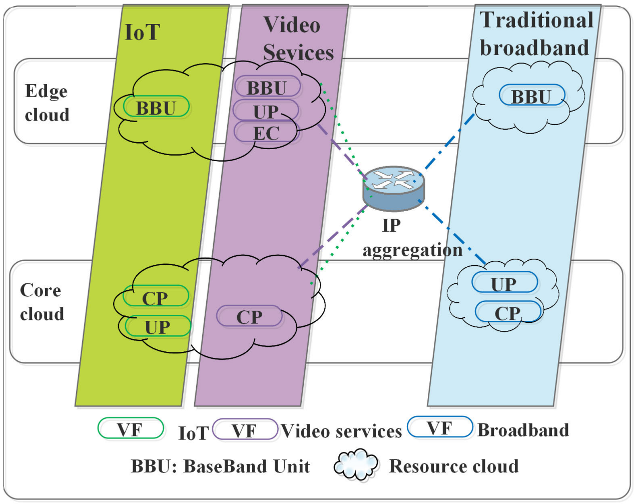


FIGURE 2. Indicative applications of 5G network slicing.

C. LIST OF ACRONYMS

The list of acronyms and abbreviations referenced throughout this paper is presented in TABLE 1.

II. SCOPE AND CONTRIBUTION

Starting from the philosophy of one size fits all design of the network, potential wireless networks will use the NS approach to accommodate applications with a wide range of specifications across the same physical network and to efficiently control, allocate and manage the slice resource. In this context, several research papers [15]–[19] focus on the algorithmic challenges of NS that arise in different fields as well as necessitating novel techniques. In [15], authors present the algorithmic aspect of NS that requires methods from the functional research networking and computer science communities. Also, they explain the efficient NS problem as a virtual network embedding (VNE) problem. The VNE is an integer linear program (ILP) that presents an NP-hard problem. Obviously, the basic problem of NS is constrained by the optimization. This problem considers the optimal placement of VNFs at the resource node, and the reservation of the required interconnection capacity. Therefore, a lot of literature seeks several heuristics algorithms of approximation to solve this issue. Sharma *et al.* [16] present a native approach for the NS cloud. This approach covers the whole network life cycle by incorporating cloud computing technology and the theory of modern design to create a structure and innovative architecture for all life cycle phases. Zhang *et al.* [17] propose a basic architecture of 5G NS and introduce a mobility management scheme between access networks, potential, and sub-channel allocation scheme. Also, they present a handover scheme for handover management between various networks,

TABLE 1. List of acronyms.

NS	Network slicing
5G	Fifth-Generation
CN	Core Network
QoS	Quality of Service
3GPP	3rd Generation Partnership Project
LTE	Long Term Evolution
E2E	End-to-End
SDN	Software Defined Network
VNFs	Virtual Network Functions
QoE	Quality of Experience
VNE	Virtual Network Embedding
ILP	Integer Linear Program
ETSI	European Telecommunications Standards Institute
MANO	Management and Orchestration
IaaS	Infrastructure as a Service
VNF	Virtual Network Function
RAN	Radio Acess Network
UP	User Plane
CP	Control Plane
BBU	BaseBand Unit
EC	Edge Caching
IoT	Internet of Things
UE	User Experience
OPEX	Operating Expenditure
CAPEX	Capital Expenditure
NSI	Network Slice Instance
OSS/BSS	Operating/Business Support System
NSSI	Network Slice Subnet Instances
SLA	Service Level Agreement
CDN	Content Delivery Network
DASA	Dynamic Auto-Scaling Algorithm
NSOS	NS Orchestration System
ONOS	Open Network Operating System
TN	Transport Network
ENI	Experiential Network Intelligence (ENI)
NSOS	Network Slicing Orchestration System
BSRA	Bandwidth Slicing and Resource Allocation
OFDMA	Orthogonal Frequency Division Multiple Access
EVNFP	Elastic Virtual Network Function Placement
VDC	Virtual Data Centers
SECaas	Security as a Service
IMAKE-GA	Implicit Mutual Authentication and Key Establishment with Service Group Anonymity
PPOA	Privacy-Preserving One-way Authentication
PPMA	Privacy-Preserving Mutual Authentication
RM	Resource Management
MM	Mobility Management
RA	Resource Allocation
DC	Data Center
VN	Virtual Network
AC	Admission Control
OA	Optimal Allocation
NFV	Network Function Virtualization
DP	Data Plane
PS	Packet Scheduler
VNFP	VNF Placement

where the virtualized resource management is dynamically and efficiently responsible for the intra-slice and inter-slice allocation of network resources. A threefold of contributions is described in [18]: First, they devise a novel architecture service layer for solving the utilizing of agnostic architecture where this layer is liable for the entire network slice Life Cycle Management (LCM). Second, they introduce the idea of the Network Application Store (NAS) to simplify the complicated procedure of delineating the network slice. Third, they describe the realization of the basic concept of NS using the LTE network to show the usefulness of the proposed architecture by employing the existing technological landscape. A novel architecture of the 5G Transport Network (TN) is proposed in [19]. This architecture incorporates the facets of resource virtualization, network service management, and virtual infrastructure, integrating the European Telecommunications Standards Institute (ETSI) NFV management and network orchestration (MANO) system with unified SDN based control.

Nevertheless, to the best of our knowledge, there is no extensive and detailed survey paper focusing on the topic of NS algorithmic aspects. These works [3], [15], [20]–[22] presents the algorithmic challenges rising from the emerging of NS but don't cover the orchestration architecture across multiple domains: (1) They provide a limited review related to MANO aspects; (2) There is no deep analysis of NS algorithmic aspects except for the description of the NS optimization problems; (3) No comprehensive descriptions of Resource Allocation (RA) aspects; (4) There is no deep classification of NS related approaches. More specifically, FIGURE 3 illustrates a real comparison of existing works with our work. The purple color depicts the common point between all works and different points are described briefly in the scheme. The main aim of our work is to give the reader a deep vision of the NS algorithmic aspect. Additionally, we depict a profound classification of proposed works in the literature. Our contributions are outlined as follows:

- Present the generic framework of NS architecture.
- Introduce the most relevant architecture of NS Management and Orchestration (MANO) across multiple domains.
- Discuss the 5G NS algorithmic aspect and depicts a deep classification of different approaches.

III. NETWORK SLICING ARCHITECTURE

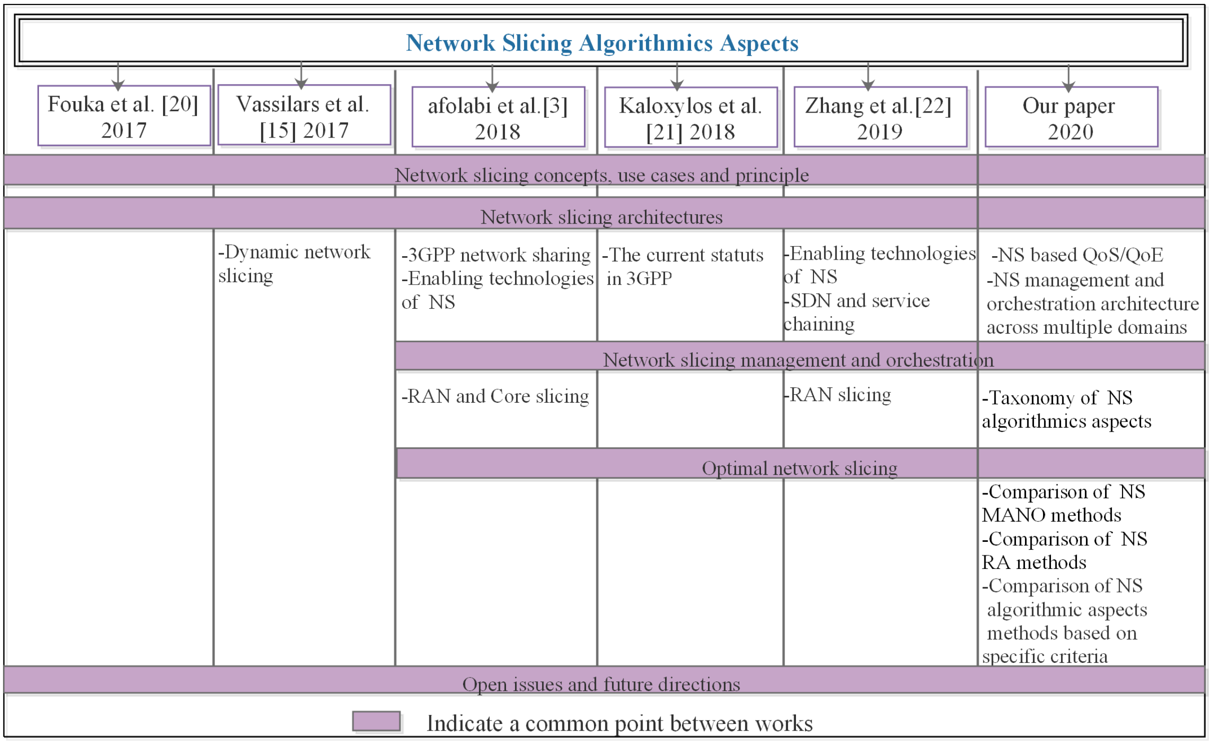
A. GENERIC ARCHITECTURE OF NETWORK SLICING

Mobility management, virtualization of wireless infrastructure, and orchestration of End-to-End (E2E) slices are challenging issues of NS due to the massive variety of applications and services that require intelligent approaches and algorithms. Recent 5G NS research focuses primarily on solving issues through effective NS frameworks. FIGURE 4 highlights the generic architecture of 5G NS based on the study provided in [20].

This architecture includes three main layers; infrastructure layer, network function layer, in addition to the service layer.

1) THE INFRASTRUCTURE LAYER

The infrastructure layer refers to the physical network infrastructure that extends both the CN, the edge/cloud, and the RAN. Some software defined techniques [23] could be used to simplify the resource abstraction within the RAN and CN. It also includes control, management, deployment of the infrastructure, and the allocation of resources (radio, storage, computing, network) to the slices as well as how the higher layers report and handle these resources.



Network Slicing Algorithmics Aspects

Fouka et al. [20] 2017	Vassilars et al. [15] 2017	afolabi et al.[3] 2018	Kaloxylos et al. [21] 2018	Zhang et al.[22] 2019	Our paper 2020
Network slicing concepts, use cases and principle					▨
Network slicing architectures					▨
	-Dynamic network slicing	-3GPP network sharing -Enabling technologies of NS	-The current statuts in 3GPP	-Enabling technologies of NS -SDN and service chaining	-NS based QoS/QoE -NS management and orchestration architecture across multiple domains
		Network slicing management and orchestration			
		-RAN and Core slicing		-RAN slicing	-Taxonomy of NS algorithmics aspects
		Optimal network slicing			
					-Comparison of NS MANO methods -Comparison of NS RA methods -Comparison of NS algorithmic aspects methods based on specific criteria
Open issues and future directions					

▨ Indicate a common point between works

FIGURE 3. A comparison on related review papers.

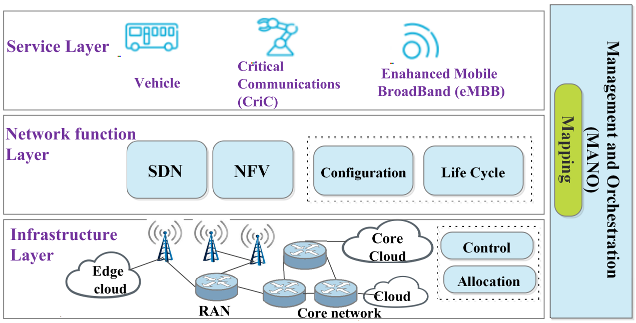


FIGURE 4. Network slicing generic architecture.

2) THE NETWORK FUNCTION LAYER

Performs all the operations and functionalities related to the configuration and LCM of the network functions. In this layer, the SDN and NFV techniques are considered as a significant technical aspect. Moreover, this layer simplifies the placement of network slices on multi-slice chaining and virtual resources [24]. It also manages efficiently both fine-grained [20] and coarse-grained [20] network functions.

3) THE SERVICE LAYER

Comprised of mobile devices, virtual reality systems, and connected vehicles. This layer is directly related to different business models, also it represents network function and network infrastructure functionality expectations. The VNFs are mapped to physical resources on the basis of a high-level definition of the applications and services in such a way that Service Level Agreement (SLA) is not violated.

4) THE MANAGEMENT AND ORCHESTRATION LAYER

It presents a transversal layer based on the following main functions:

1) Virtual Network Instances (VNI) are generated on the physical network using infrastructure layer functionalities.
2) Build a service chain by aggregation of the virtualization layer and network functions through mapping the network functions to VNI.
3) Keep communication between application, service, and NS framework to manage the life cycle of VNI and adapt the virtualized resources according to the context changing.

B. MANO ARCHITECTURE ACROSS MULTIPLE DOMAINS

To support network slices MANO across multiple (technological and administrative) operational domains, an advanced and efficient NS architecture is required. This architecture aims to expand conventional orchestration, control, and management capabilities across models and build to form a fully stitched of network slices composition. Several papers [4], [25], [26] propose a MANO model that integrates NFV and SDN components into the basic 3GPP NS management to support the composition of networking and computing/storage resources. Recently in [26] authors present a sophisticated architecture of NS orchestration. Based on the latter we propose a simplified architecture that incorporates four main Stratums such as multi-domain Service Conductor layer, domain-specific Fully-fledged Orchestration

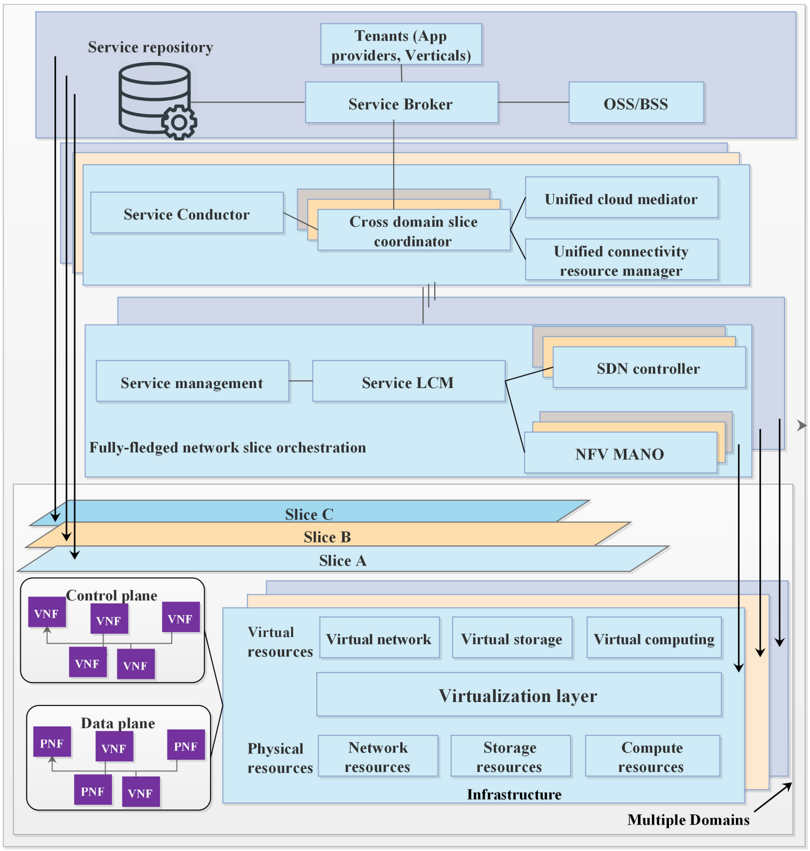


FIGURE 5. **Orchestration architecture across multiple domains.**

layer, connectivity layer, and Slice Instance layer. FIGURE 5 illustrates the orchestration architecture across multiple domains.

1) SERVICE BROKER LAYER

The Service Broker stratum addresses the incoming slice demands from verticals, application providers, and Mobile Virtual Network Operators (MVNOs) [27]. Besides, other essential operations such as slice owner/user management and relationship management are considered. This stratum allows a direct tenant interface with a multi-domain Service Conductor, control, and negotiation of network slice admission concerning service aspect, scheduling, and management of Network Slice Instance (NSI). Furthermore, a Service Broker gathers abstract network revenue information about various operational domains, providing a database that supports the global service. It interacts with the Operating/ Business Support System (OSS/BSS) to gather administrative and business information when processing requests for slices.

2) SERVICE CONDUCTOR LAYER

The Service Conductor stratum is responsible for the management and service orchestration towards federated resources linked to successfully accepted slice requests. This layer incorporates two blocks such as Service Conductor and Cross domain slice coordinator. Service Conductor disintegrates the slice demand across various administrative domains and determines the combination of fields with cross-domain connectivity. Also, it implements the readjustments of particular service towards united-domains, modifies, instantiates, and dismantles domains in case of service policy update and performance degradation. The slice coordinator manages, monitors, and controls the corresponding federated NSI tool while maintaining secure and trustworthy communication across operational domains. It also functions as a mediator between federated resources, conducting domain-specific allocation of resources, and re-adjustments to recompense in case of performance degradation.

3) FULLY-FLEDGED ORCHESTRATION LAYER

The Fully-fledged Orchestration layer communicates with the slice coordinator, allocating the resources of the internal domain to build a federated NSI. It also affords the corresponding LCM through fourth functional blocks: Service management function, slice LCM function, Sub-domain NFV MANO, and Sub-domain SDN controller.

- Slice LCM function: Identifies the corresponding network slice template from the correlating catalog and creates a logical network graph. The slice LCM function is responsible for the run time, orchestration, and instantiation of a Network Slice Subnet Instances (NSSI) taking into consideration the resource within the same

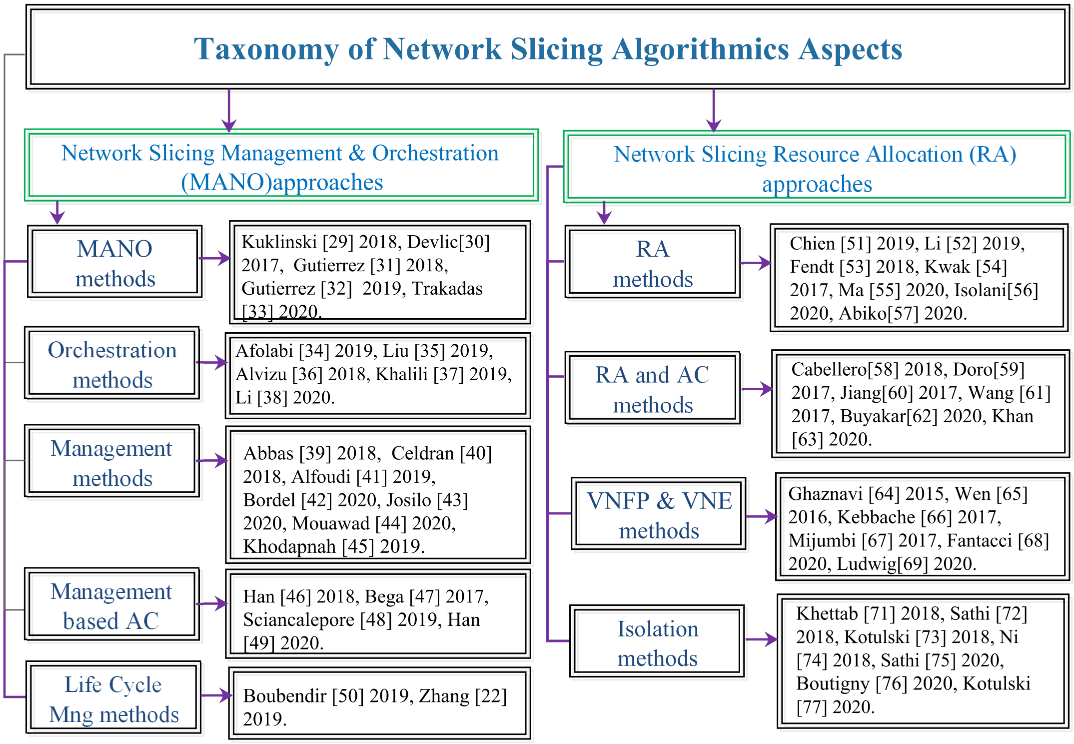


FIGURE 6. Taxonomy of network slicing algorithmic aspects.

operational domains, modification, and performing monitoring the related operations. The NSSI presented as a cluster of network functions instances, that composed of a part or complete constituents of NSI [28].

- Sub-domain NFV MANO: This block connects with the slice LCM function providing an abstracted aspect of the basic infrastructure and performs installation and execution of the VNF, storage, or computation.
- Sub-domain SDN controller: This block maintains the service chaining and network connectivity between the allocated VNFs. It provides the slice LCM function through an abstract view of network resource and control report in case of performance degradation in order to ensure the optimal SLA.
- Service management function: Consider the slice demands received from the slice coordinator and defines the role of core and RAN network that includes value-added services.

4) INFRASTRUCTURE LAYER

The infrastructure layer consists of the virtual and physical infrastructure that incorporates VNFs, the virtualization layer and virtual resources. For VNFs, the network functions are used as a 5G value-added service (firewall or Content Delivery Network(CDN)) or DP and CP functions. The virtualization layer is responsible for subdividing physical resources between operating VNFs and abstract; it decouples the basic hardware resource. The virtual resources (processing, computation, and networking) present as the abstracted physical resource that directly runs VNFs. The physical infrastructure is made up of hardware resources that present the VNFs with network connectivity functionality, storage, and processing via the virtualization layer. The multiple domains backing all technology types including RAN and multiple administrative domains. The infrastructure role will not be restrictive to connectivity. It will afford virtual resources and coordinated allocation networking. In addition, novel services are manufactured by software that will be hosted in the infrastructure factory while the network function and the resources are flexibly and dynamically provisioned and treated.

IV. TAXONOMY OF NETWORK SLICING ALGORITHMIC ASPECTS

NS methods aim to improve the network resources utilization, to enhance the satisfaction of users, the QoE, and the UE as well as to minimize the deployment cost of the network. In this context, we propose a taxonomy of NS algorithmic aspects based on different NS methods for MANO and RA approaches as illustrated in FIGURE 6.

A. NETWORK SLICING MANAGEMENT AND ORCHESTRATION APPROACHES

1) NS MANAGEMENT AND ORCHESTRATION METHODS

Slice management is extremely important, it differs from classical network management. For NS cases, we need to manage not a single, but multiple networks while the slice management functions split between NS system operators and slice tenants. Consequent to the software dimension of slices, we must provide cooperation between partially overlapped functionality of the MANO system. The paper of Kuklinski and Tomaszewski [29] handles the NS MANO scalability problem. The authors propose a Distributed Autonomous Slice Management and Orchestration (DASMO) aspect to solve this problem. In the sense of MANO orchestration, they use the orchestration concept and the classical term of slice management. The MANO orchestration is utilized for the runtime and LCM of network slices, while the management is used for the runtime management of slices only. In [30] authors offer a novel MANO architecture framework. They present a management system to be used by operators to automate the design, delivery, and configuration of network slices in various infrastructure resource domains that may include network functions from diverse vendors. Gutierrez-Estevez *et al.* [31] focus on a particular use case from the technological innovations of the 5G-MoNArch project. This project suits in the Experiential Network Intelligence (ENI) framework through the combination of Artificial Intelligence (AI) endowed orchestration system and network management. In the same context of AI authors in [32] focus on three use cases using particular Machine Learning (ML) algorithms, i.e. drawing from a subset of the entire AI range of techniques, to leverage the elasticity of resources. They propose an elastic scheduler by applying deep learning for Signal to Noise Ratio (SNR), reinforcement learning to make scheduling decisions, supervised learning for resource management established on traffic prediction, and unsupervised learning mechanism of spectral clustering for efficient slice setup. Recently, authors in [33] developed an innovative approach called SONATA for the MANO of each slice service, and compare it with the most known open source frameworks as Cloudify and Open Source Mano (OSM).

Essentially, the network slices are orchestrated to simplify the business solutions for whole 5G vertical services and industries upon application providers. From the literature, several works are suggested to address the orchestration aspect. For instance, in [34] authors suggest a Dynamic Auto-Scaling Algorithm (DASA) that is applied for a novel E2E NS Orchestration System (NSOS). They explain that the NSOS relies based on a hierarchical architecture. NSOS integrates dedicated entities per domain to handle every segment of the mobile network from access to the transport and core network component for a flexible federated network slices orchestration. The DASA allows the NSOS to adjust its resources autonomously to changes in the demand for slice orchestration requests while maintaining an average mean time required by the NSOS to process each slice orchestration request. The DASA approach includes both reactive and proactive resource provisioning techniques. Authors in [35] present a VirtualEdge system that allows the dynamic creation of a virtual node (vNode) to serve the workloads and the traffic of a network slice. This system introduces a feasible orchestration and virtualization multi-domain resource that provides isolation among network slices. Also, the authors introduce a new learning-assisted algorithm to effectively orchestrate multi-domain resources and establish a heuristic algorithm to dynamically map virtual resources to dependent physical resources. Alvizu *et al.* [36] present a network orchestration framework that is based on the hybrid transport SDN Control Plane (CP) to afford dynamic NS for mobile metro core and enterprise networks. In [37], the authors establish how different virtualization solutions address NS. They propose an orchestration platform suitable for the 5GCity project. The solution includes the creation of diverse network elements of slice such as physical networks, compute nodes, network edge resources, and radio parts with coordinating various underlying controllers. Recently, in [38] authors propose a new distributed architecture based on a new federated-orchestrator control plane entity that can manage the spectrum and computational resources without needing any exchange of base station (BS) local data and resource information. TABLE 2 provides a summary and a fine-grained comparison of diverse 5G NS MANO methods.

2) NS MANAGEMENT AND LIFE CYCLE MANAGEMENT METHODS

Due to the diversity of requirements and heterogeneity of services, network management through SDN and NFV technologies is a difficult task. Hence, an NS technique has been suggested to handle this challenge. Slice management is one of 5G network architecture's key features that has attracted a lot of attention today. In [39] authors propose a network slice management framework of TN between core and access networks using Open Network Operating System (ONOS) and OpenStack. This framework creates and manages the slice up to the user equipment. Celdran *et al.* [40] suggest an information model of NS and a mobility management architecture that integrates SDN/NFV techniques. They introduce inventive components responsible for network slice orchestration and management. This architecture is designed to consider the mobility of its components and the evolution of the dynamic scenarios. In [41] authors propose a novel mechanism of NS resource management (RM) to allocate the resources required for each slice of the LTE network, taking account of resource isolation between different slices. Also, the main objective of NS RM is to ensure that distributed bandwidths are isolated and fairly shared among users belonging to the same slice. The paper of Bordel *et al.* [42] offers a new approach for the management and implementation of slices and services in future 5G NS systems. This approach is based on virtualization technologies (Docker or Kubernetes) and lightweight algorithms. Jošilo and Dán [43] present a NS edge computing system that addresses the dynamic assignment of computational resources to slices, management of computing resources and radio within slices, and management of the network across the slice. Moreover, they formulate the resource management and joint slice selection issues as a mixed-integer issue to reduce computational task accomplishment time. The paper [44]

TABLE 2. Comparison of 5G NS MANO methods.

References	Technology	Operational objective	Orchestrator	Technology features	Management features	Architecture	Research project
[29]	NFV VN virtual resources	To simplify the management scalability issue using autonomous and distributed management architecture.	ETSI MANO OSM	Embedded Element Managers	Improved OSS/BSS to provides programmability level.	Multi-Domain	ETSI NFV 5G!Pagoda
[34]	SDN,NFV Virtual resources Cloud resources	To reduce the number of computational resources (cores CPU) to be allocated to the NS orchestration system.	Global orchestrator OSM	MANO	Auto-scaling of resources.	Multiple administrative domains	
[30]	SDN, NFV Cloud services Virtual resources	To meet the customer demands and gathered requirements from industry and standardization association.	NFV orchestrator (NFVO)	MANO NFVO	Improved OSS/BSS Monitoring Policy management	Multi-Domain Resource orchestration	ETSI NFV
[31]	NFV, Central and edge cloud Virtual resources Mobile network	To orchestrate the resource efficiently using AI and ML algorithms.	NFV MANO	———	Monitoring Policy management	Cross-domain Multi-domain Resource orchestration	ETSI NFV 5GMoNArch
[32]	SDN, NFV Cloud resources Virtual resources Mobile network	To improve the overall performance and resource efficiency of MANO machinery.	MANO	MANO OpenStack	Slice life cycle Auto-scaling of resources	Spatial domain temporal domain Resource orchestration	
[33]	SDN, NFV virtual resources Mobile networks	To achieve the optimal utilization of allocated resources and the QoS for each vertical industry.	NFVO Cloudify	Open MANO OSM Openstack OpenDayLight Transport API Kubernetes	Service monitoring Life-cycle management Policies enforcement Run-time SLA contracts	Administrative domain Service orchestration Resource orchestration	5GTANGO ETSI NFV
[35]	virtual resources Edge cloud	To ensure isolation between virtual nodes, thus maximizing the use of physical resources.	Orchestrator	———	Resource management	Multi-domain	US National Science Foundation
[36]	SDN virtual topologies network resources	To handle the heterogeneity and complexity of transport networks.	Network orchestrator	OpenDaylight	Policy management	Hierarchica architecture	Politecnico di Milano SWAN networks
[37]	SDN, NFV virtual resources VN cloud resources	To support the efficient operation of a large number of devices under dynamic conditions.	NFVO	OpenStack MANO	Life cycle management	Orchestrator architecture	ETSI NFV 5GCity
[38]	SDN cloud resources network resources	To decrease the overall latency in service experienced by IoT devices.	Federated orchestrator	———	Resource management Monitoring	Open Flow architecture	ETSI NFV

presents a mobility solution to address resource management by using games of negotiation. This solution is improved by a particular and heuristic swarm optimization algorithm. Also, the authors propose a novel resource borrowing model to readjust overloaded resources in case of an inter-slice handover. In [45] authors discuss the existing mechanism that has similar functionality in legacy networks and illustrates the strengths and limitations of those specific mechanisms for managing Radio Resources (RR) in a sliced network. In addition, they present new slice management to realize the protection of each slice. This mechanism is achieved through the limitation of the number of users admitted by Admission Control (AC) and adjust the part of radio resources allocation via the Packet Scheduler (PS). They suggest an iterative algorithm to optimize the different parameters (AC, PC) to ensure the SLA. The AC mechanism on the Service Broker layer is important for slice management. In this context authors in [46] suggest a general model for AC asynchronous for a slice and make out to be Markovian under a set of limited constraints. They propose also an empirical approximation of the matrix transition status to decrease the computational complexity of the practical applications. In [47] the authors present the NS theoretical model that is capable of the admissibility of the 5G network region. They develop an adaptive algorithm based on Q-Learning to attain optimal efficiency. Also, they suggest a semi-Markov system based on specif constraints to optimize infrastructure provider revenue. Sciancalepore *et al.* [48] suggest a novel theoretical paradigm focused on stochastic geometry theory to model practical RANs. This paradigm taking advantage of business opportunities that provide from NS. Also, they develop a new functional AC system that makes decisions taking into account the average experienced throughput guaranteed per slice by SLA. Recently, authors in [49] focused on the AC issue by means of a heterogeneous tenant request multi-queuing system. They derive the model of predictive behavior and define the logical technique of tenants in queue planted slice AC system. Also, they present an admission

TABLE 3. Comparison of resource allocation methods.

References	Resources type	Mathematical Model	Scenario	Operational Objective	Methods Description	Implementation
[51]	VNF, Computing and bandwidth resources Base station	General model	Edge+RAN +CN	To provide a flexible and scalable scheme for resource allocation with maintaining isolation	The Joint Edge and Central Resource Slicer (JECRS), manage the 2-tier MEC architecture services according to the tenants' slice requirements.	Yes
[52]	VNF and Link Network resources Network slice Storage and computation resources	Optimization framework	Access, Aggregation and core layers network	To decrease the backhaul transport latency	The branch-and-bound scheme provides the upper and lower bounds of a branch that are acquired by solving the relaxation issue.	Yes
[53]	Physical resource block Link and base station	Graph theory Optimization framework	Edge cloud +CN	To determine the optimal E2E slice embedding on shared physical infrastructure.	The optimization model works on maximizing the weighted sum of the whole embedded network slices.	Yes
[54]	Downlink and uplink network resources Base station	Lyapunov optimization Distributed algorithm	Edge+CN	To dynamic allocate the resources and to differentiate between the mixture of IoT and video streaming services.	Short time-scale and service power allocation for IoT devices, long time-scale bandwidth slicing, and quality decision for Video streaming service	Yes
[55]	Downlink, virtual and bandwidth resources	Complex theory Optimization framework	RAN+Edge +CN	To enhance the URLLC reliability and the spectral efficiency of the system	The optimization model is formulated to minimize the spectral efficiency of eMBB and URLLC slices.	Yes
[56]	Slice resources network resources	Optimization model	RAN	To minimize the system's whole queueing delay and respect the constraint of URLLC.	The QCQP ensures the maximum average queuing delay and calculates the queueing delay of each slice.	Yes
[57]	Downlink, Uplink Service resources	General model	RAN	To enhance the slice requirement satisfaction	The method controls diverse slices by monitoring the state of each slice and apply the model to controls the slices multiple times.	Yes

optimization utility model for network slices. Besides, several methods are existing from the literature that tackles the LCM of the network slice. For instance, in [50] authors propose an orchestration E2E method via managing their life cycle. This solution establishes the software modeling of resources as well as services and provides an overall view of architecture that is applied for different scenarios. Also, the paper of Zhang [22] presents a novel MANO slice that includes network slice instance LCM. The network slice life cycle is divided into four phases; design, orchestration and activation, Run-Time Assurance, and Decommissioning.

B. NETWORK SLICING RESOURCE ALLOCATION APPROACHES

1) NS RESOURCE ALLOCATION METHODS

The 5G platforms are shared by various tenants, each tenant has diverse service requirements that require several amounts of resources from the lower layer (mobile edge, and radio access network) and the upper layer (central office and TN) of the NS 5G architecture. Thus, the key issue in 5G telecommunications networks is the NS RA, which faces different challenges in terms of customization, separation, appropriate isolation, elasticity, and E2E coordination; hence playing a key role in resource utilization, networking performance, and load balancing. Several studies have been proposed in terms of NS RA [51]–[57]. Authors in [51] suggest an E2E framework for slicing both communication resources and computing. The framework isolates successfully the resources between slices and ensures that deployed slices resources are sufficient to meet the tenant's latency requirements. In [52] the authors propose a RA model to construct the relationship mapping between the substrate and logical networks in a consistent way. To enhance UE and the QoS, the RA problem is defined as a subject to the bandwidth constraints and backhaul capacity. This problem is described as an extended Virtual Network Embedding (VNE) problem and formulated as an ILP, which is solved using ILP solvers such branch-and-bound scheme, CPLEX, and Gurobi. In the same context, Fendt *et al.* [53] present the VNE problem as a directed graph for mobile network slice and developed the connection between the user equipment and network slice via the telecommunication service. To address the dynamic allocation of wireless resources (virtual base stations and cell slice), authors in [54] study the RA problem and bandwidth slicing to support the mixing of IoT and video streaming services. Recently, authors in [55] propose a novel RA algorithm that allocates the NS by applying the branch-and-bound method, to obtaining the optimal solution. The paper of Isolani *et al.* [56] presents a novel airtime RA model for NS in IEEE 802.11 RAN. The authors formulate the issue as Quadratically Constrained Quadratic Program (QCQP) in which the system's overall queueing delay is reduced while maintaining strict URLLC constraints. In [57] the authors suggest a radio RA that fulfills the service requirements using deep reinforcement learning. A deep comparison of the different RA works is highlighted in TABLE 3.

2) RESOURCE ALLOCATION AND ADMISSION CONTROL

The AC module aims to ensure that admitted users have a reasonable likelihood to see their requirements meeting rate over their lifetime, even after changes occur in the network. In the field of AC and RA, there are a significant set of existing methods that rely on the auction mechanism, which turns the optimization problem into a game for instance [58]–[63]. Authors in [58] focus on dynamic sharing in NS where the tenants backing inelastic users with a floor requirements rate. They propose a NS framework that combines AC, user dropping, and resource allocation. Doro *et al.* [59] analyze a multi-tenant SDN auction-based scheme for allocating network resources. In particular, a FlowVisor is presumed to control the resource allocation process by conducting an auction of fractions of network resources analysis. Authors in [60] present a novel auction-based model for shared resource and revenue optimization. Wang *et al.* [61] studies the relationship between profit maximization and resource efficiency and examines the dimensioning of network slice based on the pricing policy of the resources. Besides, the authors evolve an optimization framework to maximize resource efficiency and slice customer profit. Recently, authors in [62] suggest an MVNO Slice Resource Allocation Architecture (MSRAA) supports diverse slices of the 5G DP network. They estimate the criteria of bandwidth requirements for the efficient allocation of resources and propose an AC algorithm to reallocate the resources from lower priority to higher priority slices. Authors in [63] analyze the downlink/ uplink decoupled association scheme and formulate an AC and power allocation problem for the macro base stations in terms of the total rate maximization.

3) VNF PLACEMENTS AND VIRTUAL NETWORK EMBEDDING (VNE) METHODS

Slices are represented in the form of VNF chains that runs on physical and logical resources to meet the service demands. The essential idea of NS RA is to determine the feasible path onto network infrastructure for the deployment of the virtual links. Ghaznavi *et al.* [64] discuss the dynamic VNF Placement (VNFP) methods and propose an Elastic VNFP to minimize providing VNF services operational costs. Authors in [65] present two algorithms that aim to minimize the cost of mapping chain and the cost embedding of CPU, memory, physical link, and the network resource utilization rate. To address the objective of jointly maximizing the use of physical links and minimizing mapping costs, Khebbache *et al.* [66] propose a scalable algorithm of placement and VNF chaining. By using a graphic algorithm based on a neural network, authors in [67] present a topology-aware VNF embedding approach to reduce resource consumption. Recently, the authors in [68] develop a VNFs placement strategy as a matching theory basis on the forecasted customer requirements. This strategy is performed by taking into consideration that various network zones are distinguished by different provision prices and costs. Ludwig *et al.* [69] propose a network slice embedding method for the allocation and assignment of network slice resources. This heuristic approach meets the particular requirement based on the algorithm provided in [70].

4) NS ISOLATION METHODS

The isolation technique is a fundamental feature of NS 5G security, where several research papers have been done in this field. Khettab *et al.* [71] proposed intelligent security based on an auto-scaling algorithm that leverages the SDN and NFV architecture to enable slice security by using the SDN controller (ONOS). The proposed auto-scaling method aims to guarantee the resource by checking for each slice the maximum and minimum resources at the orchestrator level. For securing intra-slice network communications, a novel protocol is proposed in [72]. The basis of this protocol is the bilinear pairing on the elliptic curve and the modification of proxy re-encryption. Also, it offers mutual trust among slice components in an isolated manner. In [73] authors propose a perceptible analysis of NS isolation as a framework of a layered structure. Each layer of this framework has its isolation level and network elements, where the slice isolation is calculated through mathematical rules. From the basis of IoT, a secure and efficient method is needed to authenticate a lot of devices. In this context, authors in [74] suggested a secure authentication method for enabled 5G IoT devices. This method aims to guarantee the security of slice selection and access. In 5G networks, the use of static authentication protocols has two major issues: learning attack and exposure of users service access behavior to third-party. To tackle these issues, Sathi *et al.* [75] propose an anonymous group Privacy Preserving One way Authentication (PPOA), and Privacy Preserving Mutual Authentication (PPMA) protocols. The resources are distributed according to the requirements of the tenants, not only in the provision of QoS but also the security. Authors in [76] propose an embedding aware-security slice enabling tenants to assert security-oriented demands, which limit the disclosure of information of network infrastructure providers. Kotulski *et al.* [77] propose multiple isolation parameters and properties to enable quantitative and qualitative characterization. Also, they present a flexible approach that enables a particular isolation level for the E2E network slice. To deeply analyze the studied works for NS algorithmic aspects, we summarize in TABLE 4 the proposed methods of each work with their related segment and we make a deep comparison of these methods based on different criteria.

V. OPEN ISSUES AND FUTURE DIRECTIONS

5G networks aim to integrate diverse services into a shared infrastructure where each service has its logical network isolated from others. In this context, the emerging of NS is considered as a technology to meet these various services on the same infrastructure that compose of diverse equipment. The latest developments in NS are opening several algorithmic challenges for future network operations: How can a slice be deployed and optimized to ensure the QoS

TABLE 4. Comparison of network slicing algorithmic aspects methods.

				Criteria												
NS methods classification		Proposed methods	Segment	Latency	Cost	Throughput	QoS	OSS/BSS	Scalability	Security	Isolation	Availability	Complexity	OA	Optimization	Revenue
MANO methods	[29]	DASMO	E2E	N/A	N/A	N/A	+	+	-	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	[30]	NESMO	E2E	+	N/A	N/A	N/A	N/A	+	N/A	+	N/A	N/A	-	N/A	N/A
	[31]	MANO	E2E	N/A	+	N/A	+	N/A	N/A	-	N/A	N/A	-	+	+	N/A
	[32]	MANO	E2E				+		-						-	
	[33]	MANO	E2E	+	N/A	N/A	N/A	N/A	+	-	-	+	N/A	N/A	N/A	
Orchestration methods	[34]	NSOS	E2E	N/A	N/A	N/A	+	+	-	N/A	N/A	-	-	N/A	N/A	N/A
	[35]	Edge system	Edge	-	N/A	N/A	+	N/A	N/A	N/A	+	N/A	N/A	-	N/A	N/A
	[36]	SDN archi	TN	N/A	N/A	N/A	+	+	+	-	N/A	-		N/A	N/A	N/A
	[37]	NFV Orches	Edge	N/A	N/A	N/A	+	+	N/A	N/A	+	N/A	N/A	-	-	N/A
	[38]	Orches model	Fog	+	N/A	N/A	N/A	+	-	N/A	N/A	-	N/A	N/A	N/A	N/A
Management methods	[39]	MCORD	TN	+	N/A	N/A	+	N/A	+	N/A	N/A	-	N/A	N/A	N/A	N/A
	[40]	Mobility	E2E	-	N/A	-	+	N/A	+	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	[41]	RM	LTE	N/A	N/A	N/A	-	N/A	N/A	N/A	N/A	N/A	+	N/A	N/A	N/A
	[42]	Service manage	E2E	+	N/A	N/A	N/A	N/A	N/A	N/A	N/A	+	N/A	-	N/A	N/A
	[43]	RM	Edge	N/A	N/A	-	+	N/A	+	N/A	N/A	N/A	N/A	-	N/A	N/A
	[44]	MM	E2E	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	+	-	N/A	N/A
	[45]	RM	RAN	N/A	N/A	N/A	+		+	N/A	N/A	N/A	N/A	-	-	N/A
Management based AC	[46]	Markov model	E2E	N/A	N/A	N/A	+	N/A	+	N/A	N/A	N/A	N/A	-	-	N/A
	[47]	Q-Learning	E2E	+	N/A	N/A	+	N/A	-	N/A	N/A	N/A	N/A	-	N/A	N/A
	[48]	STORNS	RAN	N/A	N/A	N/A	+	N/A	-	N/A	N/A	N/A	+	N/A	N/A	N/A
	[49]	Controller	E2E	+	N/A	N/A	+	N/A	N/A	N/A	N/A	N/A	-	N/A	N/A	N/A
LCM methods	[50]	LCM	E2E	+	N/A	N/A	+	N/A	-	N/A	N/A	N/A	N/A	-	N/A	N/A
	[22]	LCM	RAN	N/A	N/A	N/A	+		-	N/A	N/A	N/A	+	N/A	N/A	N/A
RA methods	[51]	RA model	Edge	N/A	N/A	N/A	N/A	N/A	N/A	N/A	+	N/A	N/A	-	N/A	N/A
	[52]	Branch Bound	TN	N/A	N/A	N/A	+	N/A	+	N/A	N/A	+	N/A	-	N/A	N/A
	[53]	ILP	E2E	+	-	N/A	N/A	N/A	+	N/A	N/A	N/A	N/A	N/A		N/A
	[54]	BSRA	2E2	N/A	N/A	N/A	+	N/A	N/A	N/A	N/A	N/A	N/A	-	N/A	N/A
	[55]	OFDMA	RAN	N/A	N/A	N/A	N/A	N/A	-	N/A	N/A	N/A	N/A	+	N/A	
	[56]	QCQP	RAN	+	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	-	N/A
	[57]	Radio RA	RAN	N/A	N/A	N/A	+	N/A	-	N/A	N/A	-	N/A	N/A	N/A	N/A
RA and AC methods	[58]	NES	E2E	N/A	N/A	N/A	+	N/A	-	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	[59]	Auction	E2E	N/A	+	N/A	N/A	N/A	N/A	N/A	N/A	N/A	-	N/A	N/A	+
	[60]	Auction	E2E	N/A	N/A	N/A	+	N/A	-	N/A	N/A	-	N/A	N/A	N/A	+
	[61]	Optimization	E2E	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	-	N/A	+
	[62]	MSRAA	E2E	N/A	N/A	N/A	+	N/A	N/A	N/A	N/A	N/A	N/A	-	N/A	+
	[63]	scheme	E2E	N/A	N/A	N/A	+	N/A	N/A	N/A	N/A	N/A	N/A	-	N/A	N/A
VNFP and VNE methods	[64]	EVNFP	VN	-	+	N/A	N/A	-	N/A	N/A	N/A	N/A	N/A	N/A	N/A	+
	[65]	VDC	DC	N/A	N/A	N/A	N/A	N/A	-	N/A	N/A	N/A	N/A	N/A	N/A	+
	[66]	Cost	VN	N/A	N/A	N/A	+	N/A	-	N/A	N/A	-	N/A	N/A	N/A	N/A
	[67]	Neural graph	VN	-	N/A	-	N/A	N/A	+	N/A	N/A	N/A	+	N/A	N/A	N/A
	[68]	Federated system	E2E	+	N/A	N/A	+	N/A	N/A	N/A	N/A	N/A	N/A	N/A	-	-
	[69]	Heuristic algorithm	E2E	N/A	N/A	N/A	+	N/A	+	N/A	N/A	+	N/A	-	-	N/A
Isolation methods	[71]	SECaas	E2E	N/A	N/A	N/A	N/A	N/A	N/A	-	N/A	N/A	N/A	+	N/A	N/A
	[72]	GA	E2E	N/A	N/A	N/A	N/A	N/A	N/A	+	N/A	N/A	N/A	-	N/A	N/A
	[73]	Graph	E2E	N/A	N/A	N/A	N/A	N/A	N/A	N/A	+	-	N/A	N/A	-	N/A
	[74]	Secure service	Fog	N/A	N/A	N/A	+	N/A	N/A	+	-	-	N/A	N/A	N/A	N/A
	[75]	PPOA PPMA	E2E	N/A	N/A	N/A	N/A	N/A	N/A	+	-	N/A	N/A	N/A	N/A	N/A
	[76]	Naive algorithm	E2E	-	N/A	N/A	+	N/A	+	N/A	N/A	N/A	N/A	+	N/A	N/A
	[77]	Isolation mode	RAN	N/A	N/A	N/A	N/A	N/A	N/A	N/A	+	N/A	N/A	N/A	-	N/A

+: Advantage, -:Limitation, N/A: Not Applicable provided by the corresponding tenants and services? How to share and allocate the physical resources taking into account the isolation property to the different slices? How to model the orchestration policies within every slice?

A. NETWORK SLICE MANAGEMENT AND ORCHESTRATION

In 5G and beyond networks, SDN and NFV technologies contribute to the transition from hardware to software paradigms. This transition would entail improvements in how networks are implemented, controlled, and managed. Also, it requires new ways to orchestrate resources and to ensure dynamically the demand-based network functions instantiated. In this context, the 5G NS architectures and MANO framework provided in section III, address the virtualized MANO functionalities across multiple domains. Despite these efforts, how to move from the high-level service description to the concrete network slice is still a significant challenge. This includes the creation of a specific domain of resource/service and development of slicing languages to allow the expression of key performance indicators, specifications, and characteristics of 5G network service.

B. 5G NS RESOURCE ALLOCATION

Many current RA algorithms focus on a single subnet, such as CN or RAN. On top of that, few researchers work on E2E network slice. In [51], communication and computing resources are abstracted for RA schemes. In practice, these resources are suitable for a particular type of network slice. The coordination of multiple subnets, sharing the physical resources to the diverse slices taking into consideration the properties of isolation, and decomposition of SLA are the main challenges of 5G NS RA. The tenant may only provide an SLA to network slice management function without the need for each subnet caused the lack of basic communication knowledge. Thus, SLA decomposition for RA is still an inevitable step. Also, when updating the allocation scheme, the coordination among multiple subnets well significant.

C. 5G NETWORK SHARING AND SLICING

The development of the network sharing concept to the NS paradigm allows the configuration of multiple VNFs on the same NFV platform, that creates several large slice management problems. The resource sharing can be introduced by dynamic and partition sharing. From the network load characteristics, the dynamic sharing of resources between slice tenants represent the use of efficient resources, which requires intelligent scheduling algorithms. However, the inter-slice, intra-slice management, slicing orchestration, and the placement of NFs within the slice needs a significant effort to realize NS. Also, other issues that need more explorations as mobility management, security, and isolation between slices. Several consistent policies and suitable mechanisms should be clearly defined in each virtualization layer to achieve isolation.

D. RAN VIRTUALIZATION AND SLICING

Virtualization is the key technology for the implementation of NS where the main challenges for infrastructure virtualization lie in the RAN subnet. Additionally, applying RAN slicing in a virtualized 5G environment is not yet adaptable [78]. The problem is not adequately addressed by the application of containers such as VM-based solutions for RAN virtualization, because these solutions do not enhance any virtualization dimension and radio resource isolation (e.g. hardware). Although, multiple RATs (5G new radio and NB-IoT) are expected to be a universal 5G networks standard. However, the greatest importance is the ability of RAN virtualization to accommodate multiple RATs. This requires a RAN slicing dynamic strategies that can be backing several criteria such as isolation, the flexibility that enhance multiplexing benefits in term of modularized RAN configuration, the dynamic implementation of RAN, and decomposition of network service.

E. MOBILITY AND NS MANAGEMENT

Mobility aspects such as interference management and seamless handover (caused by the increasing of diverse vertical industries) bring new challenges to NS. 5G network slices need varying latency and mobility characteristics where the specification of mobility management and handover is distinct from the mobile broadband management slice. Generally, NS management is still difficult despite various technologies are included in their architecture levels such as activate, maintain, load balance, and isolation, as well as intra-slice and inter-slice resource sharing.

F. 5G NS SECURITY AND PRIVACY

In 5G NS, the notion of sharing resources between slices may create security problems. Network slices provide diverse types of services for various verticals that can require different levels of the privacy policy and security. This calls for the new creation of security and privacy protocols for 5G NS that take into account the allocation of resources into particular slices. Besides, as 5G NS is introduced in multi-domain infrastructures, security problems become much more complicated. Hence, efficient mechanisms and security policy of communication between different administrative domains in 5G systems must be established and developed to address this issue.

VI. CONCLUSION

NS for 5G networks presents a key solution to accomplish its design principles are known as scalability and multi-tenancy, fragmentation of administrative fields, as well as efficient orchestration of network functions and services. Several challenges associated with network slice MANO, 5G network sharing and slicing, RAN virtualization, mobility and NS management, 5G NS security, and privacy. In addition to 5G NS RA can be considered as an interesting challenge. The NS RA scheme is considered at different time scales (macro and micro). At the macro time scale, the physical resources are firstly shared between the slices based on their usage and requirements. At the micro time scale, the efficient RA scheme encounters two dependent problems as inter-slice (VNE) and intra-slice (Service Function Chaining (SFC)) problems. In our future work, we plan to focalize on how to share and allocate the physical resources to the diverse slices taking into consideration the properties of isolation.

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