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Survey on Network Slice Isolation in 5G Networks: Fundamental Challenges

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Abstract

5G technology is the future of mobile networks, and in different countries, 5G mobile networks are launched. Different use cases have different requirements for the function and the performance of 5G network. They would require different types of factors and networks which include data rate, delay and scalability. Those requirements will be met in 5G by using network slice architecture, which uses network virtualization technology The paper will analyze the state-of-the-art 5G network slice, address a number of network slicing architecture issues, and highlight some open research questions.

Keywords: network slice; isolation; 5G network.

I. Introduction

The 5G technology is providing high-speed communication services because it is using millimeter waves to transfer data from one location to another location. 5G is also supporting many devices because the network speed is very high. It can be improved by introducing a new architecture, and this architecture is known as network slicing. Network slicing is an important architectural technology for 5G [1], [2].

Network slicing is the most important concept to realize personalization of mobile networks for users [3].

Basically, logical networks will be virtually representing the 5G single physical network, and each one called network slice. Every network slice will have specific network functions to provide different services for different requirements. Network slicing offers better business agility, flexibility, and cost-efficiency

It is challenging to design a robust network slice architecture. Currently, it is found that the full network slice isolation is not met yet. Full isolation means that each network slice instance has its own function without sharing with the other slices. Each slice should have its own path for its data traffic and store its data in separate storage or memory without sharing that with network slice instances.

Currently, the 5G networks are supporting high speed with many numbers of connections. But this speed can be affected because 5G is going to support IoT devices and these devices are increasing day by day [4]. Thus, the main issue is to enable 5G networks to behave like multiple slices, and each slice must be working independently.

This paper begins by presenting the key management issues of 5G network slice. Next, the state-of-the-art, including existing architectures, is discussed in section 2. Section 3 subsequently discusses the existing work relevant to it. Then

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the underlying problems of 5 G network slicing are answered by section 4. Ultimately, this paper is concluded in section 5.

2.State-of-the-art

The network slice in 5G networks is discussed in this section. This introduces the definition and the existing architecture of the network slice.

2.1. Network slice definition

A network slice is basically a logical network that provides specific network capabilities and characteristics

Network slicing helps the operator to build tailored networks in order to provide integrated solutions for various needs. In [5], the author believes that one of the most critical developments in the fifth-generation networks is network slicing. Slicing mechanism allows virtual networks to provide personalized services on request.
By 2020, a wide variety of services and applications will be provided by the 5G mobile networks to meet the connected users' requirements. [6], [7].

2.2. Network slice architecture

There are architectures for slicing networks from different resources [8]. Fig. 1 shows the Network slicing conceptual outline, according to NGMN as below

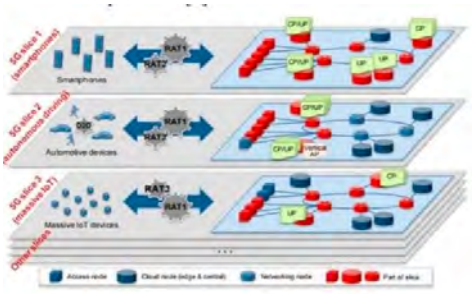

Fig. 1. Network slicing.

Besides, fig. 2 shows the control plane (CP) architecture for network slicing as below:

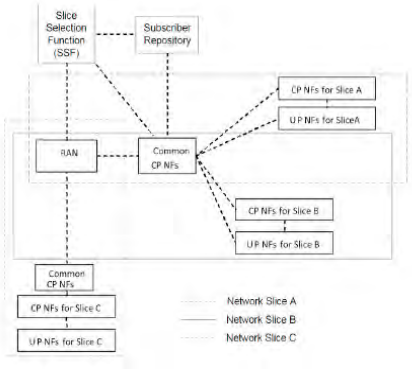

Fig. 2. CP for Network slicing.

Furthermore, fig 3. shows an application scenario of network slicing

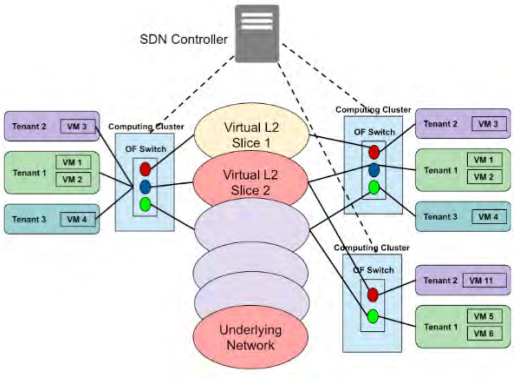

Fig3. Network slice use case

3. Related work

5G mobile networks are expected to deliver a significant digital revolution that will provide unparalleled information-sharing opportunities to individuals, businesses and governments. The consensus of the industry is that 5 G should be recognized not only for its state-of - the-art wireless connectivity technology but also for the manner in which it incorporates cross-domain networks so that operators can provide networks on a consumer basis. In [9], "Each network slice works independently and virtually represents the end-to-end network, and all slices work simultaneously because of slicing architecture".

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In [5], the author believes that in the fifth generation (5G) mobile networks, network slicing has been considered one of the key technologies. Slicing mechanism allows virtual networks to provide personalized services on request. The 5G E2E network slicing is seen as a key factor in achieving this challenging goal. [10]. The challenge is how to provide very different types of services and support 5 incompatible 5G core features with a single network infrastructure. The solution is to create multiple networks customized to each service and main capabilities. The distinction from the current network model is that each network is a logical network based on a single network infrastructure that is virtualized. Logical network consists of a collection of network functions chosen for a service and is known as a network slice [11]. A network slice is a logical network that provides unique network capabilities and network features.

In [12], where to go from a high-level definition of the service to a practical slice in terms of infrastructure and network functions is a major challenge for the realization of a network slice. The question of service definition has been described in the literature, but without satisfactory resolution
. The 5G technology is going to accommodate many areas of life, but it is the chance, that IoT devices will reduce the speed of this 5G technology. To overcome this issue and to get more reliable network speed, the network slicing is the natural solution, because this solution can easily accommodate multiple services. In [13] these slices can be controlled by using the software. In this technique, the networks will be transformed by using the solutions of software-based. For this purpose, the Software-Defined Network technique is being used. SDN is providing software-enabled virtualization where many virtual or logic networks can be created. These virtual and software-enabled networks are known as slices of the network. These slices will be enabled on one network; it means, one network will be divided into multiple logical networks. In [14] this technique is not new, because on traditional networks VPN is the example of the slice. But slices will be independent mutually, and all the control and management system of each slice is independent. These slices can be created according to the requirement or on-demand. This technique can be helpful for different business domains to work on their one slice which same sharing infrastructure of the networks. In [15] the main requirement of this 5G network slicing is the isolation of all the slices. Thus, strong isolation is required, where all the slices will be working parallel by sharing the same network architecture. The isolation must be considered based on the performance of each slice like each slice must provide all the required services. The performance of isolation is measured in the end to end connections. That's why in isolation, each slice must provide the performance according to the specific performance requirements.
In [16] also the isolation of each slice is measured in the form of privacy and security, like if there will be any security threat or security issue with anyone slice, then this threat to security will not affect the performance of other network slices. Each slice must be working independently based on defined security measures and security solutions

provided for each slice. In this way, only authorized people can access the slice; the unauthorized access can't change any configuration of the slice. That's why the security impact of each slice must be isolated from other slices. Isolation of each slice also depends on the management, like every slice must be managed independently because each slice must be working as a separate network. In [17] 5G network slicing can be configured based on layers, and each layer must be working to provide isolated services to all the slices. This architecture can improve the overall connectivity of the networks. Because right now, the complete isolates networking slicing technology is not working, because still, slices of the network depend on the other slices, that's why the performance is not according to the requirements. Network slicing architecture is based on the software because the software will virtually divide the network into multiple slices. Table 1 shows a summary of related survey papers on network softwarization and 5G network slicing [30].

Table 1
A Summary of Related Survey Papers on Network Softwarization and 5G Network Slicing.

Contributions and covered scope	[15]-2016	[16]-2016	[17]-2016	[18]-2017	[19]-2017	[20]-2018	[21]-2018	[22]-2018	[23]-2018	Our paper-2019
5G Service Quality Requirements	✗	✗	✗	✗	✓	✓	✗	✗	✗	✓
5G Market Drivers & Key Vertical Segments	✗	✗	✓	✗	✗	✓	✗	✗	✗	✓
Network Softwarization	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓
5G Networks Considerations	✗	✗	✓	✓	✓	✓	✓	✓	✓	✓
Network Slicing concepts, history and principles	✗	✓	✗	✗	✗	✓	✗	✓	✗	✓
Virtualization Hypervisors	✓	✗	✗	✗	✗	✓	✗	✗	✗	✓
Placement of Virtual Resources and VNFs	✗	✓	✗	✓	✓	✗	✓	✓	✓	✓
5G Network Slicing Standardization Efforts	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓
5G network slicing PoC	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓
5G Collaborative Projects	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓
Orchestrators for Network Slices	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓
Multi-Domain Orchestration and Management	✗	✗	✓	✗	✓	✓	✗	✗	✗	✓
Single-Domain Orchestration and Management	✗	✓	✗	✓	✓	✗	✗	✓	✓	✓
Network Slicing Management in MEC and Fog	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓
RAN Slicing	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓
5G Network Slicing Architectures and Implementations	✗	✗	✗	✗	✗	✓	✗	✗	✗	✓

** Proof of Concepts = PoC.
"✓" indicates that the attributes are provided or applicable in the research work.
"✗" indicates that the attributes are unspecified or non applicable in the research work **

Table 1. Related Survey papers

The author [1] is stating that the network slicing can also work for edge nodes and this node can easily offer low latency services to the end-users. The centralized applications, services and can be shifted towards the edge slices of the network to perform better services. For this purpose, a complete management model is required to hand over all the services and applications to the edge slices of the network. In [18], a complete 5G network slicing architecture is proposed and presented based on physical resource allocation to the virtual slices. This slicing architecture can be implemented in the local area network by introducing scheduling between all slices. SDN can easily manage all the workings of the resource allocation for central slices because the management of mobility can be performed by the SDN quite accurately in slicing networks. Also, the designing of slicing network architecture for the 5G network is based on the control of hardware and infrastructure of software. The slicing is interconnectivity or interworking between software and hardware. The slices of the network must be sharing the same network resources, and physical infrastructure will be shared between all slices, but they will be working separately as an isolated network [18]. The [2] is identifying SDN as a software control because SDN is being used widely for implementing the slicing in the network and for this purpose the network virtualization is used. In [19], the novel network slicing mechanism is introduced in 5G networks. There are three-fold involve, in the first-fold, there are 3 layers, the first layer is introducing the service layer of the network slice, the second layer is introducing the applications and network idea, and third is being used for the realization of network slicing. This architecture is generic because this architecture can be used for LTE and 5G as well. This is called novel slicing network architecture. The author [20] is stating that the slicing networks are providing many advantages. Like slicing, networks will be more flexible as compared to the tradition networks because network equipment is very costly, and when many slicing networks are the same share hardware, then the overall cost of the network will reduce. That's why slicing networking architecture is very strong to provide flexible services. Table 2 show the comparison of 5G slice modelling approaches [31].

Comparison of 5G slice modelling approaches.

	Service-driven	Resource-driven	Deployment-driven
Slice lifecycle development	+ The entire slice lifecycle management can be implemented via OSS/BSS extensions that interact only with the NFVO. – Modelling everything that needs to run on the set of slice resources as a standard NS might be undesired due to complexity of NSD creation, lack of ETSI NFV expertise, or conceptual distance of the deployables with the ETSI NFV standard.	+ Cloud resource orchestrators can be used for the slice resources management, while services can be potentially modelled with less complexity than ETSI-based solutions. – The absence of linking to NS descriptors can lead to duplications or incompatibilities between the slice lifecycle management implementation and the NS lifecycle management implementation.	+ The implementation of the slice resource management can be done outside of the NFVO (as in the resource-driven approach), while services deployed on the slice during its lifecycle are not restricted to be modelled in a specific way. – The conformance of the models of the deployable instances (right part of Fig. 3) with the resources-related part of the slice model (left part of Fig. 3) might be challenging to achieve in complex systems. This refers mainly to correctly modelling the weak dependencies of Fig. 3.
Standards alignment	+ Intuitively close to the 3GPP and ETSI NFV expectations of how a slice data model should look like. – Heavily dependent on the endorsement of ETSI NFV-based modelling of (network) services.	+ Intuitively close to the Cloud-native way of modelling resources (e.g., note the similarity to OpenStack resource types and hierarchy). – Structurally disconnected from other existing standard models.	+ Aligned to Cloud-native standards for the modelling of resources as well as to 3GPP and ETSI for the modelling of services. – Risks incompatibilities with those standards by having the loosest integration between the "services part" and the "resources part".
Supported standards	+ 100% support of any ETSI NFV-modelled solution. – Support of the deployment of services modelled based on other standards (e.g. ETSI MEC or Cloud-native standards) is possible either with additional efforts or not at all.	+ Supports the inclusion of any kind of services in the slice instance. – It requires its custom service modelling even for services that are already modelled based on other standards.	+ It supports ETSI NFV and ETSI MEC service descriptors, as well as any other standard descriptor that can be linked to its resources representation. – It does not support NSs that describe their (required) "host" resources in a way that cannot be mapped to any of the slice resource chunks.
Network sharing functionality	+ It can be built on top of existing NFVOs. – All the aspects and the phases of the network sharing functionality are dependent on the NFVO and its way of operation.	+ Slice resource sharing is decoupled from runtime constructs (e.g., service instances), so that it can be implemented at a pre-runtime phase and without having to go into the heavyweight details of NS design. – Limited flexibility with regard to quickly building slices by composing off-the-shelf services from NS catalogues.	+ Slice resource sharing is decoupled from runtime constructs (as in the resource-driven approach), while service creation and instantiation can also be facilitated by an NFVO and other NFV-related modules such as NS catalogues. – Higher complexity during operation due to the heterogeneity of the models of the diverse service instances that are deployed on the slice.

Table 2. comparison of 5G slice modelling approaches

In [21], the slicing networks can provide unified management, where centralized networking services will provide perfect network control, particularly this logical centralized control is helpful for heterogeneous networks, and the traffic requirements are controlled by the network according to the demand of the slices. Each slice must have a self-management and run as a separate network [22], [23]. In [24], the author states that Software-Defined Networking (SDN) and Network Function Virtualization (NFV) are the main technologies for implementing network slicing. The author [25] also is stating that the slicing networks are used for simplification of the network operations because network operators are going to control few centralized networking operations and entities and these few entities are enough to control the whole network perfectly. In [26], the slicing network architecture is enabling to innovate things, because the functions of the controller are modified according to the performance requirements of each slice. In this way, the new services and new functions can be introduced in the core architecture. This whole process can be completed in a few hours because SDMC apps are providing a controller to modify any service and any function of the slicing network. The [17], the slicing network can improve the programmability of the network admins because it is allowing to schedule the functions, services, and selection of the channel. In the way, this architecture is providing inter-slice resources control mechanism as well, this will help to allocate resources in compliance with users' requirements. SDMC is also allowing to assign idle resources to the other slices, and even services of the third party can utilize all the unutilized resources. The way we classify users and ensure isolation is an open research topic, while the network operator must provide slice / system monitoring APIs for slice life management. [13] Author [27] is stating that the slice network architecture is going to face many challenges as well like resource sharing can be a big issue, because in traditional slicing networks we can add more hardware devices to the network to avoid hardware constraints. However, in 5G the limited spectrum can cause an issue of limited hardware resources. In RAT (radio access technology) the sharing of the spectrum can be a big issue for slicing networks. Sharing constraints like information sharing, MAC layer sharing, physical resource sharing, and physical layer sharing constraints can be more difficult to manage during the resource management process. In [28], the author states that the problem of isolation is still less dealt with in the literature, despite being one of the major research challenges in this area

In [29], the transparency is another big challenge, because the slicing networks will be extended to different countries, that's why it could be difficult to manage transparency of the network when the network expands. Unlimited requests of slices will also cause a big issue because we can't keep the network architecture to access all requests and if all request is accepted, then the whole network will go down due to overwhelming requests.

4. 5G network slice challenges

What is 5G network slicing and its challenges? It's a common but very important question we need to answer it. Undoubtedly, its fifth' generation internet but in real it's the name of logical networks which deploying on a physical common infrastructure. In other words, an individual stable network working as a core which provides multi-service as the control plane and the end-user data plane are completely separate. It's not a node base, however, there are many challenges which need to resolve. Where it is to understand slicing limits is a big challenge. Because still, it couldn't compute that what are the limits of network slicing with 5G networks? Although, it is not hard to understand a slice of network. Basically, slice of network consists of common network services and management. So, concept is not tough but implementation of the network slicing with 5G network is a big challenge. There are a few suggestions for network slicing and relation between 5G networks but there are some reservations still, such as mobility management.

4.1. Recourse allocation

Fast mobility services and compatibility with 5G network slicing is another big challenge. The slice network provides all services but mobility support to some specific network slicing not meet with all network slicing. Ultimately, it's a mobility management failure because it doesn't get success to connect with every slice network.

4.2. Isolation and security

Isolation and security are one of major challenges of slice networking with 5G networking. Isolation is a common term in networking and it's also the part of slice networking. The issue or challenge is that isolation with QoS (quality of service) and QoE (quality of experience). Ring fencing plays great role in slice isolation according security. Because ring fencing is a resource of security protocols. The inquisitive or worry-able thing is that ring fencing almost failure when slice network connects with 5G. In fact, it's not support communication between slices on the time of isolation in 5G. Isolated network slices are a significant factor for service realization in the future

network [4]. Also, without isolation, there would be opportunities to create new attack methods. If there is an attack on a weak, isolated slice, this could lead to reaching a resource and sensitive data in other slices.

4.3. RAN (Radio Access Network) Virtualization

According to a study, RAN is on early stage and needs to be flexible with the infrastructure to provide various RAT. Because RAN work multiple base stations comparatively RATs. The proper configuration of RAN has capabilities to fulfill the slice-based load balancing. However, it's the big challenge to manage the traffic with QoS accordingly. So, the goal of 5G usage with RAN is challenging and end to end 5G network is not successful though.

4.4. Coarse-Grained and Fine-Grained functions

As we know that in 5G technology there are collaboration of many slice networks. While the coarse-grained functions are very important because it plays a role to chain the interfaces together. The challenging thing is that where it defines the chain, on the other hand, it reduces the flexibility for the slice network. It also less adaptive in underlying conditions, so it's not scalable as functional in slicing. While in fine-grained function, the challenging point is service chaining because of exchanging the data or interoperability of function.

4.5. End-to-end Slice Orchestration

End-to-end slice orchestration is a major challenge in 5G slice networks. According to its functionality, it should trivial slice generation through slicing and mapping efficiently. However, it should also adaptive and deploying the

services, but it shouldn't be limited. This is the huge challenge of essential a flexible slices end to end orchestration. In other words, slice orchestration failure because of limitation functionality in virtualization.

5. Conclusion and future direction

In this paper, a set of 5g network slicing challenges have been discussed. The main challenge is how to isolate the network slices and what levels and types of isolation are required. Also, another challenge is whether or not the isolated network slices can improve overall network performance.

In future, redesigning or building new architecture should be proposed to achieve the objective of making all slices work independently without sharing resources with other slices, providing network selection, isolation / separation between storage network slices, traffic, etc., and a routing system for transmitting end-user data to the network slice. This would be done by using network simulations (eg: OMNET++) to analyze the future 5G network slicing architecture in different mobility scenarios.

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