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Network slicing: a next generation 5G perspective

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Abstract

Fifth-generation (5G) wireless networks are projected to bring a major transformation to the current fourth-generation network to support the billions of devices that will be connected to the Internet. 5G networks will enable new and powerful capabilities to support high-speed data rates, better connectivity and system capacity that are critical in designing applications in virtual reality, augmented reality and mobile online gaming. The infrastructure of a network that can support stringent application requirements needs to be highly dynamic and flexible. Network slicing can provide these dynamic and flexible characteristics to a network architecture. Implementing network slicing in 5G requires domain modification of the preexisting network architecture. A network slicing architecture is proposed for an existing 5G network with the aim of enhancing network dynamics and flexibility to support modern network applications. To enable network slicing in a 5G network, we established the virtualisation of the underlying physical 5G infrastructure by utilising technological advancements, such as software-defined networking and network function virtualisation. These virtual networks can fulfil the requirement of multiple use cases as required by creating slices of these virtual networks. Thus, abstracting from the physical resources to create virtual networks and then applying network slicing on these virtual networks enable the 5G network to address the increased demands for high-speed communication.

Keywords: 5G communication, Software-defined networks, Network slicing, Slicing use cases, Network function virtualisation

1 Introduction

Over the recent years, the substantial increase in the use of handheld gadgets has resulted in a massive surge in the volume of mobile traffic across private and enterprise networks as well as across the global internet [1]. Virtual reality (VR) and augmented reality (AR), which are relatively new application/service types, have emerged and added to the mobile data traffic exponentially. This increased demand in traffic along with higher bandwidth requirements are reasons to upgrade the fourth-generation (4G) network architecture with the new fifth-generation (5G) network. The 5G network can provide high data rates and improved reliability with low delay and latency while supporting high mobility of users. However, the 5G network has several shortcomings that prevent



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the upgrade from achieving all the above mentioned characteristics [2]. Although hardware upgrades can be used to address these shortcomings, such upgrades can be expensive and are therefore not feasible. Recent technologies, such as software-defined networking (SDN) and network function virtualisation (NFV), have made addressing such issues possible without the need to upgrade the physical infrastructure [3]. Using these technologies also enhances network flexibility and scalability. SDN and NFV can be used as the key components in the architecture of the 5G network, and using these technologies allows the network to be separated into different slices, which can then be dedicated to different use cases, such as Internet of things (IoT), smartphones applications and intelligent vehicles. This feature of creating network slices that correspond to the demands of each service can be a major differentiating feature of the next generation 5G network. Concepts of SDN and NFV play an important role in the creation of network slices by allowing software abstraction and virtualisation of networks. Given the advanced nature of the applications and devices in use today, SDN and NFV allow for the management of network resources and services in a flexible and dynamic manner to meet the demands of today's network [4]. This work on network slicing will help provide a better understanding of the 5G network architecture, network slicing architecture and the effectiveness of network slicing in terms of performance, resource utilisation and flexibility. In this article we provide a comprehensive taxonomy of a network slicing model that is used in the 5G network domain. This taxonomy is based on different factors, such as network nodes, slicing scope, slice isolation and slice management, which are the types of use cases served by the 5G network and enabler techniques, namely SDN and NVF. The key contribution of this work is threefold:

- to introduce the network slicing concept, which includes areas of the 5G network in which slicing will be implemented
- to understand different use cases that need to be served by the network slices to allow the understanding of different types of network slice requirements and
- to showcase enabler techniques, which include understanding a range of techniques that will enable the process of network slicing in the 5G network architecture.

In conceiving the design of network slices architecture, different past and current systems can be compared and analysed based on the work conducted. In this article, we briefly outlined the 5G network nodes, network slicing use cases and the enabler techniques that establish a 5G Network Slicing Use Cases with Enabling Techniques (5G-NSUE) paradigm. Each major component required for network slicing was defined and discussed along with clear examples. This analysis and validation of the major entities of the current system will allow future researchers to easily recognise the components that can be reused and need improvement or different solutions and approaches.

The remainder of this paper is organised as follows: Sect. 2 introduces the concept of network slicing in a context of communication technology. Section 3 provides a discussion of previous work on network slicing in 5G network. Section 4 presents discussion related to the system components that are required for a network slicing model ED paradigm and describes them briefly. Section 5 discusses and illustrates how the classification can be used in a real-world scenario, in which the taxonomy is instantiated by

classifying recent publications in this domain. In Sect. 7 a detailed discussion to validate the architecture and its application in various technologies has been discussed. Finally, Sect. 8 presents the conclusion.

2 Technology background

As the name suggests, network slicing involves creating the slices of a designated network. The key feature of this technology is that each created slice has different attributes, such as low latency, ultra-high bandwidth and mobile broadband. The advantage of these slices is that they can now be used to serve multiple different use cases according to need. For example, real-time streaming application requires a low-latency network slice, whereas streaming high-definition videos requires an ultra-high bandwidth slice. The applications are endless. In [5] authors have presented a design of radio access network (RAN) slicing model by characterising diverse radio resource management (RRM) strategies for multi-service 5G scenarios. The model has been designed and tested using a slicing-aware resource allocation procedure that utilised Markov modelling approach to capture the responses for different radio links experiencing diverse user experience. Using network slicing in a 5G network responds to the potential popularity of 5G as the next-generation cellular network that can serve a large number of use cases. The 5G network can provide high-speed network connection with high reliability and low latency, which makes 5G the preferred network for different use cases. The 5G network can be the serving network of IoT. Thus, the base network for all these use cases will be the 5G network. Network slicing should be conducted to efficiently use the underlying resources of 5G networks. The limitation of network slicing in a 5G network is its infancy; it has not been extensively researched and used, thus giving rise to different issues and challenges. For example, network slicing implementation on radio access network (RAN) in 5G environment is a difficult task and calls for complex network designs. The current network architecture needs to be modified to fit the network slicing model. The goal of this work is to create a network slicing model with few modifications to the already existing network architecture of 5G.

Network slicing can be defined as the process of creating slices in the network according to the needs of different end users. The requirement of end users varies from one to another. Thus, the network service provided to these users should vary according to their need. However, the physical network infrastructure is not yet vast and complex enough to serve user needs. Moreover, implementing a user-based network service in terms of physical infrastructure is a difficult task that requires a considerable amount of money, expertise and labour. However, softwarisation and virtualisation of the network infrastructure make providing user-based network services possible. In the context of the 5G network, this feature is important because 5G is deemed to serve a wide variety of use cases. This necessity calls for the concept of network slicing to be implemented in the 5G network. Network slices are created according to demands and are supplied by the telecommunication network, which is 5G. Network slicing involves slice creation, slice isolation and slice management. The process of network slicing will be implemented on the core network as well as on RAN. The concept of network slicing will provide users with small network slices rather than the whole network services. For network slicing to be possible, the techniques that need to be embedded are SDN, which enables the creation

of softwarisation abstracts of the network functions, and NFV, which virtualises the network functions. Finally, the virtual network can be sliced in different ways as required.

3 Literature review

This section presents the recent literature based on network slicing. Prior research was focused on network slicing limited to LTE and 4G networks [6]; however, the emphasis on establishing 5G networks for all use cases has made the network slicing important for today's telecommunication industry. Although the research on network slicing in 5G networks has been conducted in the recent literature, but these projects were mostly implemented on the core network of 5G. In [7], the authors highlighted the need of utilising SDN/NFV-based technology to handle the massive growth in data associated with IoT devices. Authors have presented a design and analysis of mathematical model to compare the cost and energy consumption for SDN/NFV network and a traditional 4G network.

In [8], the authors provided the conceptual description of network slicing in 5G networks and focused on the coexistence of slices from an architectural point of view. The authors added a few methods to enable flexible RAN considering its impact on the 5G network design. Based on the topological information, a mathematical model was presented for the deployment of end-to-end slicing in a 5G network. The network slice implementation algorithm was proposed for three distinct types of network slices. Through simulation, the performance of the proposed algorithm was assessed for different slices. In [9], the author elaborated the 5G network slicing concept, provided insights on SDN and NFV and emphasised the combination of the two technologies to achieve network slicing. Other works on network slicing involved network slicing on the core network, network slicing on the access network, resource management using network slicing, isolating network slices and improving resource utilisation and latency using network slicing. The authors in [10] described the 5G network architecture with respect to elasticity and scalability requirements for network slicing to provide customisation at granularity levels. This research provided a personalised mobile telecom (PERMIT) approach for network slicing. This approach acts as a catalyst for structural changes to the current telecommunication system configuration by making changes to the mobile delivery network and services. User mobility patterns, service usage behaviour patterns and dynamics of underlying infrastructures are considered. Also, this research presented the insights on network slicing along with SDN, NFV, mobile edge computing (MEC) and other technologies that will soon become major points in the service-oriented 5G network architecture.

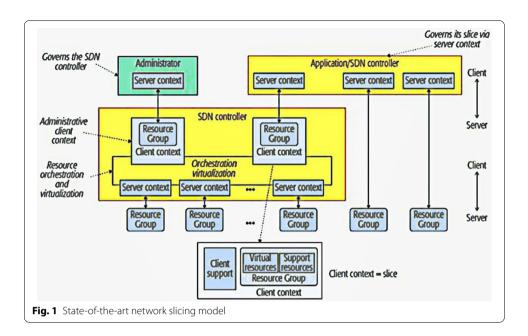
In [11], the authors discussed different network slicing techniques and pointed out several open research challenges in network slicing. In [12], the authors described the role and importance of network slicing in vehicle-to-everything (V2X) services with regard to 5G networks by addressing the design for dedicated V2X slices. In [13], the authors discussed network slicing architecture that features RAN abstraction. The proposed model is based on the principle of an exclusive core network assigned to separate traffic from the appropriate core network and uses a two-level scheduler to abstract and share resources among the slices. As per the requirements for each slice, the proposed architecture provides flexibility by adapting the resource allocation policies as required.

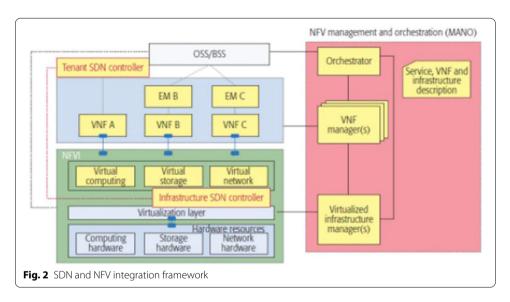
In [14], the authors proposed RAN runtime slicing architecture that provides an adaptable execution environment for running customised slice instances with desired isolation levels while sharing the same underlying RAN infrastructure. In [15], the authors provided a cloud-native approach for 5G network slicing by considering the slice life cycle. Given the requirements of different new services, this approach will help serve and deliver such requirements. For example, the proposed approach can help mobile network operators to devise network architectures and plan their deployment scenarios in accordance with the requirements of their business models, use cases and service groups. In [16] the authors presented a common framework for bringing together and discussing existing works in 5G network slicing in a holistic and concise manner. This proposed framework groups several proposals of slicing according to the architectural layer they targeted. The authors also evaluated the maturity of current proposals and identified several gaps in the literature.

The core concept of network slicing is discussed in [17]. The environment of the 5G network is shown in this research, and a model for a network slice architecture is provided. The matching process of the network slicing selection matching model is also proposed. In [18], authors have provided various approaches for RAN slicing. The authors compared the approaches by identifying their advantages and disadvantages based on various scenarios. Finally, analysis and simulation on network slices and isolation are presented. In [14], the authors described the importance and role of network slicing in a runtime environment in 5G networks and addressed the design for runtime network slicing.

A good understanding of resource allocation framework, which can pave the road for wireless network virtualisation is presented by the authors in [19]. The authors introduced 5G networks and the importance of slicing and discussed several open issues in 5G network virtualisation. The authors provided a logical architecture for 5G systems based on network slicing. The authors used SDN and NFV technologies to demonstrate the evolution of network architecture along with the implementation of network slicing. Additionally, the authors have also presented handover procedures for mobility management, which offers flexible and agile customised services in network slicing-based 5G systems.

The authors in [20] proposed a RAN slicing technique based on separation of control and user planes. The authors implemented the proposed architecture to transmit control data at a low frequency and user data at a high frequency. Thus, the created slices are further 3 divided into control and user plane slices. This plane separations and RAN slicing provide system flexibility to satisfy user demands appropriately. In [21], the authors reviewed the notion of plastic architecture and presented end-to-end network slicing in 5G networks. Several key issues involved in slice selection were identified, and the DTNC mechanism for end-to-end network slice selection was presented in this research. In [22], the authors have provided a framework for RAN slicing in 5G networks. This framework establishes the information and configuration of RAN node, thus enabling multiple RAN slices with different radio protocol behaviours and different levels of resource allocation and isolation multiplexed over the same cell. This work helps in providing an understanding of different RAN slice features, policies and resources for L1, L2, L3 protocol layers of radio interface. Another





comprehensive review that provided a deep insights on SDN and NFV and emphasised on combining these two technologies for establishing network slicing design has been captured in [23]. Figures 1 and 2 depict a network slicing model presented in [23] and elaborates on combining these two technologies for effective network slicing.

In [24], the authors conducted a comprehensive survey about recent advancements of network slicing with a focus to enable Internet of things applications. The authors have structured the review around selected parameters such as resource levels, function chaining schemes, physical infrastructure as well as security. The authors also discussed the open research areas in network slicing domain.

The purpose of our research is to create a network slicing architecture that will integrate the SDN and NFV technologies to create slices of the 5G network. This article is

similar to some of the prior research streams in considering the different components of the network for network slicing, such as the core network and RAN. The author presented an architecture that integrates SDN and NFV with the intention of creating and managing network slices, isolating slices and managing resources. The author also considered several use cases in relation to 5G network slicing and explained different challenges that arise from implementing network slicing. Figure 1 shows the network slicing architecture proposed by the authors based on involving SDN. Figure 2 shows integration of SDN controllers into the NFV architectural framework at the two levels required to achieve slicing. Various ideas have been proposed for network slicing in mobile networks and specifically for the 5G network domain. However, network slicing concept is new to the mobile communication network domain, related works are in their infancy and a detailed overview of the full network slicing architecture in a 5G network is missing. A complete overview of the network slicing model was designed using the previous works and latest technologies, such as SDN and NFV.

4 System components

The 5G-NSUE model has been developed after undertaking a comprehensive review of past and present network slicing systems. The proposed system has been built by utilising software and virtualisation techniques on the underlying network infrastructure to create network slices according to different use cases. With the help of domain experts in SDN, 5G networks, virtualisation and network slicing, the classification was refined according to the most relevant factors for the design, modelling, validation and evaluation of the network slicing system. On the basis of the review and prior knowledge of the field in order to create slices in the 5G network, four main points need to be considered:

- 1. selection of network area on which network slicing should be implemented on;
- 2. the scope of the slices of the 5G network;
- 3. how the network slices should be delivered to different use cases, and
- 4. which technologies should be integrated with the network slicing model.

These factors are crucial elements of network slicing architecture and will help provide an understanding of the requirements that should be considered for creating any network slicing architecture on 5G networks. Moreover, these factors are classified with their attributes to provide an in-depth understanding. Previous works studied several of these factors in their architectural model, but did not consider all these factors at the same time. Moreover, previous state-of-the-art models considered using either only SDN or NFV in their architecture. By contrast, the proposed model considered these factors, which are equally important for network slicing. Given that the previous models considered typical cases, such as core network slicing or RAN slicing, the proposed model considered slicing on the core network, RAN and user equipment, which constitute the complete network slicing of the 5G network.

The first considered point is the area for the slicing model in the 5G network. This network area can be divided into three main components that are RAN, core network and the user equipment. These components are the important aspects of the network node that should be considered when deciding which area of the 5G network where network

slicing will be implemented on. The main 5G network components include underlying physical infrastructures, such as base stations, end devices, switching centres and mobility management units. These components are important because of the possibility of creating slices of the 5G network in these individual components and in the combination of them. The second considered factor for slicing for slicing model is the network slice scope or the network slicing step, in which the overall slicing processes are performed. The subclasses in this factor are slice creation, isolation and management. As evident by the name, aforementioned components are useful for creating and managing the network slices in a 5G network. This step can be termed as the key part of the system model given that this factor involves the main task of the research. Moreover, the SDN controller is further divided into infrastructure and tenant SDN controllers.

The third factor is 5G network node and considered use cases of the network. The network nodes are subclassed into three groups: RAN, core network and user equipment. The bases for the 5G network are the different use cases that the network will serve. To serve different use cases, the 5G network will use network slicing to create slices with different attributes that are required by the multiple use cases. The importance of this factor is to understand the requirements and be able to create the network slices to feed their necessity and demands. The subclasses in this factor are mobility, resource management, security, low latency and high and low bandwidths. These subclasses show the nature of requirements that need to be facilitated by the network slices. The fourth and final factor in this system model is the use of virtualisation and software techniques. These integrated techniques form the foundation for network slicing in the 5G network architecture and are integral factors that cannot be missed from the system model. The subfactors are SDN and NFV. SDN is simply an abstraction for describing components and functions, as well as the protocols for managing the forwarding plane. This system model concept using NFV emphasises the use of virtualisation for various network node functions.

Table 1 shows the components and sub-components of the proposed network slicing model. The columns of the table present the main attributes of each component and their sub-components along with several common instances for each case. The components column includes the name of the components required in the model while the main attributes column includes value/feature/function for the respective components. Instances are the generic examples for the respective components. Following the table is the component diagram, Fig. 3 illustrates the relationship between these components and their sub-components and how they are linked with each other. This figure shows different components of the 5G-NSUE system model. The four units indicate four different components and their sub-components in the system. The component and subcomponent are connected using dotted lines. The solid lines are used to communicate between multiple components or to and from sub-components of the same factor/ component. Integrated techniques comprised sub-components used to softwarise and virtualise the physical infrastructure of the 5G network. This step is achieved by using SDN and NFV, which are applied on physical infrastructures such as RAN, core network and user equipment. User equipment is connected to the network via RAN, which is connected with the core network. The core network helps connect with third-party networks, such as the public Internet. By using the virtualised and softwarised components

Table 1 5G-NSUE proposed system components

Components	Main attributes	Common instances
I. 5G network nodes		
1. Core network	Fifth generation cellular network	IP multimedia system
		Mobility management entity
		Packet data gateway
2. Radio access network	Mobile base station, antennas	Generic radio access network (GRAN)
		GSM edge radio access network (GERAN)
		UMTS terrestrial radio access network (UTRAN)
		Evolved universal terrestrial radio access network
3. User equipment	Devices	Mobile, computers, servers
II. Network slices		
1. Slice creation	Slice type	End to end slice, vertical slice
2. Slice isolation	Scheduling	Slice scheduling algorithms
3. Slice management	MANO	Management, orchestration
III. Use cases		
1. Mobility	Vehicular	V2X (vehicle to everything)
2. Resource management	Efficiency	Scheduling, usage, infrastructures, network
3. Security	Reliability	Slice security, privacy, isolation
4. Low latency	Delay, wait time	Ultra-low latency in nanoseconds
5. Ultra-high bandwidth	Speed, data rate	Ultra-high speed, high speed
6. IoT	Machines, humans	Machine to machine, machine to human
IV. Enabling techniques		
1. Software-defined networking	Abstraction, programmability	OpenFlow
2. Network function virtualisation	Virtualisation	Virtualised load balancer
		Virtualised firewall
		Virtualised WAN accelerators
		Virtual routers, switch and gateway

of the network, the network slicing component will cut the slices of the network. The slices are created according to the demands and requirements from the different use cases that are connected with the network. These requirements are received when the request for slices is made by the use case. After the slice is created, the isolation of these slices must be considered depending on the type of slices. This step is performed by the slice isolation sub-component, while slice management component is responsible for the overall management of the slice orchestration and management of network slices. The remainder of this section will define each of the four factors and their subclasses and justify why each factor is used for classification. Diagrams of the classes and subclasses, which make up each of the factors, are illustrated accordingly. Table 1 shows a component table for the network slicing model and shows the required components along with its sub-components. Each component and sub-component are further provided with their attributes and instances in other columns of the table.

4.1 Network node

Network slicing can be created on different areas of 5G network. An important factor is to consider the network area where network slicing is to be implemented. Before

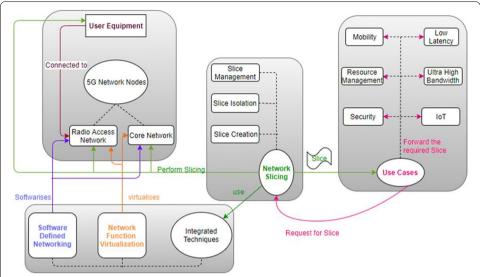
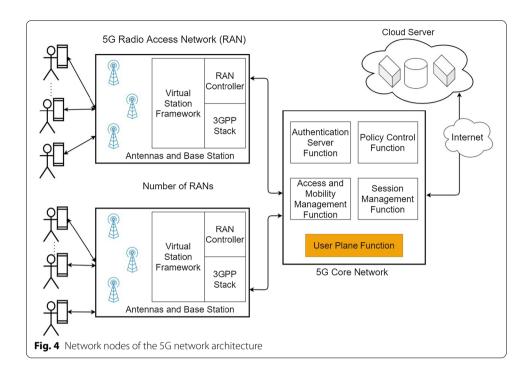


Fig. 3 Proposed network slicing model. Dotted lines show sub-components whereas solid lines depict an action or process coloured solid line are used to show which process is involved with each component/sub-component. The process belongs to the sub-component from which the solid line starts from. For example, blue solid line belongs to the SDN sub-component as the blue solid line starts from SDN sub-component and ends at RAN sub-component. Blocks are used to group each component and its sub-component to a single unit

the advent of 5G technology, the core network and RAN did not distinguish between the devices that connected with them. The same core network and RAN served all the devices, hence the need for clear distinction between these areas of the network. Network slicing can be implemented on different areas of the network, such as the core network, RAN and user equipment. The different reviewed studies implemented network slicing on these different areas of the 5G network. Several articles have been found that have implemented network slicing on the core network and the RAN, but few instigated network slicing on the end user equipment. Most studies applied network slicing on individual areas only and not combined, such as the core network or RAN only. Carefully selecting the area of the network on which the slicing is to be implemented is important. The most effective configuration for network slicing is the combination of all the three areas, where network slicing is performed at different network nodes and areas.

Figure 4 shows a design architecture of 5G network with different nodes. The main network nodes of the 5G network are RAN, core network and user equipment. The RAN connects the user equipment with the core network. The RAN comprises connected base stations with controllers. For 5G, the RAN (also called NG-RAN) base station (also called gNB) has three main function units: The Centralized Unit (CU), the Distributed Unit (DU), and the Radio Unit (RU), which can be implemented in various combinations. The core network is also incorporated different units, with each unit responsible for performing different functions.

The control and user planes are separated to distinguish between the user plane function and control plane function. Different control plane functions include authentication, policy control, access and mobility and session management. The core network



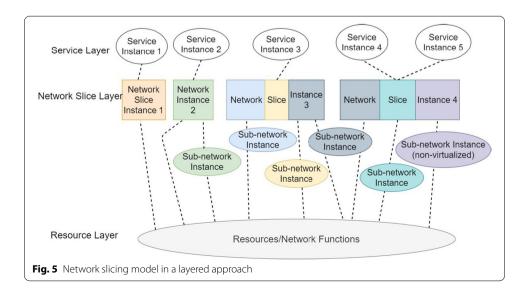
can be connected to third-party networks, such as cloud servers, via the Internet. The purpose of using a network node as part of the model will identify the part of the 5G network where network slicing will be executed/implemented. In addition, this step will determine the extent of the network slicing. For example, network slicing can be performed on only one area of the network or on a combination of multiple areas of the network. As the nodes of the network in which network slicing is increased or combined, the complexity of network slicing will increase. However, doing such might create network slices in multiple nodes and thus complete network slicing on the 5G network, which will increase the performance of the slicing. The subfactors involved in this classification are user equipment, RAN and core network. When we think of network slicing, we mainly focus on core network slicing. To extend this definition, we can also think of network slicing in RAN node. However, performing network slicing on the RAN seems more complex and difficult than performing network slicing on the core network only. Moreover, network slicing can be implemented on end devices or the user equipment. However, the problem with network slicing in user equipment is in its initial phase and network slicing in user equipment seems to be a far-fetched concept at this moment. Nonetheless, the location is still a potential area, and achieving network slicing on user equipment will enhance the overall performance of the 5G network.

4.2 Network slicing

Network slicing can be defined as the technology that enables the creation of different virtual networks on top of physical infrastructures. Network slicing is the central figure in the system model. This component will help create network slices according to various demands, which come from another component of the system model, namely the use cases. Different use cases exist. Thus, the requirements from these use cases are different in nature. These varying demands needs to be fulfilled by today's 5G network,

which is provided with the proposed network slicing component. The Integrated technique component will create a virtualised network scenario in which the physical infrastructure of the 5G network is secondary, and the logical components that are the abstractions of the underlying physical infrastructure are of prime importance and are primary components. These primary or logical components can fulfil specific purposes according to the need from the use cases. The important aspect to consider in this situation is that the logical network is adaptable and can make adjustments according to the changes in needs by devoting more/less resources in the process. With network slicing, the 5G network can now be deployed more quickly given that only fewer functions need be deployed according to the use case (unlike when all functions are being deployed) and the users utilise only what is needed. This network slicing component is dependent on the network nodes, which include the core network, RAN and the end device. The reason for this dependence is that network slicing needs to be implemented on these infrastructures. Network slicing can be deployed on the core network only, on the RAN only or on the combination of both. The sub-components of network slicing involve slice creation, which enables the development of 5G network slices; slice isolation, which isolates the different type of slices from one other; and slice management, which, as the name suggests, manages the overall process from slice creation to slice delivery to the use case.

Figure 5 shows three different layers: the resource, network slicing and service layers. The resource layer consists of the physical resources or the network functions, which are used to provide services to the end users. Before services are delivered to the end users, the resources are first sliced to create different instances called subnetwork instances, which are then utilised to form the network slice instances. Several subnetwork instances may coalesce to form a single network slice instance as depicted by the colour of the blocks. Alternatively, a network slice instance may be directly delivered from the network functions and shown with Network Slice Instance 1, which is created directly from the network function rather than by using subnetwork instances. Finally, the network slice instance is used to create the service instance, which provides specific services to the end users. These service instances are created per the demands of different use

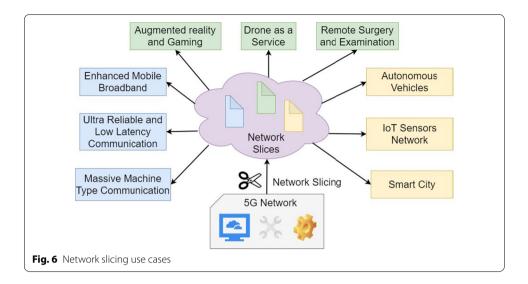


cases. The purpose of using network slicing as part of the model is to identify the aspects of network slicing used. For example, most of the reviewed literature uses the slice creation aspect of network slicing, but not all of them considered the slice isolation aspect of network slicing. Accordingly, we used network slicing as part of the model. Moreover, network slicing is the core of this paper's research topic. Thus, classifying prior studies according to network slicing seems obvious. Different aspects were used as part of the model under network slicing, including slice creation, slice isolation and slice management. Slice creation is mostly used in all the extant research, while few selected literature focused on slice isolation and slice management. Considering the aspect of slice isolation and slice management is crucial because these aspects will identify the efficiency and effectiveness of network slicing; thus, they are used in the model. Creating isolation between the different types of slices is also vital so that they can be delivered to different use cases as required. Furthermore, slice management will ensure that the overall process of network slicing is performed in a controlled way and the slices are processed through slice management and the orchestration unit. The problem with slice management and slice isolation is that they require advanced computation and processing which will increase the model complexity; however, the inclusion of these aspects will possibly ensure the complete package of network slicing.

4.3 Use cases

Many use cases must be served by the 5G network. The 5G network needs to be sliced according to the varying requirements of different use cases. The emergence of IoT has added to the brackets of use cases that the 5G network must serve. Network slicing must be implemented such that these use cases are delivered with the right network slice according to their demands and requirements. Furthermore, the dynamic nature of use cases adds to the complexity of network slicing. Network slicing must be flexible and dynamic enough to sustain the needs of the changing nature of the requirements of use cases. Use cases have different attributes, such as ultra-high bandwidth use cases, very low-latency use cases, ultra-reliable low-latency use cases, high-bandwidth use cases and massive IoT use cases. Massive IoT [25] is one of the most anticipated use cases of the 5G network and will require the sliced form of the 5G network. It uses the sliced 5G network to seamlessly connect different embedded sensors all over the world. The attributes of such use case include smart cities, assets tracking and smart utilities up to agriculture industries. Ultra-reliable low-latency use cases use highly available low-latency links for purposes such as remote control of critical infrastructures, smart grid control, the automation of industries, robotics and drones. Enhanced event experience use cases have attributes that are related to VR videos, as well as high-definition and high-fidelity media experiences.

Figure 6 shows a simple demonstration of different use cases to be served by the 5G network slices. Different colours show different types of slices, and slices with similar requirements are grouped together. Different use cases require different types of network slices and thus, the created slices serve multiple use cases, as shown in Fig. 6. The purpose of utilising use cases as part of the classification is that the use cases will help differentiate the type of slices that will be created. Numerous use cases must be served by the 5G network, and all these use cases require different types of network services



and demand different natures of network slices. Thus, with the use of the slicing algorithm, different types of slices can be created and delivered to these use cases. Use cases will help identify the nature of slices that must be created by the 5G network. Thus, considering use cases as part of classification was vital. Different subfactors under use cases were used for classification. The major ones include mobility, resource management, security, IoT, low-latency and ultra-high bandwidth use cases. These different use cases can accommodate many industries, companies and end users that the 5G network will be serving; hence, the classification includes these use case subclasses. The major problem with some use cases, such as mobility, is that it must serve all the mobility aspects of the end user. In reality, mobility requires dynamicity and flexibility in the network slice that is serving the end user with the mobility requirement. Fortunately, network slicing facilitates the creation of a network with high flexibility.

5 Component classification

Based upon the components defined in the previous section, the following section further breaks down the components to the sub-component level and provides a detailed discussion as well as classification of these components with respect to some reviewed articles in this domain.

5.1 Core network

One of the frontline factors in cellular wireless technology is the core network, which remains a highly rich and essential area of innovation as it is the key element of the future of wireless networks. The primary function of the core network is to connect the RAN with the third-party network for providing end-to-end connection. The third-party network instances include public telephone network, switched network and the Internet. The three different planes used in core network functionality are service management, session management and mobility management. In the case of the 4G network, the main function of the core network is to provide an efficient data pipe. The core network can connect to the public Internet quickly by using two of its major functions, which are

the serving and the packet data gateways. The mobility management unit in the core network manages the sessions of the user data as the user moves around the network. In the case of the 5G network, the whole core network architecture is designed to provide the network as a service, which makes it a service-oriented architecture. The overall core network is broken down into detailed created functions and subfunctions. These functions include the session management, mobility management, access management and user plane functions. The 5G network core is now designed to function as a flexible network or as a service solution. Creating flexible and dynamic services will enable network slicing to satisfy the demands of the multiple use cases that exists in today's 5G network domain.

5.2 Radio access network

Radio access network (RAN) is the major sub-component of the 5G network and has been used in the telecommunication industry since cellular technology emerged. It has been evolving ever since through different generations of mobile communication. RAN was used in initial generations such as 1G and 2G, has evolved through 3G and 4G and finally reached the 5G network. The main components within RAN are the base stations and the antennas. These components are responsible for providing network coverage all over the world. Radio sites are the main factor within RAN that are responsible for providing radio access, as well as coordination and management of different resources across multiple radio sites. Networks transmit all over the world by using RAN. Specifically, the RAN transmits the signal to various wireless endpoints, and this signal travels with another network traffic. The major types of RAN include the generic radio access network (GRAN), GSM edge radio access network (GERAN), UMTS terrestrial radio access network (UTRAN) and the evolved universal terrestrial radio access network (E-UTRAN). GRAN is the type of access network that uses base transmission stations and controllers for managing different radio links for the purpose of circuit-switched and packet-switched core networks. GERAN involves the type of access network that mainly provides support for real-time packet data. UTRAN provides circuit-switched and packet-switched services, and E-UTRAN is used for high-data-rate and low-latency communication and focuses only on packet-switched services. Another factor in RAN that must be considered is the RAN controller, which is responsible for controlling the connected nodes. The RAN controller provides functionalities, such as management of radio resources, mobility management and data encryption. Clearly, today's RAN architectures are mostly based on the separation of control and the user plane. In such scenarios, the RAN controller exchanges the user messages through SDN switches. The separation of the control and user planes aligns with the SDN and NFV techniques that will be integrated with the 5G network architecture for the purpose of network slicing.

5.3 User management

User equipment is another major factor to be considered in network slicing architecture. User equipment involve the end devices employed by the end users that are served by the 5G network slices. These end devices range from mobile devices and personal desktops to high-capacity servers and data centres. The instances of mobile devices include

Android, Windows and iOS devices, which refer to the major operating system devices currently used all over the world.

5.4 Slice creation, isolation and management

Slice creation involves creating the virtual network according to demands. Creating slices entails using techniques such as virtualisation and softwarisation. The underlying physical network is virtualised by using SDN and NFV to create network slices. Different types of network slices can be created in the 5G network architecture. The type of network slices created depends on the use cases that require the slice. For example, for low-latency use cases, the created slice would be the ultra-low-latency slice. Besides this, slice isolation is another important factor to consider in network slicing architecture. The objective of slice isolation is to create slices and then differentiate them from among each other depending on the nature and type of use cases they will serve. The different slices of the network must not be mixed up with one another; slice isolation will play a vital part in preventing such occurrence.

Slice management is another aspect of network slicing that will help manage the 5G network slice. This feature will manage the overall process starting from slice creation until the slice is delivered to the appropriate end users. The role of slice management and orchestration unit will be to manage the slice. This unit is integrated into the network slicing architecture and will manage the slice from tasks such as slice scheduling, slice resource management and slice nature.

5.5 Software-defined networking

SDN is one of the major components implemented in the 5G networking architecture in order to reduce limitations often placed by the use of hardware. The major purpose for utilising SDN is to separate the control plane outside the switches and provide external data control using a logical software component called the SDN controller. SDN is simply an abstraction for describing components, their functions and the protocols for managing the forwarding plane. SDN is further subclassified into the SDN controller and SDN manager. SDN also provides management for mobile IP from a remote controller through a secure channel. Moreover, SDN helps solve the inability of mutual access between multiple parts of today's heterogeneous networks. Currently, the number of mobile network users is rapidly growing. Thus, an expensive upgrade is needed on the hardware elements of backhaul infrastructure. The use of SDN makes performing upgrades easier by deploying new services and applications. The main objective of implementing SDN is to create a network with a completely automated administration, allowing the administrator to manage the network in an efficient manner via a control plane by applying required policies on network routers and switches. In such a setup, the network administrator has complete capability to monitor the whole network remotely. The major concept in SDN is the application of a programmable network infrastructure and the decoupling of the data plane and control plane. Thus, SDN helps provide simplified management of network and facilitates the introduction of new services or any changes in the network. Some of the benefits of SDN application include programmability of the network, centralised management of the network, reduced operational and capital expenses, and agility, flexibility and innovation in the overall network. Although SDN seems to be the solution for the next-generation 5G network to serve multiple use cases, it does have some limitations. A main limitation comes from the computing capabilities and resources of mobile devices; the overhead increases to significant levels with the increase in the mobile user's request.

5.6 Network function virtualisation

The virtualisation component used in the network slicing architecture is the NFV technology. This architecture concept using NFV emphasises virtualising the entire class of network node functions. These virtualised node functions are then connected to create communication services per the use case demands. A virtualised network function comprises one or more virtual machines that have different software and processes running on them on top of servers, switches, storage devices and cloud infrastructure. Figure 6 illustrates the mapping between the NFV and network slices. Different communication services require network slices to provide the services. These network slices may have subnet/s. This situation means that a network slice can be composed of one or more slice subnets. Each individual subnet is responsible for carrying out a particular network function. These network functions depend on the services required by the use cases. Moreover, the virtual network functions are directly derived from the physical network functions that are provided by the underlying physical infrastructures.

6 Analysis of article classification

Based around the key components defined above, some selected recent articles in this domain were analysed and the results are tabulated in Table 2. Most of the search results included various network slicing architectures used both in the past and presently, as well as the benefits of using network slicing as an efficient resource utilisation and bandwidth optimisation tool. Few results are focused on isolation and scheduling of network slices. It is to note that only those articles that were published between 2012 and 2020 were selected in this review. In order to capture the use of these classification attributes at application level, Table 3 highlights other features and parameters such as slicing time, resource management, scheduling, bandwidth and scheduling and the implementation of SDN and/or NFV that are considered for the analysis of the selected publications. Furthermore, Tables 4 and 5 present the analysis of different publications based on implementation goal, technique utilised as well as the key feature of this implementation. Additionally this data also highlight the limitation of each of these implementations.

7 Discussion

The following section explores the components of the 5G-NSUE taxonomy by drawing on examples from the literature to demonstrate that the 5G-NSUE components are present in network slicing systems in the 5G network domain and are therefore relevant to such a taxonomy. Furthermore, this section highlights the importance of carefully considering particular solutions for the components. Network slicing was well defined in the 16 chosen publications, but only few described or included network slicing on the core network and RAN in a combined way. Moreover, only two publications considered network slicing on user equipment, which we believe is a necessary factor missing in the 14 other papers. Furthermore, only five papers considered network slicing with respect

 Table 2
 Classification table for selected publications

Publications	Network nodes	des		Network slice			Use cases						Integrated technique	ed e
	Radio access network	Core network	End device	Slice creation	Slice isolation	Slice management	Mobility	Resource management	Security	Low latency	High bandwidth	Po	SDN	NFV
[8]											\	\		_
[6]		`_		/								`_		
[10]				/			\				/			
[11]				/									<u></u>	
[12]		`	/:	/										
[13]				/										
[23]			/:	/									<u></u>	
[26]				/									\ <u></u>	
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[17]		`							`			`_		
[18]	`,			/	`									
[14]														
[19]									/:					
[20]														
[28]		`	/-			,						`_		
[21]					` `				<u>`</u>			`,		
[22]					`,							`_;		
[29]	/		`										`,	\ <u></u>
[30]		`											`,	
[31]	<u></u>			`				/				`,		`,
[32]	`	/					`			`_			`,	`,

Table 3 Analysis table for selected publications

Publications										
	Publications Architectural aspect	,		Features						
	Slicing method	Standardisation Protocol/model	Protocol/model	Slice execution time	SDN implementation	NFV implementation	Resource	Bandwidth efficiency	Scheduling Performance	Performance
8	End-to-end		Complex network theory							
[6]			Layered approach							
[6]			Layered approach							
[11]	End-to-end		Bi-resource slicing scheme							
[12]	End-to-end									
[13]		3GPP								
[23]										
[56]			Genetic algorithm							
[27]	Bandwidth slicing		Stackelberg game approach							
[14]			RAN runtime slicing							
[15]	End-to-end		Cloud-native approach							
[16]	End-to-end	5GPP	Generic 5G architectural framework							
[17]										
[18]			RAN slicing at multiple levels							
[14]										
[19]	End-to-end									
[20]			RAN slicing using C/U separation							
[28]										
[21]	End-to-end		Device-triggered slice selection							
[22]	RAN slicing									
[59]	RAN slicing	5GPP	RAN slicing based on SDN machine learning							
[30]	RAN slicing		Multi-slice and multi-BS RAN slicing using band- width allocation							
[31]	RAN slicing	5GPP	RAN slicing based on SDN traffic classification							
[32]	End-to-end	4G/5G	5GIIK open source testbed							

Table 4 Validation of publications using different factors

Author	Goal	Component units	Techniques/ methods	Major features	Limitation
[8]	Efficient utilisation of limited network resources	WLAN	Deployment algorithms	Improves utilisation of resources	
		LTE/5G access			
		Access node			
	Better acceptance ratio	Transport node	Complex network theory	Increases service provider revenue	
		Core node			
		Edge cloud			
		Core cloud			
[9]	Establish network slicing	Sensors	Virtualisation	Provide architec- tural framework for 5G network slicing	No concrete solution for the service layer
		Radio	Multi-tenancy support		
		Server	Integrated net- work program- mability		
		5G Core	SDN		
	Life cycle manage- ment	Network function	NFV		
[10]	Support vertical industries in 5G networks	5G software- defined infra- structure	Network slicing framework	Layered approach to 5G network slicing	Fails to address dynamic slice creation and management
		Virtual resource layer			
		Application and service layer			
		Slicing manage- ment and orchestration			
[11]	Create network slices in wire- less/wired 5G networks	Mobile terminal	Dynamic radio resource slicing scheme	Identify bandwidth slicing ratio for creating network slices	
		Macro-cell base station			
		Small-cell base station			
		Wireless commu- nication link			
		SDN-enabled virtualisation controller			
[12]	Support V2X network	RAN	End-to-end net- work slicing	Presents 5G slicing for future auto- motive market	Slicing complexity in V2X
		Core network			
		End devices			
		Slice manager			
		Slice orchestrator			
		Virtualisation layer			
[13]	Deploy network slices in 5G	eNodeB controller	Radio resource abstraction	Proof of concept on RAN slicing	

Table 4 (continued)

Author	Goal	Component units	Techniques/ methods	Major features	Limitation
		User equipment	Fully program- mable network slicing		
	Provide program- mable RAN to enforce network slicing	RAN			
	To abstract and share physical resource	Core network	Two-level MAC scheduler		
		Slice orchestrator			
[23]	Study SDN archi- tecture to create network slices	NFV infrastructure	SDN architecture	Integration of SDN and VNF for network slicing	
		Infrastructure SDN controller			
	Study NFV archi- tecture to create network slices	Virtual network function (VNF)			
[26]		Management and orchestration	NFV architecture		
		Application controller			
		Network manage- ment system			
	Integrate SDN and VNF to meet network require- ments	Tenant SDN con- troller	Integration of SDN and NVF		
	Optimise resource utilisation	Slicing as binary sequence	Genetic algorithm	Determines slicing performance	Failure to achieve global optimum of utility effi- ciency
		Genetic slicing strategy opti- miser			
	Create RAN runtime slicing system	Slice data	RAN slicing	Provides RAN runtime slicing system	Does not address all the challenge highlighted
		RAN runtime services			
		RAN runtime application programmable interfaces			
[15]	Lifecycle of net- work slices	User devices	Cloud-native approach	Provides cloud- based approach for network slicing	
		IoT devices			
		Networks			
		Cloud			
		Service orches- trator			
		Network orches- trator			
		Network slices			

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Table 4 (continued)

Author	Goal	Component units	Techniques/ methods	Major features	Limitation
[16]	Identify challenges for the service- oriented 5G vision	Service layer: Operators Verticals Enterprise Third party	Generic 5G architectural framework	Presents a com- mon framework for 5G network slicing	Issues, e.g. virtuali- sation in RAN are unresolved
		Network function layer			
		Infrastructure layer: RAN Core network Control			
[17]	Achieve better utilisation of resources	User equipment	Network slicing architecture	Explains process for slice creation defined	Slicing in RAN and user equipment is not addressed
		RAN			
		Network slice instances			
	Optimise network performance	Subscriber repository	Network slicing access selection		
	Shorten the slice creation time	Common control plane function			

to the use cases. The publications failed to identify use cases for network slicing because network slicing is in its infancy, and the authors may have deemed use cases as unimportant in this scenario. However, in our opinion, using the 5G network as part of the main network is vital because it will serve all the use cases, and the importance of the use cases in network architecture also needs to be considered. The enabler techniques included in the network slicing model include SDN and NFV. Almost 50% of the chosen publications identified the necessity of such techniques, but they failed to provide insights on how they can be implemented on such systems. The use of SDN and its subcomponents such as the SDN controller and SDN manager are missing in the publications. Network slicing on user equipment, which needs to be considered, is also missing. Moreover, use cases that consist of the important factors in network slicing architectures are surprisingly absent. These use cases provide the type of slices that must be created, and thus, the failure to discuss use cases in many publications is surprising. In [14], the authors discussed the utilisation of use cases for the network slicing model. They examined the design challenges and evaluated the importance of including different use cases in their system model. In [15], the proposed model which uses the cloud approach considered the importance of different use cases. The authors described the life cycle of the network slice and the requirements from the end users in the slice they offered. They further provided insights on adaptation to the changes on the requirements from end users. Thus, their work considered the importance of use cases in a network slicing model. The authors in [18] have also studied the utilisation of use cases and the different types of slices, such as mobile broadband slices.

In our opinion, the inclusion of use cases in the network slicing model is important. Some publications involved different use cases in their model, which we believe is because they are valuable for network slicing. Different use cases provide the type of

Table 5 Validation of publications using different factors

Author	Goal	Component units	Techniques/ methods	Major features	Limitation
[18]	Analysis of RAN slicing	Spectrum plan- ning	RAN slicing at spectrum plan- ning level	Alternatives are presented for RAN slicing	No discussion on slicing in core network and user equipment
	Splitting of radio resources among slices	Inter-Cell Interfer- ence coordina- tion (ICIC)	RAN slicing at ICIC Level		
		Packet scheduling	RAN slicing for packet scheduling		
		Admission control	RAN slicing for admission control		
[20]	Enable customisation for different users	Hypervisor	RAN slicing for C/U plane sepa- ration	Separation of control and user plane creation of network slices	Discussion missing on effects of sepa- ration of planes or slicing
		Controller			
		Fronthaul			
[28]	Customise mobile telco services	Slice plane	PERMIT framework	Achieving flex- ibility, efficiency, and scalability by creating on- demand VMN slices	
		VMN slice orches- trator			
		Virtual resources			
		Physical infrastruc- ture			
	Combining SDN, NFV and cloud and edge	Users			
		VFN manager			
		NFV orchestrator			
		Virtualised infrastructure manager			
[19]	Provide a logical architecture	Core cloud	Mobility manage- ment scheme	Mobility manage- ment	Latency issues in network slice management due to space limitations are not addressed
		Edge cloud			
		Access unit			
	Managing mobil- ity	Control unit	5G network slicing		
		Data unit			
		Application			
		Virtualised infrastructure management			
		VNF management			
		SDN controller			
		Management and orchestration			

Table 5 (continued)

Author	Goal	Component units	Techniques/ methods	Major features	Limitation
[21]	End-to-end net- work slicing	Compute nodes	Device triggered network control	Slice selection mechanism	Lack of depth in architectural features
		SDN controller			
		Forwarding ele- ments			
		SDN controller switch	End-to-end network slicing architecture		
		Physical link			
		5G network slices			
[22]	Identify design challenges	User equipment	RAN slicing	Establish con- figuration of RAN node for RAN slicing	Involves RAN slicing only
		RAN			
	Realise and customise RAN slices	Core network			
[29]	Reducing handoff cost	RAN	RAN slicing	Machine learning with less impact on the through- put	More overhead on the user equip- ment
		User equipment			
	Better utilisation of the throughput	Third party for encryption			
[30]	Maximising resource utilisa- tion	RAN	End-to-end net- work slicing	Machine learning with less impact on the through- put	Latency issues are not addressed
		Core network			
[31]	Minimise latency	RAN	RAN slicing	Low latency and packet loss with better traffic management	The system evaluated under small use case
	Better throughput	SDN controller			
	Managing traffic	SDN agent			
[32]	End-to-end network slicing testbed archi- tecture	RAN	End-to-end net- work slicing	Open source	Limited parameters
		Cloud-based SDN/ NFV		Flexibility	Architecture is not clear

slices that must be created. Moreover, depending on the use cases, the nature of the slice required can change accordingly. Thus, considering such use cases is crucial to create the network slices according to demands. The purpose of creating network slices is to serve end users. Thus, failure to take end users into consideration in the architectural model will create an inefficient and ineffective slicing model. Therefore, consideration of use cases is an integral part of the network slicing model.

It is clear from the reviewed papers that the slicing approaches will be an important part of the future 5G wireless networks. The huge number of Internet of things (IoT) devices and smart devices that rely on cloud application will end up with different types of traffics and

Quality of Service (QoS) requirements. The current traditional solutions will not be able to handle such various types of traffic that change rapidly over time. Our proposed model that integrates the SDN and NFV with the 5G slicing architecture will allow better implementation of slicing. The NFV will provide a virtualisation view of underlying resources and the SDN fine-grained control of the traffic for the 5G network. We took into consideration in the proposed models that the IoT nodes are usually based on limited resources in terms of computation and power. The design of the slicing model will be more adaptive to the end services or IoT nodes QoS requirements. This will lead to better use of the resources and better experience from the end-users and applications.

8 Conclusion

Network slicing will be one of the most influential technologies used in the 5G network domain and will change the face of the telecommunication industry. The 5G era requires accommodating rapidly increasing devices and end users in its network with wide diversity. Thus, network slicing is the sought-out option. To enable network slicing, softwarisation and virtualisation of the underlying network infrastructure are needed, which, in turn, are fulfilled using SDN and NFV techniques. This article presented a comprehensive comparison of different studies in the field of network slicing and provided a network slicing architecture by integrating SDN and NFV to create a flexible and dynamic architecture that serves the wide variety of applications in today's world. A system model for network slicing in the 5G network is also provided. This system model will help support the diverse needs of different vertical industries by making the network architecture flexible and dynamic.

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Authors' contributions

PS carried out the investigative study by conducting a thorough analysis of the existing research as a part of his final year Masters research-project. AA and PC supervised PS for this research project and with the conception of project design. SR and MI were involved in manuscript writing and revision process. SA gave some valuable suggestions and participated in the paper revision and editing. All authors have contributed to this research. The final manuscript has been read and approved by all authors. All authors read and approved the final manuscript.

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Declaration

Competing interests

The authors declare that they have no competing interests.

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