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5G Communication Systems: Network Slicing and Virtual Private Network Architecture

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Abstract. 5G communication systems are being rolled out with multiple technological solutions and applications being fielded on existing as well as enhanced infrastructure. The utilization of 5G systems and infrastructure by verticals over different platforms as well as industries is achieved with slicing. Slicing in 5G provides guaranteed resources for end users of vertical industries and applications over varied platforms, architecture, and infrastructure. Standards for network slicing in 5G have been formulated by 3GPP and further specifications are being released. Implementation of slicing at various layers are being researched. This Paper reviews the advancements in development of specifications for Layer 2 implementation of slicing and communication systems using virtual Private Network and Virtual Transport Network and its architecture. The enhancements to communication systems using existing Multi-Protocol Label Switching (MPLS) and its exploitation based on slicing technology has been reviewed. The research challenges and way ahead on same have been discussed including end resource allocation.

1 Introduction

5G Slicing has been described and characterized by varied standard organizations and covered in number of research papers [1] [2] [3]. A logical End to End virtual connectivity setup between the end users and the intended application is called "Slicing in 5G." It assures the proper allocation of the network resources needed to make the given services or applications operational. It guarantees re-sources for achieving the desired Quality of Services (QoS) and meeting mutually accepted and predefined Service Level Agreements (SLA). 5G slicing provides SLA based virtual and logically isolated networks with access to authorized user/ entity enabling multi layered security mechanisms. The siloed and one size fit all networks architecture used in classical mobile communication systems to provide services has thus been obviated in 5G system and challenges of supporting vertical industries has been overcome by employing slicing [4]. In this paper implementation of 5G Slicing and layer 2 architecture for virtual transport network (VTN) in 5G communication system has been reviewed.

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2 Slicing

Network slicing in next generation system has been described with network architecture in 3GPP TR 23.799 [5]. The 3GPP has imparted importance and included network slicing in Release 15, Release 16 and its technical specifications. 3GPP Service and Systems Aspects (SA) Working Group (WG) in [6] [7] specifies management architecture and specifications for network slicing with performance and fault management. The network architectural and management changes with mandatory slicing features in 5G has been covered in [8]. 3GPP technical specification (TS) 23.501 defines stage 2 architecture with slicing, it defines network slice as logical network providing specific network capabilities and characteristics [9]. Further, Network Slice instance is set of Network Function instances and required resources that form Network Slice [9]. The provisioning of network slices, device association with slices, and performance isolation during regular and elastic slice operation are all covered by 3 GPP TS 22.261 [10]. The Enhanced Network Slicing (eNS) capability and 5G prospects including im-proved latency industry IoT and autonomous driving are already included in the 3GPP Release 16. Enhancements in network slicing and network slice specific authentication and authorization procedures have also been covered in 3GPP Release 16 and [10]. Thus, 5G core architecture has been envisaged to be de-signed with network slicing as an essential component. Slicing is achieved by utilizing flexibility achieved by Software Defined Radio (SDR) and Network Function Virtualization (NFV) and combines network slicing design, slice assurance, orchestration, and slice life cycle management operations to address slice additions, modifications and deletions, based on inputs either enterprise or operational. Summary of related work on 5G slicing is shown in Table 1.

Table 1. Summary of related work on 5G Slicing

Paper Reference	[1]	[2]	[3]	[4]	[5]	[6]	[8]	[10]	[11]	[12]	[13]
Network slicing basics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Orchestration	X	Yes	X	Yes	Yes	Yes	Yes	X	Yes	Yes	Yes
VNF	X	Yes	X	Yes	Yes	Yes	Yes	X	Yes	Yes	Yes
Multi domain	X	Yes	X	X	Yes	Yes	X	X	Yes	Yes	Yes
Management of network slicing	Yes	Yes	X	Yes	Yes	Yes	X	X	Yes	Yes	X
Slicing functionality	X	Yes	X	X	Yes	Yes	X	Yes	X	Yes	X
RAN virtualisation	X	Yes	X	X	X	Yes	Yes	X	X	X	X
Architectural framework	X	Yes	X	Yes	X	Yes	Yes	X	Yes	Yes	Yes
Slicing application	Yes	X	Yes	X	Yes	X	X	Yes	X	Yes	X
Machine Learning	Yes	X	X	X	X	Yes	X	Yes	X	X	X
Security	X	X	X	Yes	X	Yes	X	Yes	X	Yes	X
Challenges	X	Yes	Yes	Yes	Yes	Yes	X	Yes	Yes	X	Yes

3 Slicing Layers

Service, network, and resource are three functional layers for network slicing. Multiple instances may be configured at network and resource layer for dedicated service layer slice.

3.1 Service layer

Services are provided by tele service provider or network operator. It is end user service interacting directly with user, user equipment and their applications. Thus, it is configured based on end user or business requirement and specifies the stringent characteristics required by slice including throughput, latency, reliability etc.

3.2 Network service layer

Network slice instance layer may or may not incorporate sub network layers. It establishes slice instances by direct physical or logical isolation through multiple domains like RAN, Edge, Core Network, Transport etc. It is manifested as logical network utilizing virtualized network functions [14]. Network slice instances may be fully or partially isolated incorporating physical or logical isolation. The logical network is established with predefined network characteristics as re-quired by the service instance.

3.3 Resource layer

Resource Layer includes NFV Infrastructure [15], VMs (storage, computing, networking), Radio resources etc. to create network slice instances or the sub net-work instances. It includes physical as well as logical resources for both physical and logical network. It facilitates efficient utilization of cellular network, access nodes, clouds, smart devices, storage and computation including edge computing to meet the specifications and latency requirements.

4 MPLS VPN

Utilization of existing infrastructure and Internet Protocol Multi-Protocol Label Switching (IP MPLS) networks for realization of 5G network slices is work in progress [16] and internet drafts(working documents of the Internet Engineering Task Force) for same have been published. MPLS provides the transport layer model for realization of network slices. MPLS has been already fielded in most of the communication systems and provides label appendment mechanism facilitating faster routing. The MPLS technology was conceived initially to overcome the speed limitations of switches and routers and speedily switch packets based on simplified header utilizing labels. Advancement in switching technology and overhead imposed by label header appears to have reduced the importance and initial advantages of MPLS. However, the features like Traffic Engineering, Generalized Multiprotocol Label Switching (GMPLS) or Lambda Switching, MPLS Virtual Private Networks (VPN) etc have significantly enhanced the applications and integration of MPLS systems [17]. Further the MPLS technology is here to stay due to varied enhancements and features like MPLS VPN fielded by MPLS enabled communication systems.

MPLS VPN provides flexible inter site communication network utilizing elements from overall network architecture. It is configured by VPN service provider based on Quality of

Service (QOS) and administrative policies demanded by VPN clients. MPLS VPN is one of the most prominent features being optionally utilized by service providers and has large use cases. VPN can be configured as layer 2 VPN on costumers connected utilizing Frame Relay Data Link Connection Identifier (DLCI), ATM Virtual Circuit or Point to Point connection. Layer 3 VPNs connect costumer end points peer with provider routers facilitating single peer relationship. The major features of VPN are:

- Inter-site connectivity is scalable flexible and reconfigurable.
- VPN can be either intranet or extranet.
- VPN, may overlap and sites may be in more than one VPN.
- Sites from multiple service providers can be logically connected.
- Provider IP QoS and traffic engineering.

4.1 Limitations of VPN

VPNs share network resources of ISP. Thus, two VPNs of different costumers may be logically separate, however physically the infrastructure used may be shared. VPNs are configured with SLA; however shared resources may lead to situations wherein implementation of stringent SLA becomes challenging. Thus, traffic of VPN 1 may interfere with VPN 2 challenging the stringent Service Level Agreement (SLA) specified between ISP and costumers. In a scenario with SLA for constant Bit Rate Traffic between two sites of VPN 1; any variation due to burst traffic in VPN 2 utilizing same infrastructure with lead to delay and packet loss.

Standard VPNs offer connectivity at fixed data rates with traffic engineering features utilized by ISP to distribute flow of traffic within network. However, new use cases and applications being fielded require low latency and delay variation between varied VPN sites. These limitations of classical VPN have been pro-posed to be addressed in enhanced VPN to suit the requirement of next generation applications and dynamic services.

4.2 Enhanced VPN

Standards for IP router protocol enhancements (segment routing, L3VPN etc) are being explored and analysed. Interfaces for RAN and core network slicing management are also being evolved. Enhanced VPN is one such proposal being analysed by international standards organizations. VPN+ or enhanced VPN guaran-tees the basic network resources for network slice in 5G ecosystem and also enhanced network connectivity services for existing systems. Enhanced VPN con-sists of VPN overlay and underlying Virtual Transport Network (VTN) [18]. Customized network using physical, virtual or logical elements is designed based on end user requirements. As compared to VPN, enhanced VPN is envisaged to achieve greater isolation and better performance guarantees meeting the network slicing requirements. Enhanced VPN services can be achieved by creating multiple Virtual Transport Network (VTN) as underlay. Integration of overlay connectivity and the underlay network characteristics is achieved by VTNs [16]. One or group of enhanced VPN services require VTN to be created with specific isolated or shared network resources allocated from underlay network. VTN Identifier (ID) [17] is inserted in MPLS label stack for identification and processing of data packets within enhanced VPN. The processing of VTN header in MPLS packet and network is similar to the MPLS packet routing from egress, ingress and core routers. Research challenges for fielding of enhanced VPN service include development of Operation, Administration and Management (OAM) methods, de-sign of data plane, control and management protocols and integration mechanisms for overlay and underlay. IETF internet drafts have been hosted for same and is work in progress.

5 Challenges

5.1 Standards

Network slicing must comply with various architectures and services on various service providers' infrastructure. As a result, compliance criteria must be developed. A variety of standards development organizations are developing specifications and requirements for network slice lifecycle operations and management [18]. To reach agreement and standardization, it is essential that industry consortia, service providers, vendors, and standard development organizations (3 GPP, ETSI, IETF, O RAN etc) work together.

5.2 Ecosystem

The implementation of evolving 5G use cases necessitates a 5G ecosystem of devices. Applications must be able to use network features, such as low latency, dependability, high speed, and redundancy, that are provided by the underlying end-to-end slice, in addition to devices. Return on investments and Business Economics have a role in the development of products, services, infrastructure, and use cases. It is necessary to support several vendors and multiple vertical business models in the pricing strategy and the availability of operating support systems and business support systems (OSS and BSS). Thus, in order to manage and deploy slices, the 5G ecosystem must evolve, which is a necessary precondition.

5.3 Slicing toolset

The development and fielding of centralized toolset to configure and allot re-sources for varied network slice and sub net slice instances covering RAN, edge, core, transport etc is challenging. In order to construct and provide network slices across different domains, service providers must design an end-to-end network slice-orchestration and operations solution. Dynamic slice configuration and management with wireless resource virtualization and mobility has research challenges [4].

5.4 Edge

Edge computing resources for 5G network slicing, and computing power at the edge needs to ensure quality of service. End to end packet level QoS is one of the most important components in building viable transport slice architecture. The edge devices and edge computing is yet to meet the requirements to support QoS for the slice over legacy, virtualized and network environments of different ser-vice providers.

5.5 Latency

5G networks increasingly utilise network function virtualisation, cloud architecture and edge processing to promise low latency network. Implementation of VPN in 5G slicing network is a challenge as VPN may introduce its processing delays. Further implementation of VPN over different slicing layers may require configuring VPN over different hardware and edge devices over varied slices.

6 Conclusion

5G slicing technology provides avenues for fielding number of use cases in vertical industries. 5G infrastructure and networks can be sliced logically into sub networks with varied security specifications and assurance on services including high bandwidth and ultra-low latency. Applications with Service Level Agreement (SLA) can be provided as a solution by 5G service providers by configuring slice in existing infrastructure and networks like IP MPLS. Enterprise use cases can be supported with fielding of end-to-end ecosystem of network devices, logical connectivity, and applications. Communication systems are thus undergoing paradigm shift and will provide necessary impetus to 5G slicing for optimal utilization of existing and futuristic systems.

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