Transport slicing in end-to-end 5G networks

Maximize operational flexibility and efficiency to meet the demands of 5G

White paper

5G network slicing is a fundamental technology for concurrent delivery of 5G services and is key for a service-driven evolution that can meet unprecedented SLAs deterministically across end-to-end network resources.

This paper focuses on the application of network slicing in the transport domain and explains how its concepts fit in the 3GPP 5G architecture, including transport slicing (also known as transport sub-slicing). It describes the benefits of slicing in maximizing operational flexibility and efficiency. It introduces the concept of a transport slice controller for automating transport network slice creation, optimization and assurance in supporting a large range of 5G deployment scenarios, including 4G/5G hybrids leveraging existing network investments.

Contents

Drivers for 5G evolution

The 5G evolution has been described as a "service-driven evolution" with tremendous revenue potential. Enhanced mobile broadband (eMBB) is one of the first 5G target applications, but 5G is much more than higher speeds and greater capacity (bandwidth). 5G adds unique capabilities to generate new streams of revenue by providing ultra-reliable, low-latency communications (URLLC) and massive machine communications (MMC) for mission-critical applications. This will require a broad range of service level agreement (SLA) requirements depending on the application type and varying connectivity needs for end-to-end (E2E) 5G network services.

Many new and innovative applications are on the horizon with 5G that will automate industries and enhance our daily experiences in the world around us. These include industrial automation, autonomous vehicles, vehicular connectivity, augmented reality, drone surveillance and more. These types of applications (and others that complement them) have dubbed 5G a "service-driven evolution" and will require very stringent SLAs for high reliability/low latency (e.g., URLLC) and high-bandwidth throughput.

Achieving this 5G service-driven evolution will require a transformation of not just mobile access and core domains, but also the E2E network, including transport connectivity. While the access evolution on its own is a big leap from previous mobile generations, the E2E network evolution aspects are very significant and offer the promise of making 5G networks massively scalable, more responsive, dynamic and self-healing.

Maximizing efficiency with network slicing and automation

Network slicing is essentially a network virtualization feature that allows multiple services with different requirements to efficiently share a common physical network without resource contention issues. A network slice is a logical or virtual network partition that contains all dedicated resources that are required to support an isolated set of services, applications or users/tenants with different and potentially conflicting resource requirements and constraints. Efficiency is further improved as communications service providers (CSPs) can track and scale the capacity of each slice to optimize network utilization.

However, network slicing does introduce additional management challenges and Nokia Bell Labs estimates that the added complexity of performing network slicing manually will increase the TCO by 30 percent versus that of traditional networks[1]. Automated slicing helps to manage this complexity and offset this increased cost. It is also critically important for operators to achieve the speed and efficiency they need to make network slicing economical. Automation is key for the full life cycle from network slice creation, to assurance and monitoring, to optimization and dynamic remediation for proactive prevention of service impacting issues.

Automation has already been a focus of many CSPs to improve the efficiency and profitability of existing service delivery processes and to support mass customization with customer self-managed services. Automating network slicing will inevitably become a prerequisite for digital service providers (DSPs) to implement a digital storefront for E2E 5G services with automated digital life-cycle management (LCM) of business systems and operations support systems (OSS). Automating network slicing will be essential for efficiently delivering, optimizing and assuring these services across E2E 5G networks.

1 Bell Labs Consulting: Narayan Raman et al, "Future X Network Cost Economics - A network operator's TCO journey through virtualization, automation, and network slicing", July 2018.

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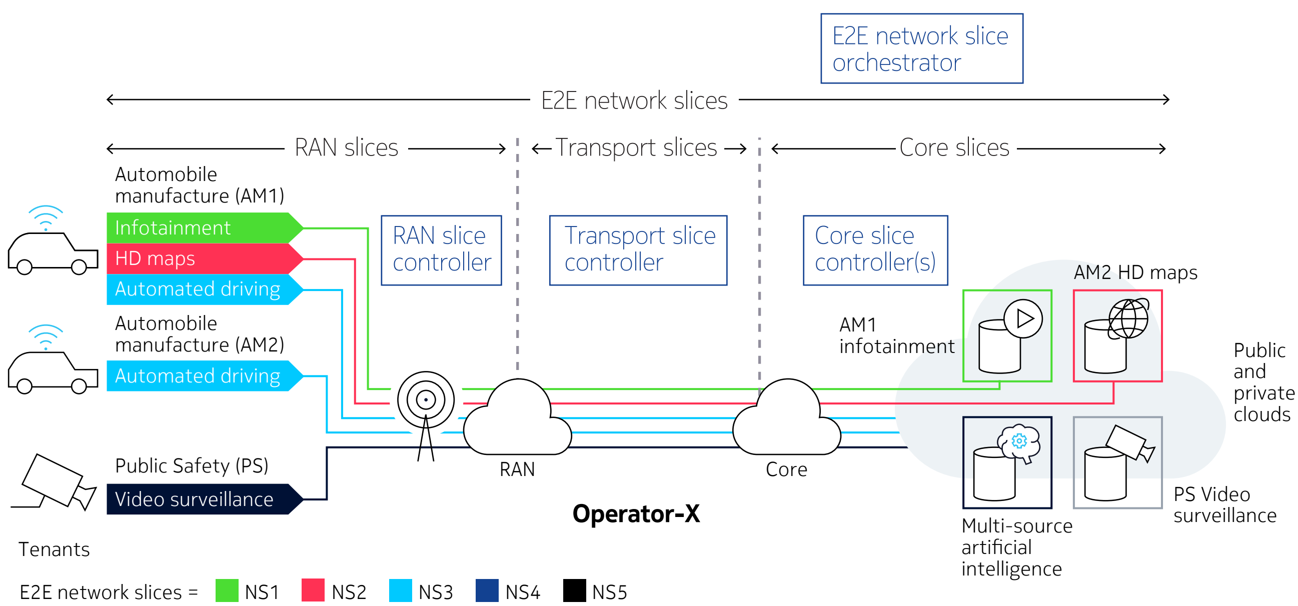
Network slicing in 5G

Network slicing in the context of 5G is a mechanism that a CSP can use to create independent logical networks within its common or shared network infrastructure. These network slices can be for tenants that are customers or internal tenants within the operator's organization.

A 5G network slice is inherently an E2E concept used to connect the user's equipment to tenant-specific applications. Network slicing receives attention because 5G services and devices need to have their own SLA requirements, which vary widely depending on the application. An E2E network slice consists of multiple slices: a RAN slice, a core slice and one or more transport slices. Each network domain has its own slice controller(s) and contributes to meeting the E2E SLA across the 5G network. An E2E 5G network slice orchestrator coordinates the actions of the domain controllers for the RAN, core and transport slices. (Note that the RAN, core and transport slices are also called "sub-slices" or "slice subnets" in some standards development organizations.)

Figure 1 gives an example of an E2E 5G network slice with five network slices (i.e., NS1 to NS5) in which each color represents a different SLA. Each E2E network slice supports a specific customer or "tenant" and a specific service (e.g., eMBB services, CCTV services for public safety, infotainment for automobile companies). Any of these can be shared slices that carry multiple services as well.

Figure 1. E2E 5G network slicing



The E2E network slice orchestrator and the domain controllers (for RAN and core) are defined by the 3GPP as the E2E Network Slice Management Function (NSMF) and the Network Slice Subnet Management Function (NSSMF) respectively. The 3GPP currently defines the interfaces for the NSMF to communicate to both the RAN NSSMF and core NSSMF. However, currently 3GPP has not yet defined the same interface for the transport domain. Nokia is championing the work in the IETF in the context of the "transport slice connectivity interface", with several leading CSPs (NTT, Telefonica I+D, InterDigital, NICT, Orange, BT) and other participating network equipment vendor(s) to help specify the transport slicing interface, including the information model for automating the creation, optimization and monitoring of transport slices[2].

2 Reza Rokui (Nokia), IETF Draft, "5G Transport Slice Connectivity Interface", https://tools.ietf.org/html/draft-rokui-5g-transport-slice-00, July 2019.

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For E2E 5G networks, the transport slice controller interacts with the NSMF (an E2E network orchestrator), which increases the importance of standardizing a transport slicing interface for transport controllers. The transport slice controller abstracts the complexity of the underlying transport network for the E2E orchestrator and provides domain-specific functions to support creation, assurance and control of transport slices with deterministic SLAs. This typically includes software-defined network (SDN) control capabilities to compute optimal transport paths, for example using a transport slice controller to implement traffic engineered paths with a Path Computation Engine (PCE) function. This can be done between 5G edge cloud data center gateways that connect 5G core functions to the 5G RAN.

Transport slices in 5G cloud RAN and E2E networks

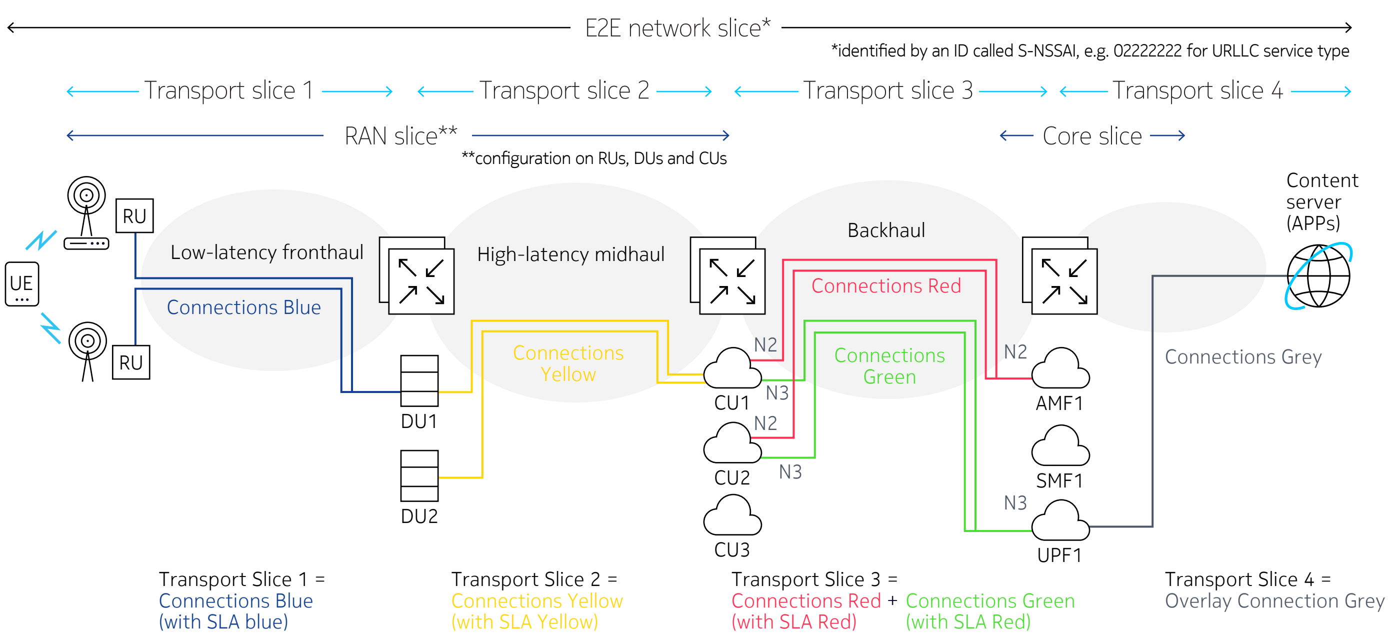
According to recent IETF drafts on the definition of a transport slice[3], a transport slice is as follows:

"A Transport Slice is an abstract network topology connecting different endpoints with appropriate isolation and specific Service Level Agreement (SLA) described in terms of shared or dedicated network resources, level of isolation etc."

In other words, a transport slice is a group of connections which connect various endpoints in the network to achieve a specific SLA for a customer.

In the context of a typical 5G network deployment of a cloud RAN, there may be multiple transport slices required for an E2E network slice. Figure 2 gives an example of a cloud RAN with a single E2E network slice containing multiple transport slices, which provide the transport connectivity between various network elements in the network across fronthaul (slice 1 using blue connections), midhaul (slice 2 using yellow connections) and backhaul (slice 3 using red and green connections). Transport slicing may also be applied between the 5G core and public networks or clouds (slice 4 using grey connection).

Figure 2. Transport slices across fronthaul, midhaul and backhaul



Note: All the networks are realized (implemented) by various services/path/tunnels

3 Reza Rokui (Nokia), "IETF Definition of Transport Slice", https://tools.ietf.org/html/draft-nsdt-teas-transport-slice-definition-00, November 2019

The introduction of a transport slice controller will become important for maximizing operational efficiency as CSPs evolve to E2E 5G networks. This includes the benefit of operational continuity for 4G/5G hybrid deployments. 5G transport domain control will also enable the ability to better and more consistently enforce SLAs across all of the transport network slice's implementation. The transport slice controller brings the benefits of SDN and intent-based networking automation and programmability to transport network slicing while improving SLA adherence on a per-slice level.

The transport slice controller provides an abstract, programming interface to enable the E2E network orchestrator to create, optimize and assure transport slices across the fronthaul, midhaul, backhaul, cloud interconnect and overlay networks. This programmability can flexibly be extended to cover any vendor's equipment and any supporting technologies:

- Networking technologies: IP, optical, passive optical network (PON) or microwave
- Tunnel types: IP, MPLS, segment routing or optical data unit (ODU)/optical channel (OCH)
- Service types: L0/L1/L2/L3 service types.

Separating the transport slice realization and its abstract definition enables significant flexibility in implementing slices with different underlying technologies without having to change northbound interfaces to the E2E network slice orchestrator. It also allows network operators to maintain consistent operational practices as they evolve their transport networks for 5G.

Benefits of transport slicing

Transport slicing can significantly enhance E2E 5G operations for delivering innovative 5G services such as eMBB and URLLC connectivity services for digital enterprises, industry 4.0 and smart city infrastructure. There are several advantages for using transport slicing in E2E 5G networks: improved SLA adherence, operational simplification, ease of integration and implementation flexibility.

Improved SLA adherence

A key benefit of transport slicing is support for connectivity services with deterministic SLAs. Although traditional virtual private network (VPN) services also provide traffic isolation, they do not provide resource isolation and typically use technology-specific QoS implementations to classify and manage different types of traffic.

The transport slice controller must insure that all transport slices across the E2E 5G network adhere to SLAs. To meet optimization objectives such as latency, throughput or path diversity, modern IP/MPLS and optical backhaul transport networks typically perform a path computation function using an SDN PCE in combination with source-based routing (e.g., MPLS segment routing or GMPLS) to engineer optimal traffic routes.

Transport slicing also gives more flexibility in stitching and concatenating connectivity segments to build E2E service flows. For example, network slicing typically starts in the multi-access network where traffic flows are classified and marked with a specific class of service (CoS) profile (e.g., 3GPP QoS Class Identifier, IP DSCP or 802.1q VLAN tag). The traffic flows are subsequently mapped into a proper transport network slice that supports the E2E transport SLA that meets the latency, delay, jitter and packet loss objectives of the CoS profile.

Operational simplification

E2E 5G transport networks are complex infrastructures, often with multiple administrative and operational domains containing different networking technologies from various equipment vendors. Transport slicing enables operators to break this complexity down into manageable pieces that can be automatically assembled to support zero-touch service delivery, closed-loop assurance and network optimization.

Related use cases cover both self-service delivery models and well as internal operator network sharing.

- For self-service delivery models, transport slices can be viewed in a simplified way as independent logical networks that support one or multiple tenants along the E2E physical connectivity path. Individual tenants can initiate the creation, management, assurance and optimization of their own E2E network slice through a customer portal that front-ends the E2E orchestration. All required domain sub-slices will be handled with respective slice controllers (across RAN, transport and core) in a distinct and secure manner that is independent of other tenants' slices and the operator's own production network. Tenants also have an abstracted view for E2E service visibility that hides the complexity and details of the underlying operator's domain infrastructure; this includes the ability to monitor SLAs, turn up new services, change bandwidth between sites, redirect connectivity paths for services between sites, and rapidly adapt to changing service requirements or network conditions.
- The operator retains a global view of the network and the ability to manage and monitor all slices for all tenants, including internal operator slices for network sharing use cases. For 5G operators, the deployment of 5G network slicing introduces simplification benefits specifically for transport domain control where vendor-agnostic technology interfaces abstract the data communication model between the E2E network slice orchestrator and RAN, core and transport slices. This dramatically simplifies operations and the expertise required in terms of development and integrations needed for OSS.

Ease of integration

Specifically, what is new with the 3GPP 5G standards is the introduction of a global ID assigned to an E2E network slice; in 3GPP standards this identifier is called the "Single Network Slice Selection Assistance Information" (S-NSSAI). Consequently, all RAN, core and transport slices will be aware of this S-NSSAI, and this dramatically simplifies the development and integration needed to effectively automate 5G network sub-slicing. In this standardized way, RAN, core and transport slices can associate their sub-slices to the overall E2E network slice.

In addition, for the transport domain, the abstract "transport slice connectivity interface"[2] between the E2E orchestrator and transport slice controller can dramatically simplify the creation, optimization and assurance of the transport slices. This is important due to the multivendor nature of today's networks, where multiple vendors' equipment is supported by different transport technologies, tunnel types and services types – all of which must be stitched together.

The transport slice controller presents the E2E network orchestrator with an abstract interface for automating and programming the delivery, optimization and monitoring of transport slices across fronthaul, midhaul, backhaul and overlay network connectivity.

Implementation flexibility

Transport slicing techniques enable far more flexibility in implementing virtual private connectivity services that can leverage various networking technologies, tunnel types and service types (including VPNs) and can easily be ported between technology implementations as connectivity requirements evolve.

To best fit the needs of existing "brownfield" networks, multiple vendors' equipment and networking technologies must typically be supported by a single transport slice. This capability is also critical to accelerating E2E network deployments for 5G, including for 4G/5G hybrid networks, which will allow CSPs to leverage existing transport network investments to ease transformation to E2E 5G networks.

In addition, more flexibility in creating individual transport slices also caters to specific customer needs and application requirements in the way they are implemented across the network infrastructure. Transport slice realization using “hard slices” provides deterministic resource guarantees by allocating dedicated network resources, or by using “soft slices” it allows for the use of logical data plane resource constructs to provide isolation for shared physical network resources. Hard and soft slicing are complementary and may be used in concert.

- Hard slicing may be required for critical machine-type and control applications and provides bandwidth and latency guarantees, even under failure conditions.
- Soft slicing allows for a shared and managed use of transport resources, which results in a more economical use of network resources for high-volume applications with relaxed latency constraints, such as streaming video.

Leveraging its IP market and technology leadership, Nokia’s Network Functions Interconnect (NF-IX) architecture is an example of innovation to enable the flexible and efficient realization of transport slices by using a 5G transport slice controller.

Conclusion

E2E network slicing will be a fundamental capability to enable the delivery of E2E services over a common physical transport network. Within this E2E network slicing, the slicing of the transport network will be foundational. Transport slicing is critical for 5G success because it maximizes operational flexibility and efficiency of zero-touch service delivery with support for deterministic SLAs on throughput, latency and availability.

A transport slice controller is a key building block that coordinates the creation and monitoring of E2E transport slices in multi-domain, multi-technology and multivendor environments. It plays an important role in the 3GPP 5G architecture and is a prerequisite for automating the creation, optimization and assurance of transport slices within the context of E2E 5G networks.

Abbreviations

3GPP	3rd Generation Partnership Project
AMF	Access and Mobility Management Function
CoS	class of service
CSP	communications service provider
CU	central unit
DSCP	differentiated services code point
DSP	digital service provider
DU	distributed unit
E2E	end-to-end
eMBB	enhanced mobile broadband
GMPLS	Generalized MPLS
IBN	intent-based networking
IETF	Internet Engineering Task Force
LCM	life-cycle management
MMC	massive machine communications
MPLS	Multiprotocol Label Switching

NF-IX	Network Functions Interconnect
NSMF	Network Slice Management Function
NSSMF	Network Slice Subnet Management Function
OCH	optical channel
ODU	optical data unit
OSS	operations support system
PON	passive optical network
PCE	Path Computation Engine
QoS	quality of service
RAN	radio access network
RU	radio unit
SDN	software-defined networking
SLA	service level agreement
SMF	Session Management Function
S-NSSAI	Single Network Slice Selection Assistance Information
TCO	total cost of ownership
UE	user equipment
UPF	User Plane Function
URLLC	ultra-reliable, low-latency communications
VLAN	virtual LAN
VPN	virtual private network

Related resources

- Whitepaper: "5G transport slice control in end-to-end 5G networks: Best practices for a transport slice controller"
- White paper: "Network Functions Interconnect Architecture: A dynamic and smart network fabric for mobile broadband evolution, the Internet of Things and 5G"
- Application note: "Network automation and programmability: Using the Nokia NSP for intent-based networking (IBN)"

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