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Network Slicing Architecture

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Abstract

This document defines the overall architecture of network slicing.

Base on the general architecture, basic concepts of network slicing

and examples of network slicing instances are introduced for

clarification purposes. Some architectural considerations about the

data plane, control plane, management and orchestration of network

slicing are described to give a general view of network slicing

implementation principles. This also helps to identify the gaps in

existing IETF works relating to network slicing.

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# Introduction

The Internet has always been designed to support a variety of

services. The emerging 5G market is expected to bring this diversity

of services to a new level. Typical examples of new bandwidth-hungry

services enabled by 5G include high definition (HD) video, virtual

reality (VR) and augmented reality (AR). The high bandwidth

requirement of these services is not particularly challenging thanks

to the continuing advancing technologies. However, the guarantee of

high bandwidth performance of these services based-on a spontaneous

on-demand pattern is fairly challenging. Moreover, providing high

bandwidth with strict packet loss tolerances and high mobility is

also difficult for the current networks which are commonly designed

for best effort purposes.

Given that most Internet protocols are designed to comply with a best

effort, or enhanced best effort paradigm, it is inevitable that the

network will suffer from performance degradation in case of

congestion. Recent work on deterministic networking (DetNet) aim to

improve this situation by providing a ceiling on latency for a

particular traffic flow, which significant improves packet error rate

for specific DetNet services. This pioneering work gives a great

example that new approaches are investigated to make the Internet

aware of certain performance requirement other than the bandwidth.

Taking a look at the network infrastructure, service provider used to

build dedicated network and resources for services requiring

guaranteed performance. This is simply not cost-effective, neither

is it flexible. The emergence of virtualization and VPN technologies

make it possible to set up logically isolated computing and network

instances from shared infrastructures. This can be used dedicatedly

by specific services for improved performances. However, many

questions are still to be answered as different technologies in

various domains need to be combined to build network slices, which

may require the separation of different resources and various types

of performance guarantees.

## Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT",

"SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this

document are to be interpreted as described in RFC 2119.

Additionally, the key words "MIGHT", "COULD", "MAY WISH TO", "WOULD

PROBABLY", "SHOULD CONSIDER", and "MUST (BUT WE KNOW YOU WON'T)" in

this document are to interpreted as described in RFC 6919.

## Terminology

The following usage of terms have referenced by this draft.

Editor Note: Terms highlighted in yellow are subjected to be discussed whether they should be remained in this draft. Many of them have common definition in IETF domain.

I. Networking & Servicing Terms

Software-Defined Networking (SDN) - A programmable networks approach that supports the separation of control and forwarding planes via standardized interfaces. It is a of techniques that enables to directly program, orchestrate, control and manage network resources, which facilitates the design, delivery and operation of network services in a dynamic and scalable manner.

Network virtualization - A technology that enables the creation of logically isolated network partitions over shared physical networks so that heterogeneous collections of multiple virtual networks can simultaneously coexist over the shared networks. This includes the aggregation of multiple resources in a provider which appear as a single resource.

Network softwarization - An overall transformation trend for designing, implementing, deploying, managing and maintaining network equipment and/or network components by software programming, exploiting the natures of software such as flexibility and rapidity all along the lifecycle of network equipment/components, for the sake of creating conditions enabling the re-design of network and services architectures, optimizing costs and processes, enabling self-management and bringing added values in network infrastructures.

Software Network - An approach to computer networking that allows network administrators to manage network services through abstraction of higher-level functionality. This is done, for example, by decoupling the system that makes decisions about where traffic is sent (the control plane) from the underlying systems that forward traffic to the selected destination (the data plane).

Programmable networks - Networks that allow the functionality of some of their network elements to be dynamically programmable. These networks aim to provide easy introduction of new network services by adding dynamic programmability to network devices such as routers, switches, and applications servers. Network Programmability empowers the fast, flexible, and dynamic deployment of new network and management services executed as groups of virtual machines in the data plane, control plane, management plane and service plane in all segments of the network. Dynamic programming refers to executable code that is injected into the execution environments of network elements in order to create the new functionality at run time. The basic approach is to enable trusted third parties (end users, operators, and service providers) to inject application-specific services (in the form of code) into the network. Applications may utilize this network support in terms of optimized network resources and, as such, they are becoming network aware. The behaviour of network resources can then be customized and changed through a standardized programming interface for network control, management and servicing functionality.

Service - A piece of software that performs one or more functions and provides one or more APIs to applications or other services of the same or different layers to make use of said functions and returns one or more results. Services can be combined with other services, or called in a certain serialized manner, to create a new service.

Service Instance - An instance of an end-user service or a business service that is realized within or by a network slice. Each service is represented by a service instance. Services and service instances would be provided by the network operator or by third parties.

Administrative domain - A collection of systems and networks operated by a single organization or administrative authority. Infrastructure domain is an administrative domain that provides virtualized infrastructure resources such as compute, network, and storage, or a composition of those resources via a service abstraction to another Administrative Domain, and is responsible for the management and orchestration of those resources.

Multitenancy domain – It refers to set of physical and/or virtual resources in which a single instance of a software runs on a server and serves multiple tenants.

Tenant - A group of users who share a common access with specific privileges to the software instance. A service or an application may be designed to provide every tenant a dedicated share of the instance including its data, configuration, user management, tenant-specific functionality and non-functional properties.

Functional requirement – This is a description of a function, or a feature of a system or its components, capable of solving a certain problem or replying to a certain need/request. The set of functional requirements present a complete description of how a specific system will function, capturing every aspect of how it should work before it is built, including information handling, computation handling, storage handling and connectivity handling.

Functional entity - An entity that comprises an indivisible set of specific capabilities. Functional entities are logical concepts, while groupings of functional entities are used to describe practical, physical implementations.

Interface - A point of interaction between two entities. When the entities are placed at different locations, the interface is usually implemented through a network protocol. If the entities are collocated in the same physical location, the interface can be implemented using a software application programming interface (API), inter-process communication (IPC), or a network protocol.

Reference Point – It is a group of interfaces that would be used for exchange of information and/or controls between two separate (sub)systems which are sharing a boundary. The exchange can be between software, hardware, network devices, network elements, network functions, humans and combinations of these

II. Communication Systems Specification Terms

Planes - A plane is a subdivision of the specification of a complete communication system, established to bring together those particular pieces of information relevant to some particular area of concern during the analysis or design of the system. Although separately specified, the planes are not completely independent; key items in each are identified as related to items in the other planes. Each plane substantially uses foundational concepts. However, the planes are sufficiently independent to simplify reasoning about the complete system specification.

Data /Forwarding/ User Plane (FP) - The collection of resources and components across all network devices responsible for forwarding traffic. The set of functions used to transfer data in the stratum or layer under consideration.

Control Plane (CP) - The collection of functions responsible for controlling the operation of one or more network devices plus the functions required to support this control. It instructs network devices with respect to how to process and forward packets. The control plane interacts primarily with the forwarding plane and, to a lesser extent, with the operational plane.

Management & Operational Plane (MP) - The collection of resources responsible for managing the overall operation of individual network devices plus the functions required to support this management. It includes the collection of functions responsible for monitoring, configuring, and maintaining one or more network devices or parts of network devices. The management plane is mostly related to the control plane (it is related less to the forwarding plane).

Orchestration Plane (OP) - An automated arrangement, coordination of complex network systems and functions including middleware for both physical and virtual infrastructures. It is often discussed as having an inherent intelligence or even implicitly autonomic control. Orchestration results in automation with control network systems. Orchestrator is n entity that fulfills orchestration functions. An entity that manages network service lifecycle and coordinates the management of network service life cycle, network function lifecycle and network function infra resources to ensure optimized allocation of the necessary resources and connectivity.

Application Plane (AP) - The collection of applications and services that program network behavior.

III. Network Resource Terms

Resource - A physical or virtual (network, compute, storage) component available within a system. Resources can be very simple or fine-grained (e.g., a port or a queue) or complex, comprised of multiple resources (e.g., a network device).

Logical Resource - An independently manageable partition of a physical resource, which inherits the same characteristics as the physical resource and whose capability is bound to the capability of the physical resource.

Virtual Resource - An abstraction of a physical or logical resource, which may have different characteristics from that resource, and whose capability may not be bound to the capability of that resource.

Network Function (NF) - A processing function in a network. It includes but is not limited to network nodes functionality, e.g. session management, mobility management, switching, routing functions, which has defined functional behaviour and interfaces. Network functions can be implemented as a network node on a dedicated hardware or as a virtualized software functions. Data, Control, Management, Orchestration planes functions are Network Functions.

Virtual Network Function (NFV) - A network function whose functional software is decoupled from hardware. One or more virtual machines running different software and processes on top of industry-standard high-volume servers, switches and storage, or cloud computing infrastructure, and capable of implementing network functions traditionally implemented via custom hardware appliances and middleboxes (e.g. router, NAT, firewall, load balancer, etc.)

Network Device (NE) - A component that performs one or more network operations related to packet manipulation and forwarding. This reference model makes no distinction as to whether a network device is physical or virtual. A device can also be considered as a container for resources and can be a resource in itself.

Network Element / Entity - A network element is defined as a manageable logical entity uniting one or more network devices. This allows distributed devices to be managed in a unified way using one management system. It means also a facility or equipment used in the provision of a communication service. Such term also includes features, functions, and capabilities that are provided by means of such facility or equipment, including subscriber numbers, databases, signaling systems, and information sufficient for billing and collection or used in the transmission, routing, or other provision of a telecommunications service.

IV. Slicing Terms - Definition in this draft

Resource Slice - A grouping of physical or virtual (network, compute, storage) resources which. It inherits the characteristics of the resources which are also bound to the capability of the resource. A resource slice could be one of the component of Network Slice, however on its own does not represent fully a Network Slice.

Network slice - A Network slice is a managed group of subsets of resources, network functions / network virtual functions at the data, control, management/orchestration planes and services at a given time. Network slice is programmable and has the ability to expose its capabilities. The behaviour of the network slice realized via network slice instance(s). A network slice is consist of the following components.

1. **The Service Instance component**

• Represents the end-user service or business services.

• An instance of an end-user service or a business service that is realized within or by a NS.

• Would be provided by the network operator or by 3rd parties.

1. **A Network Slice Instance component**

• Represented by a set of network functions, virtual network functions and resources at a given time

• Forms a complete instantiated logical network to meet certain network characteristics required by the Service Instance(s).

• Provides network characteristics which are required by a Service Instance.

• May also be shared across multiple Service Instances

1. **Resources component** – it includes: Physical, Logical & Virtual resources

• Physical & Logical resources - An independently manageable partition of a physical resource, which inherits the same characteristics as the physical resource and whose capability is bound to the capability of the physical resource. It is dedicated to a Network Function or shared between a set of Network Functions.

• Virtual resources - An abstraction of a physical or logical resource, which may have different characteristics from that resource, and whose capability may not be bound to the capability of that resource.

1. **Slice Element Manager (SEM) and Capability exposure component**

• Slice Element Manager (SEM) is instantiated in each Network Slice and it manages all access permissions and all interaction between a Network Slice and external functions (i.e. other Network Slices, Orchestrators, etc). Each SEM converts requirements from orchestrator into virtual resources and manages virtual resources of a slice. SEM also exchanges information of virtual resources with other slice element managers via a dedicated resource interface.

• Allow 3rd parties to access via APIs information regarding services provided by the slice (e.g. connectivity information, QoS, mobility, autonomicity, etc.)

• Allow dynamical customization of the network characteristics for different diverse use cases within the limits set of functions by the operator. Network slice enables the operator to create networks customized to provide flexible solutions for different market scenarios, which have diverse requirements, with respect to the functionality, performance and resource separation.

• It includes a description of the structure (and contained components) and configuration of the slice instance.

Network slice template - A complete description of the structure, configuration and the plans/work flows for how to instantiate and control the Network Slice Instance during its life cycle.

Network Slice Instance - An activated network slice. It is created based on network template. A set of managed run-time network functions, and resources to run these network functions, forming a complete instantiated logical network to meet certain network characteristics required by the service instance(s). It provides the network characteristics that are required by a service instance. A network slice instance may also be shared across multiple service instances provided by the network operator. The network slice instance may be composed by none, one or more sub-network instances, which may be shared by another network slice instance.

Network Slice Repository – A repository that in each domain consists of a list of active Network Slices with their identifiers and description. This description defines also the rules that have to be fulfilled in order to access a slice. Network Slice Repository is updated by slice orchestrator. In case of recursive slicing the Network Slice Repository keeps information about all slices that compose a higher level slice but such slice has its own identifier and descriptors.

Slice Border Control – A functional entity that is used for users to slice attachement and in recursive slicing, in which an end-to-end slice is a horizontal combination of per domain slices. It’s role is to expose information about a slice to other slices in order to provide efficent slice connection (i.e. topology information exchange, etc.) and to perform necessary protocol translations.

Slice Selection Function – A functional entity that is used by the end-users in order to attach to a slice. It provides mechanisms related to slice advertisement, on request passes information related to slice attachement to the end-users and optionally authenticate users. In case of lack of an active slice as descibed in user request it may provide slice matching and also trigger the creation of a slice on-demand.

# 2. Demand for Network Slicing

It is expected that a diversity of new services will emerge in 5G

network. These services including smart home, industrial control,

remote healthcare, Vehicle-to-Everything (V2X) and etc. will

eventually create an ecosystem of "Internet of Everything". With

hundreds of billions of devices from different business sectors

connected, the future network needs to meet the diversified Quality

of Experience (QoE) demands of different vertical industries.

Typical QoE requirements for the end users or the applications are

extremely low latency and high reliability, whilst the purchaser of

the slice is looking for short time-to-market and rapid deployment of

the service infrastructure needed to provide the technical

underpinning of their business. Service providers' networks need to

continuously evolve to adapt to this change. As a result, it is

believed that future networks should be able to provide services with

guaranteed performances together with the existing best-effort

services. In order to achieve this, it is preferred that dedicated

resources in the network could be used by different vertical industry

customers. Network slicing is proposed as an end-to-end solution for

this purpose.

## Guaranteed Service Performance

One of the most challenging requirements for future network is to

provide guaranteed performance for varieties of new services whilst

maintaining the economies of scale that accrue through resource

sharing. It has been foreseen that the requirements of different

services would be diversified and complex.

Taking augmented reality (AR) service as an example, it requires high

bandwidth to provide a local video feed to the augmenter, and high

quality augmented video back to the user. At the same time, it also

requires extremely low latency since the created reality and the

user's view must be synchronized to avoid reaction mismatch. Another

example is the vehicular communications where the delay in traffic

control system may directly jeopardize the road safety.

Network slicing can deal with these challenges by mapping the

performance requirements to physically or logically dedicated

resources.

## Domain & End-to-end Customization

Customization is another significant feature of future services.

Many vertical industries are expected to offer customization

capabilities as a service to both internal manufacturing processes

and specific end users. Meanwhile, these customized services need to

be deployed with short time-to-market. The network needs to adapt to

this challenge since customers may frequently adjust and refine their

customization requirements.

There is ongoing work such as network orchestration, software defined

networks and network function virtualization that aims to address

this problem. In principle, these new technologies share a common

request for the network to provide the ability to provide agile

resource allocation. <!--

## Network Slicing as a Service

It is anticipated that the operation of 5G and future networks will

involve new business models. Given that the network is more

flexible, elastic, modularized and customized, the shared network

infrastructure can be sliced and offered as a service to the

customer. For instance, dedicated, isolated, end-to-end network

resources with a customized topology can be provided as a network

slice service to the tenant of this network slice.The tenants are

allowed to have a certain level of provisioning of their network

slices. -->

# Network Slicing Architecture

This section introduces the general system architecture of network

slicing.

## Basic Concepts

Editor’s note: 3.1 could be removed by merging to terminology. Would like to discuss with the group.

Network slicing is a collection of technologies that are used to

establish logically dedicated resources including but not limited to

connectivity, computing, storage, provisioning and specific network

functions. The logical resources are a part of the larger common

network infrastructures that are shared among various network slice

instances. These dedicated resources can be customized to meet the

diversified requirements of different vertical industries. The

following sections describe some basic concepts of network slicing.

### Network Slicing Provider

A network slicing provider, typically a telecommunication

service provider, is the owner or tenant of the network infrastructures from

which network slices are created. The network slicing

provider takes the responsibilities of managing and orchestrating

corresponding resources that the network slicing consists of.

### Network Slice Instance

A network slice instance (NSI) is the end-to-end realization of

network slicing, which consists of the combination of physically or

logically dedicated resources. An NSI typically associates with

components from different network domains including core network,

transport network and access network. It may also require cloud

resources from data centres. Furthermore, end-user terminals may

also allocate dedicated resource to a specific NSI.

Each NSI is defined and created for specific service-oriented

requirements. The logically dedicated resources allocated to NSIs

may be intrinsically isolated physical instances. They may also

share common physical infrastructures according to implementation

choices.

### Network Slice Type

Network slices are categorized into different types according to the

abstraction of characteristics of the services they facilitate. The

methodology used for defining network slice types may be different

for the network slice provider. Some typical

examples of network slice types according to 5G implementation

include eMMB, mMTC and URLLC. Network slice type may be used to map

specific network resources, VPNs, QoS categories according to real

implementation. It is advised that mutual types should be defined

according to existing main-stream service implementation scenarios.

Extensions should be allowed for network slicing service provider to

make according to new requirements.

### Network Slice Template

A network slice template is an abstraction of the resource

requirement for a set of similar network slice instances. Different

templates are defined for individual network slice types. These

templates are used to create certain network slice instances.

### Network Slice Tenant

A network slice tenant is the user of specific NSIs, with which

specific services can be provided to end customers. Network slice

tenants can make requests of the creation of new network slice

instances. Certain level of management capability should be exposed

to network slice tenant from network slice service provider.

## Reference Architecture

Figure 1 illustrates the general reference architecture of network slicing. It can be seen that two network slice instances are created from the

shared network infrastructures. In principle, the network elements

(NEs) represent any general network infrastructures for demonstration

purposes. The two instances created do not know the existence of

each other. However, they may share the computing, connectivity and

storage resources of the NE, whether they are in physical or virtual

forms. Meanwhile, the owner of a particular network slice instance

is allowed to adjust the instance by requesting changes via the

network slicing management and orchestration system.

+------------------------------------------------------------------+

| Network Slice Management and Orchestration |

| +--------+ +-----+ +--------+ +-------------+ +----------------+ |

| |Template| | NS | | Slice | | E2E Slice | |Life cycle Mngt.| |

| | Mngt. | |Repo.| |Sel.Fun.| |Orchestration| |and monitoring | |

| +--------+ +-----+ +--------+ +-------------+ +----------------+ |

| Created Network Slice Instances |

| +--------------------------------------------------------------+ |

| | | |

| | +---+ +---+ +---+ +-----+ | |

| | |NE1+----+ |NE3| |NE5|----| SBC | | |

| | +---+ | +-+-+ +-+-+ +-----+ | |

| | +-+-+ | | | |

| | |NE2+-----+ | | |

| | +-+-+ | Network Slice | |

| | | | Instance 1 | |

| | +------------------------+ | |

| +--------------------------------------------------------------+ |

| +--------------------------------------------------------------+ |

| | | |

| | +---+ +---+ +---+ +-----+ | |

| | |NE1+----+ +--+NE5+------+NE6|---| SBC | | |

| | +---+ | | +-+-+ +---+ +-----+ | |

| | +-+-+ +---+ | | | |

| | |NE2| |NE4+-+ | | |

| | +-+-+ +-+-+ | Network Slice | |

| | | | | Instance 2 | |

| | +------------------------+ | |

| +--------------------------------------------------------------+ |

+------------------------------------------------------------------+

+------------------------------------------------------------------+

| Physical Network Infrastructures |

| +---+ +---+ +---+ +---+ |

| |NE1+----+ |NE3+------+ +--+NE5+------+NE6| |

| +---+ | +-+-+ | | +-+-+ +---+ |

| +-+-+ | +-+-+ | | |

| |NE2+----+ |NE4+-+ | |

| +-+-+ +-+-+ | |

| | | | |

| +------------------------+ |

+-----------------------------------------------------------------+

Figure: Network Slicing Architecture

It is fundamental to network slicing that slices may be created, the

topology and/or its resources modified, and that the slices may be

decommissioned in a timely manner with minimum work by the network

slicing provider or the customer. This is not however unique to

network slicing, it is a goal of modern classical networks to be able

to do this.

### Template management

Text needs to be added

### Network Slice Repository

Editor’s note: A more detail description than terminology may be required here.

A repository that in each domain consists of a list of active Network Slices with their identifiers and description. This description defines also the rules that have to be fulfilled in order to access a slice. Network Slice Repository is updated by slice orchestrator. In case of recursive slicing the Network Slice Repository keeps information about all slices that compose a higher level slice but such slice has its own identifier and descriptors.

### Network Slice Selection Function

Editor’s note: A more detail description than terminology may be required here.

A functional entity that is used by the end-users in order to attach to a slice. It provides mechanisms related to slice advertisement, on request passes information related to slice attachement to the end-users and optionally authenticate users. In case of lack of an active slice as descibed in user request it may provide slice matching and also trigger the creation of a slice on-demand.

### End-to-End Slice Orchestration

Editor’s note: end-to-end slice orchestration need some description here.

### Life-cycle management and monitor

Network slicing enables the operator to create logically partitioned networks at a given time customized to provide optimized services for different market scenarios. These scenarios demand diverse requirements in terms of service characteristics, required customized network and virtual network functionality (at the data, control, management planes), required network resources, performance, isolation, elasticity and QoS issues. A network slice is created only with the necessary network functions and network resources at a given time. They are gathered from a complete set of resources and network /virtual network functions and orchestrated for the particular services and purposes.

The reference framework is represented by two distinct levels:

• “network slice life-cycle management level” (i.e. the series of state of functional activities through which a network slice passes: creation, operation, deletion) and

• “network slice instances level” (activated network slice level) as shown in next figure.

Functions for creating and managing network slice instances and the functions instantiated in the network slice instance are mapped to respective framework level.

+------------------------------------------------------------------------------+

+ +--------------------------------+ +-----------------------+

+ + Service Plane + + + +

+ +--------------------------------+ + Management + +

+ | + + Plane + +

+ Embedded +--------------------------------+ + + +

+ Softwarization + Orchestration Plane + + + +

+ +--------------------------------+ + + +

+ | + + +

+ +--------------------------------+ + + +

+ + Slice Networking + + + +

+ +--------------------------------+ + + +

+ | + + +

+ +--------------------------------+ + + +

+ + Control Plane + + + +

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+ + Data Plane + + + +

+ +--------------------------------+ + + +

+ | + + + +

+ +-------------------------------------------- + + + +

+ + + Network (Virtual) + + + +

+ + Network + Functions + + + +

+ + Infrastructure + Network Resources + + + +

+ + ------------------------------------------- + +--------------+ +

+------------------------------------------------------------------------------+

| Instantiation

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+------------------------------------------------------------------------------+

+-------------+ +--------+ +----------------+ +---------+

+Service Plane+ + Manag + + Service Plane + + Manag +

+ ------------+ + Plane + +----------------+ + Plane +

+ ------------+ + + + ---------------+ + +

+Orchestration+ + + + Orchestration + + +

+ Plane + + + + Plane + + +

+ ------------+ + + + ---------------+ + +

+ ------------+ + + + ---------------+ + +

+ Slice + + + \*\*\*\* + Slice + + +

+ Networking + + + + Networking + + +

+ ------------+ + + + ---------------+ + +

+ ------------+ + + + ---------------+ + +

+Control Plane+ + + + Control Plane + + +

+ ------------+ + + + ------------------+ +

+ ------------+ + + + ------------------+ +

+ Data Plane + + + Data Plane + +

+ ------------+ +--------+ + ------------------+ +-------+

Figure: Network Slices Life-cycle Reference Framework

Editor’s note: 3.2.6 need some discussion, do we still want this section

### Network Slicing for different domains(Luis)

3.2.1.3. Network Slicing for Core Networks

3.2.1.4. Network Slicing for Transport Networks

3.2.1.5. Network Slicing for Access Networks

3.2.1.6. Network Slicing for Terminal Devices

[Slawomir] We should discuss terminal agnostic vs slice specific terminal functions as well as support of terminal in simultaneous multi-slice terminal attachement.

### Multi-domain and E2E Slices (Slawomir)

An important feature of network slicing is to provide predefined slice properties (like end-to-end-delay) and service features for all users that are attached to a specific slice. In some cases the users can be connected to a slice within single administrative or technological domain, however in most cases a slice will span over multiple domains. In order to deploy the end-to-end slice in that case the concatenation of per domain slices can be applied. Such recursive creation of an end-to-end slice is performed by the E2E Orchestrator that in a hierarchical way cooperates with domain level orchestrators. Each of the orchestrators has repository of its domain specific NS templates and according to the negotiation with the E2E orchestrator selects the template that matches the E2E orchestrator request. The deployment of domain slices that contribute to the end-to-end slice takes into account global policies provided by the E2E Orchestrator. The necessary operations related to concatenation of slices of different domains are support by Slice Border Control functio nal entity that provides necessary conversions of protocols and exchange of information between domains. For the new end-to-end slice a new Slice Boarder Entity is assigned.

## Network Slicing Capabilities (Alex)

### Reclusiveness

Recursion is a property of some functional blocks: a larger functional block can be created by aggregating a number of a smaller functional block and interconnecting them with a specific topology. As such one could summarize the concept of recursive network slice definition as the ability to build a new network slice out of existing network slice (s). A certain resource or network function /virtual network function could scale recursively, meaning that a certain pattern could replace part of itself. This leads to a more elastic network slice definition, where a network slice template, describing the functionality, can be filled by a specific pattern or implementation, depending on the required performance, required QoS or available infrastructure. If a certain part of a network slice can be replaced by different patterns, this can offer some advantages:

• Each pattern might have its own capabilities in terms of performance. Depending on the required workload, a network function /virtual network function might be replaced by a pattern able to process at higher performance. Similarly, a service or network function /virtual network function can be decomposed so it can be deployed on the available infrastructure.

• From an orchestrating point of view, above way of using recursive network slice templates, can be beneficial for the placement algorithm used by the orchestrator. The success rate, solution quality and/or runtime of such an embedding algorithm benefits from information on both possible scaling or decomposition topologies and available infrastructure.

• Enabling methods for network slice template segmentation allowing a slicing hierarchy with parent - child relationships.

### Protection

Protection refers to the related capability and mechanisms so that events within one network slice, such as congestion, do not have a negative impact on another slice.

### Elasticity

Elasticity refers to the capability, mechanisms and triggers for the growth /shrinkage of network resources, and/or network and service functions in an Network Slice as function of service needs.

### Extensibility

Extensibility refers to the capability and ability to expand a network slice with additional functionality and/or characteristics, or through the modification of existing network function / virtual network function while minimizing impact to existing functions.

### Safety

Safety refers to the conditions in within one network slice of being protected against different types and the consequences of failure, error harm or any other event, which could be considered non-desirable in an other network slice.

### Isolation

Efficient slice creation is expected to guarantee the isolation and non interference between network slices in the Data /Control /Management planes as well as safety and security for multi-tenancy in slices.

## Network Slicing Capability Exposure and APIs (Kiran)

### Life-cycle Management of a Slice (Carlos)

Editor’s note: This section is mentioned in previous discription of life-cycle management

### Different viewpoints on Slices (Liang)

Editor’s note: viewpoint might not belong to architecture, there are some viewpoints text in usecase and problem statement documents

# Data Plane of Network Slicing

In the network slicing architecture, the data plane in the edge and

core of the network will likely be one or more of the standard IETF

data planes: IPv4/IPv6, MPLS or Pseudowires (PW). This section

assumes that the IETF protocol stack exists as-is, and describes the

performance consideration in different layers of the data plane.

## Propagation of Guarantees

Guarantees of delay start at the physical layer and propagate up the

stack layer by layer. Any layer can add delay, and can take various

steps to minimize the impact of delay on its layer, but no layer can

reduce the delay introduced by a lower layer.

Guarantees of loss and jitter can, by contrast be upheld or improved

at any layer of the protocol stack, but usually at a cost of

increased delay. Where delay is a constrain as it is in some 5G

applications the option of trading delay for better loss or jitter

characteristics is not an option. In these circumstances it is

critical that the quality characteristics start at the physical layer

and be maintained at each layer of the protocol stack.

## The Underlying Physical Layer

A point to point dedicated physical channel provides the delay,

jitter and loss characteristics limited only by the media itself.

This does not fulfil the need for rapid reconfiguration of the

network to provision new services.

To address the need to provision a slice of the data-plane one

approach that can be deployed is to time-slice access to the physical

service. Ignoring many of the classic TDM offering as being too

slow, a number of technologies are available that might be applied

including OTN and FlexE. Whilst the provisioning of the channel

provided by underlays such as FlexE and the interconnection of FlexE

channels is within the scope of this architecture the operation of

the underlay is outside its scope.

The logical sub-division of a physical channel be that a single

channel with the full bandwidth available or a channel multiplexed at

the physical layer such as is provided by FlexE we will consider in

the following section.

## Hard vs Soft Slicing in the Data-plane

Hard slicing refers to the provision of resources in such a way that

they are dedicated to a specific NSI. Data-plane resources are

provided in the data-plane through the allocation of a lambda,

through the allocation of a time domain multiplexed resource such as

a FlexE channel or through a service such as an MPLS hard-pipe. Note

that although hard-pipes can be used to allocate dedicated, non-

shared resources to an NSI, the using of allocation is bandwidth,

which can result in more "lumpiness" in the physical channel that

would not be present with a true physical layer multiplexing scheme.

Soft slicing refers to the provision of resources in such a way that

whilst the slices are separated such that they cannot statically

interfere with each other (one cannot receive the others packets or

observe or interfere with the other's storage), they can interact

dynamically (one may find the other is sending a packet just when it

wants to, or the other may be using CPU cycles just when the other

needs to process some information), which means they may compete for

some particular resource at some specific time. Soft slicing is

achieved through logically multiplexing the data-plane over a

physical channel include various types of tunnel (IP or MPLS) or

various types of pseudowire (again IP or MPLS). Although the design

of deterministic networking techniques helps, it is not possible to

achieve the same degree of isolation with these techniques as it is

possible to achieve with pure physical layer multiplexing techniques.

However where such techniques provide sufficient isolation their use

leads to a network design that may be deployed on existing equipment

designs and which can make unused bandwidth available to best effort

traffic.

## The Role of Deterministic Networking

Deterministic networking is a technology under development in the

IETF that aims to both minimize congestion loss and set an upper

bound on per hop latency. It allows a packet layer to emulate the

behaviour of a fully partitioned underlay such might be provided

through some physical layer multiplexing system such as FlexE.

Deterministic networking works by policing the ingress rate of a flow

to an agreed maximum and then scheduling the transmission time of

each flow to reduce the "lumpiness" and hence the possible buildup of

queues and hence congestion loss.

Whilst deterministic networking is not as perfect as physical layer

multiplexing in terms of latency minimization, because the scheduling

is hop by hop and not end to end meaning that at each hop a packet

has to wait for the transmission slot allocated to its flow, it has

the advantage that it is able to allocate slots not needed by the

allocated traffic to best effort traffic. This reallocation of the

unused transmission slots to background traffic significantly

improves the efficiency of the network by amortizing the cost between

the scheduled high priority users and the best effort users.

## The Role of VPNs

VPNs are considered candidate technologies for network slicing. The

existing VPN technologies mainly focus on the isolation of forwarding

tables between different tenants and provide a virtual topology for

the connectivity between different sites of a tenant. The VPN layer

and the underlying network resources are usually loosely coupled, and

statistical multiplexing is adopted to improve network utilization.

Although VPNs have been widely used to provide enterprise services in

service provide networks, it is unclear that whether VPNs along with

existing underlying tunnel technologies can meet the performance and

isolation requirements of critical services in the vertical

industries.

## Dynamic Reprovisioning

A requirement of the network slicing system is that it can be

dynamically and non-disruptively reprovisioned. That is not an

unusual requirement of a modern network. However the frequency of

reprovisioning with network slicing will be relatively high, such

that it in many cases it is not possible to hide any disruption

during a "quiet" time.

Physical multiplexing methods such as FlexE have the ability to

seamlessly reprovision multiplex slots. At the network layer

techniques such as make-before-break, segment routing, and loop-free-

convergence can be used to provide uninterrupted operation during a

topology change.

## Non-IP Data Plane

Non-IP data plane in support of Information Centric Networking (ICN),

some of the IoT services and other similar requirements will be added

in a future version.

# Control Plane of Network Slicing

There are two control plane systems that need to be considered. The

first is the control plane of the slicing infrastructure itself, the

second is the control plane of an individual slice.

The control plane of the network slicing system receives the instruction of creating a network slice with particular requirements from the orchestration layer, then the control plane would create the network slice by establishing a logical network, and allocating a set of network resources associated with the network slice in the corresponding network infrastructure. The control plane is also responsible for the dynamic adjustment to the logical network and the allocated network resources according to the network slice change request from the slice tenant, and the changes occured in the network infrastructure. As it is critical to always meet the service requirement of a network slice no matter what happened in other network slices or in the network infrastructure, appropriate service assurance mechanisms should be deployed in the network, and the control plane MUST be able to react fast to any network events, such as resource add, resource fail, creation of new network slice and the deletion of an existing network slice.

In order to provide the flexibility and egility as required by the diverse and dynamic network slices, the control plane of the network slicing system needs to based on the SDN architecture with the help of logically centralized controllers, while distributed control protocols can provide some benefits in scenarios which require fast reaction, robustness and efficient information distribution. It is unticipated that a hybrid control plane would be used for the network slicing system.

Within a network slice, the full range of existing control plane technologies

needs to be permissible. Some slices will run the existing IGP

protocols (such as IS-IS or OSPF) whilst others may use BGP. Some

slices may be controlled by their own SDN controllers. However the

architecture needs to be sufficiently general so as not to restrict

the control protocols that may be used within a network slice.

## Control Operations (Stewart,Jie)

TBD

## Programmability of the Control Plane

TBD

## Control plane slicing protocols

TBD

# Management and Orchestration of Network Slicing (Carlos)

The management and orchestration layer of network slicing system is

responsible for the slice template management, active slices repository management, slice selection/matching, slice orchestration

and life cycle management and monitoring of network slices. Network

slice templates can be generated according to the functional and

performance requirements of the tenants. The slice template deployment can be based on operator’s policies. In different network

domains, different technologies may be used for network slicing, and

orchestration is needed to build E2E network slice. The

provisioning, runtime assurance and decommissioning of E2E network

slices is also the key function of this layer.

It is expected that the management and orchestration layer would use

state of the art management technologies to support short time-to-

market, and help the operators to build an open ecosystem for new

services in vertical industries.

In multi-tenant environment the slice tenants can trigger the creation of slice instances for them by interacting with the E2E Orchestrator. After the creation of the slice the slice tenant is able to monitor slice KPIs (performance, faults) and send slice reconfiguration requests to E2E Orchestrator. All these operations are support by slice tenant portal and SEM. The slice tenant portal should enable the tenant to deploy new slice services using slice exposure function.

## Inter-Network Slices Orchestration

This section describes Inter-Network Slices Orchestration and its functionality. Orchestration refers to the system functions in a domain that

automate and autonomically co-ordination of network functions in slices

autonomically coordinate the slices lifecycle and all the components that are part of the slice (i.e. Service Instances, Network Slice Instances, Resources, Capabilities exposure) to ensure an optimized allocation of the necessary resources across the network.

coordinate a number of interrelated resources, often distributed across a number of subordinate domains, and to assure transactional integrity as part of the process.

autonomically control of slice life cycle management, including concatenation of slices in each segment of the infrastructure including the data pane, the control plane, and the management plane.

autonomically coordinate and trigger of slice elasticity and placement of logical resources in slices.

coordinates and (re)-configure logical resources in the slice by taking over the control of all the virtualized network functions assigned to the slice.

it is the continuing process of allocating resources to satisfy contending demands in an optimal manner. The idea of optimal would include at least prioritized SLA commitments , and factors such as customer endpoint location, geographic or topological proximity, delay, aggregate or fine-grained load, monetary cost, fate- sharing or affinity. The word continuing incorporates recognition that the environment and the service demands constantly change over the course of time, so that orchestration is a continuous, multi-dimensional optimization feedback loop.

it protects the infrastructure from instabilities and side effects due to the presence of many slice components running in parallel. It ensures the proper triggering sequence of slice functionality and their stable operation. It defines conditions/constraints under which service components will be activated, taking into account operator service and network requirements (inclusive of optimize the use of the available network & compute resources and avoid situations that can lead to sub-par performance and even unstable and oscillatory behaviors.

+ ------------------------------------------------+

| Inter-Network Slice Orchestration |

+-------------------------------------------------+

| | |

+----------+ +-----------+ +----------+

| Network | | Network | | Network |

| Slice 1 | | Slice 2 | | Slice N |

| SEM |------| SEM |------ ... -- | SEM |

+----------+ +-----------+ +----------+

| | |

+-------------------------------------------------------------+

| Resources / Network Functions |

+-------------------------------------------------------------+

| | | |

+--------+ : +--------+ : +--------+ : +--------+

| NE 1 |----- | NE 2 |----- | NE 3 |----...-- | NE n |

+--------+ : +--------+ : +--------+ : +--------+

Figure : Inter-Network Slice Orchestration

## Network Slice Creation - Reservation / Release Messages Flow

The establishment of Network slices is both business-driven (i.e. slices are in support for different types and service characteristics and business cases) and technology-driven as network slice is a grouping of physical or virtual resources (network, compute, storage) and a grouping network functions and virtual network functions (at the data, control and management planes) which can act as a sub network at a given time. A network slice can accommodate service components and network functions (physical or virtual) in all network segments: access, core and edge / enterprise networks.

The management plane creates the grouping of network resources (physical, virtual or a combination thereof), it connects with the physical and virtual network and service functions and it instantiates all of the network and service functions assigned to the slice.

Once a network slice is created, the slice control plane takes over the control, slice operations and governing of all the network resources, network functions, and service functions assigned to the slice. It (re-) configures them as appropriate and as per elasticity needs, in order to provide an end-to-end service. In particular, ingress routers are configured so that appropriate traffic is bound to the relevant slice. Identification means for the traffic may be simple (relying on a subset of the transport coordinate, DSCP/traffic class, or flow label), or identification may be a more sophisticated one. Also, the traffic capacity that is specified for a slice can be changed dynamically, based on some events (e.g. triggered by a service request). The slice control plane is responsible for instructing the involved elements to guarantee such needs.

Inter Network Slice Slice Element Element Network

Orchestrator Manager Manager Function

| | | |

| Discovery - | Discovery - | Discovery- |

| -Response | Response | Response |

| <--------------> | <---------------> | <---------------> |

| | | |

| | | |

| Request | | |

| Net Slice | | |

| ----------------> | Request | |

| | Net Sice | |

| | --------------> | Request |

| | | Net Slice |

| | | --------------> |

| | Confirm-Waiting | |

| | <--------------- | |

| | | Negotiation |

| | |(Single/Multiple Rounds)|

| | | <---------------> |

| Confirm-Waiting | | |

| <----------------- | | |

| | Negotiation | |

| |Single/Multiple Rounds| |

| Negotiation | <---------------> | |

|Single/Multiple Rounds| | |

| <----------------> | | |

Figure: Network Slice Reservation / Release Messages Flow

## Self- Management Operations(Slawmir)

Slawomir: Self-management operations are focused on self-optimization and self-healing of network slice instances (including intra-slice functions management), network slice instance services and resources that are used for all slice instances. All these operations are combined with efficient and economical monitoring and reconfigurations at appropriate level. In order to make the management scalable and environment aware the management architecture is composed of many functional entities that follows the feedback loop management paradigm (aka autonomic management). The self-management functions may realize different goals and have to be corrdinated according to slice instance and infrastructure operator policies. The self-management deals with dynamic (1) allocation of resources to slice instances in a economical way that provides required slice instances performance, (2) self-optimization and self-healing of slice instances during their deployment (lifecycle management) and operations (3) self-optimization and self-healing of services of each slice instance. Their lifecycle, that is typically different than slice instance lifecycle should also be managed in the autonomous way.

Despite the self-managed functions may have different goals and involved entities the slice instance self-management should be coordinated with self-management of their services and self-management of resources (inter-slice operations) should be alighned with in-slice self-management operations.

In the implementation the self-management functionality is split between SEM (that is a part of slice template) and slice orchestrator in case of slice management and between service specific management and SEM in case of services that use a specific slice.

## Programmability of the Management Plane

Slawomir: The Management Plane is composed of multiple functional entities and is responsible for resource, slice instance and slice service management. In case of slice instances and services their management comes as a part of appropriate slice or service template respectively. That way slice or service related management functions are instantiated for each slice and/or service. The Management Plane may expose a set of APIs which can be used by additional management services that are added independently on service or slice instance lifecycle. Using these APIs and allocation additional resorce the slice or service operator can add advanced  and new management functions. That way the Management Plane programmability is provided.

## Management plane slicing protocols

Slawomir: At this stage it is too early do define protocols (IMHO). We have to define the management architecture first with functional entities and reference points/interfaces. Having them we could define which protocol(s) we want to use for each of them. Maybe we can mention some protocols but generally they should be a part of separate specification.

# Service Functions and Mappings (Susan)

## YANG Models for Slicing

TBD

## Service Mappings

TBD

# OAM and Telemetry(Stewart)

OAM and telemetry to instrument the system need to be provided for each NSI so that the NSI provider can monitor the health of the NSI and so that the NSI owner can independently verify the health of their NSI.

Running OAM on the NSI from the perspective of its owner can be undertaken by the owner using the native tools for the NSI network type.

For example if the NSI is IP, tools like ICMP [RFC792], ICMPv6 [RFC4443], or IPFIX [RFC7011] can be used. Similarly the native OAM tools for MPLS and Ethernet can be used. If the NSI provides a partial emulation of the network type that limits the ability to operate such native instrumentation tools, then this needs to be made clear to the NSI owner.

Similarly running OAM on the underlay will also use the native tools for the network type providing the underlay. Care must be taken that any OAM run by the NS provider does not impinge on the operation of the NSI, and SHOULD be undetectable in the NSI.

Telemetry will need to be provided to both the NS provider and the NSI owner. Telemetry of the underlay will use the NS providers pub-sub system of choice.

Telemetry of the NSI may be provided purely by the NSI owner installing a telemetry collection system. However significant efficiencies may be realised by if the NS provider exports relavent telemery to the NSI owner’s pub-sub system. Where this is done, consideration must be given to the security of the measurment and export system so to no information is leaked between NSIs.

# IANA Considerations

This document makes no request of IANA.

# Security Considerations

Each layer of the system has its own security requirements.

# Acknowledgements

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