5G-TRANSFORMER: Slicing and orchestrating transport networks for industry verticals

5G-TRANSFORMER: Slicing and Orchestrating Transport Networks for Industry Verticals

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***Abstract*— This article dives into the design of the next generation Mobile Transport Networks to simultaneously support the needs of various vertical industries with diverse range of networking and computing requirements. Network Slicing has emerged as the most promising approach to address this challenge by enabling per-slice management of virtualized resources. We aim to bring the Network Slicing paradigm into mobile transport networks by provisioning and managing slices tailored to the needs of different vertical industries, specifically: automotive, eHealth and media. Our technical approach is twofold: (*i*) enabling Vertical Industries to meet their service requirements within customized slices; and (*ii*) aggregating and federating transport networking and computing fabric, from the edge up to the core and cloud, to create and manage slices throughout a federated virtualized infrastructure. The main focus of the article is on major technical highlights of vertical-oriented slicing mechanisms for 5G mobile networks.**

I. Introduction and Motivation

Research and standardization of the 5th Generation (5G) Mobile Communication System have been quite hot areas recently, noticeably in research and industry forums such as the 5G-PPP in Europe, and Standardization Development Organizations (SDOs) such as the 3GPP, ETSI, IETF, IEEE, ITU-T, etc.

In this context, three technologies have emerged as key 5G pillars: (*i*) Network Function Virtualization (NFV) [1] [2], (*ii*) slicing [3], and (*iii*) Multi-access (Mobile) Edge Computing (MEC) [4]. In NFV, the network functions are virtualized, by properly instantiating, connecting and combining them over the underlying substrate networks. In slicing, the infrastructure sharing between different tenants highly decreases the OPEX of the network. MEC also drives OPEX reduction by handling the traffic locally and hence keeping it away from the core network, but it is primarily purposed to enable low latency services. A study[1] found that large scale deployment of commodity equipment (such as MEC data centers) can enable 50% improvement in latency and geo-targeted delivery of innovative content and services at the edge, which yields a 35% cost reduction in the backhaul. Network softwarization, virtualization and automation, supported by such commodity hardware, will significantly contribute to reduce both CAPEX and OPEX between 40 and 50%.

Leveraging these technologies, the H2020 5G-PPP 5G-TRANSFORMER project[2] set focus on evolving the mobile transport network towards an SDN/NFV/MEC-based 5G Mobile Transport and Computing Platform (MTP). NFV is gaining an incredible momentum by mobile operators as one of the significant solutions to optimize the resource allocation and system scalability in 5G networks. NFV allows infrastructure and function virtualization, where the underlying physical infrastructure and network functions can be virtualized, by properly instantiating, connecting and combining them over the underlying substrate networks. In 5G-TRANSFORMER, each network slice may span across several datacenters that provide the virtual processing resources, where network configurations/adaptations and data forwarding are managed by Software Defined Network (SDN) controllers. Orchestration is therefore a key enabler in 5G-TRANSFORMER to support slicing for different verticals, efficient load distribution and arbitration among the network slices.

One major challenge in slicing is exposing the capabilities of the network including topologies and resources via proper abstraction to the orchestration layer. 5G-TRANSFORMER will design new models, interfaces, optimization algorithms to achieve efficient orchestration, interoperability, and integration between different 5G network sites. The MTP inherits the transport infrastructure of the phase-1 project 5G-Crosshaul [5], defining an integrated network that can transport backhaul and fronthaul over the same transport substrate. In 5G-TRANSFORMER, this network will be extended to better support slicing and MEC, leveraging previous works on end-to-end slicing, such as [6] [7], and MEC [8]. In addition, 5G-TRANSFORMER will also include federation of resources from multiple domains, building on top of the research performed on the phase-1 project 5GEx [9], enabling a creation of end-to-end networks consisting of disjoint resources.

Beyond the technology development, 5G-TRANSFORMER will also explore mechanisms for

[1]Core Analysis, Mobile Edge Computing 2016, Market report, April 2016.

[2]http://www.5g-transformer.eu/

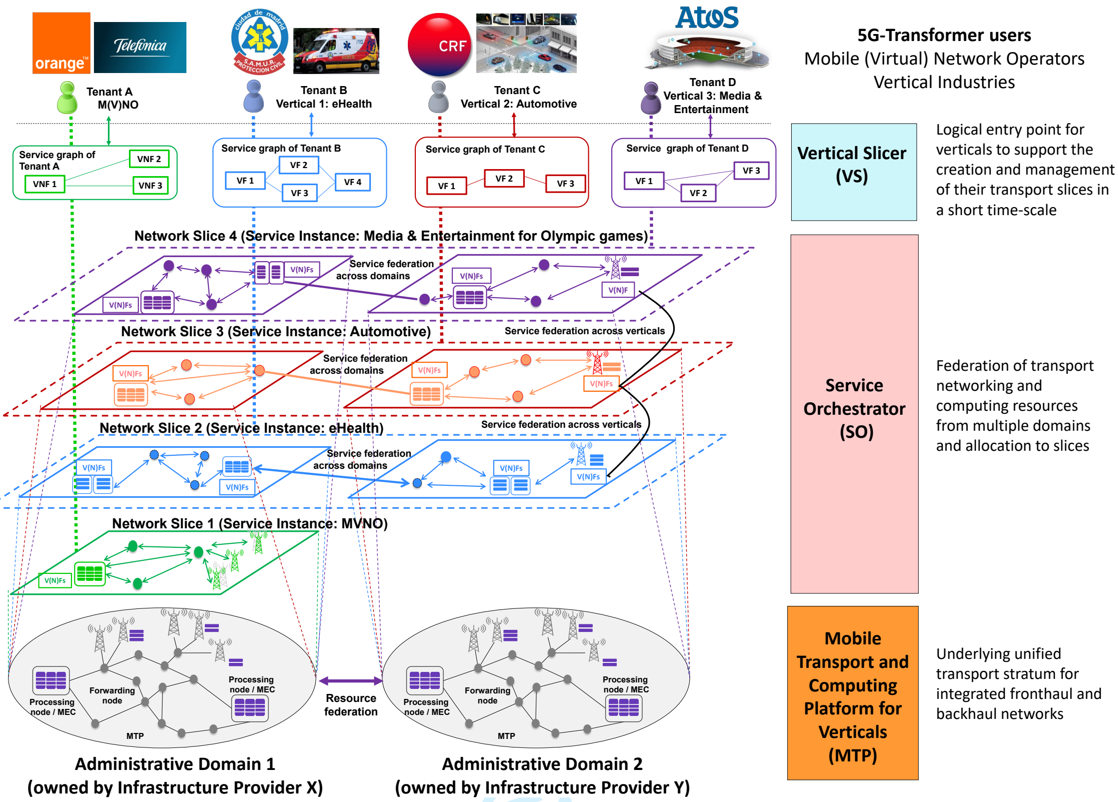


Fig. 1. 5G-TRANSFORMER Concept

generating new revenues to the operators by offering dedicated tailor-made virtual networks to the vertical industries (e.g., enterprise, manufacturing, entertainment, etc.).

The rest of this article is structured as follows: Section II presents the high-level architecture of the system while Section III presents the main research challenges that must be tackled for 5G-TRANSFORMER concept to become a reality. Finally, Section IV concludes this work summarizing the key innovations brought by 5G-TRANSFORMER.

II. The 5G-TRANSFORMER concept

A key novelty of 5G will be the creation of tailor-made infrastructure to meet vertical industries requirements. The 5G-TRANSFORMER concept is driven by the automotive, eHealth, and media & entertainment vertical industries. Table I introduces these verticals and their associated requirements for 5G networks.

A 5G-TRANSFORMER slice is defined as a dedicated logical infrastructure provided to the verticals to support their services and meeting their specific requirements. It is composed of a set of virtual network functions (VNFs) and/or virtual applications (VAs) and their required (virtual or physical) resources (including networking, computing and storage). A 5G-TRANSFORMER slice can span a part or span all domains of the network: software modules including VNFs/VAs running on cloud nodes and/or vertical domains, specific configurations of the 5G transport and core network supporting flexible location of network functions, a dedicated radio configuration or even configuration of the end devices and/or the applications of vertical users or third-party entities. The behavior of the network slice is realized via network slice instance(s). The allocation of a 5G-TRANSFORMER slice instance involves:

- The placement of functions constrained by the status of the mobile transport network, the instantiation of VNF/VAs and logical links interconnecting both the VNF/VAs and existing physical systems according to a template and a descriptor.
- The partitioning and reservation of resources - either shared or dedicated, physical or virtual - to deploy such VNF/VAs and to provide the required connectivity.
- The configuration of the underlying physical infrastructure to meet the requirements and the Service Level Agreements (SLAs) associated to the slice.
- The enabling of a set of interfaces to allow the vertical actor to monitor and operate the slice and integrate it with its own Operation and Business Support Systems (OSS/BSS).

Fig. 1 illustrates the 5G-TRANSFORMER concept. It builds on three main modules (from top to bottom as depicted on the right-hand side of the figure), namely: *(i)* Vertical Slicer (VS); *(ii)* Service Orchestrator (SO); and *(iii)* Mobile Transport and Computing Platform (MTP). These three modules jointly allow any vertical industry to obtain an end-to-end 5G-TRANSFORMER slice tailored to its needs.

TABLE I
5G-TRANSFORMER VERTICALS AND ASSOCIATED REQUIREMENTS

Vertical description and use cases	**Vertical requirements**
Automotive: Vehicular communication scenarios and use cases, for example involving: • Advanced Driver Assistance Systems (ADAS) enabling autonomous driving by taking over the vehicle (e.g., on the motorway) and only leaving the monitoring task to the driver. • On-board systems (e.g., camera systems and sensors) and smart, inter-connected networks for V2X (Vehicle-to-everything).	• Cross-domain network slice for seamless V2X communications. • Configurable network slice to serve vertical requirements. • Slices being able to reduce delay and prioritize certain classes of traffic on demand. • Interfaces for managing user authentication, data integrity, confidentiality, and user privacy.
eHealth: Communications for eHealth and emergency situations use nowadays TETRA (Terrestrial Trunked Radio) technology. Slicing may enable moving from TETRA deployments to a virtualized private network based on a federated network of private network operators, providing: • Low-latency coordination mechanisms for emergency services involving the public network and the emergency coordination network of the municipality. • The use of medical alerts from wearables for emergency detection and healthcare coordination.	• On-demand instantiation of slices with dynamic characteristics. • Integration of slices in the already deployed system, especially with Emergency Response Call Centers. • Strict priority of traffic and location services. • Deployment of third party services over MEC (e.g., applications for alarms in case a wearable detects a health problem).
Media and Entertainment: Use cases involving: • Increasing demands (data rates, number of simultaneous users connected, Quality of Experience, etc). • Immersive sports experience: smart stadiums, AR/VR, 360^o streaming.	• Dynamic creation of slices with MEC extended services, e.g., Content Distribution Networks (CDNs), and allowing isolation of the different traffic types according to the subscription level. • Dynamic deployment of on-the-fly services for geographical areas, e.g., following the movement of users. • Strict priority of traffic and location services. • Use of resources from different providers at different venues.

The *Vertical Slicer (VS)* is a common entry point for all vertical industries into the 5G-TRANSFORMER system (note that each administrative domain has one VS). It coordinates and arbitrates vertical slice requests for the use of networking and computing resources. Slices are requested at the VS through a new defined interface using templates (called blueprints) with simple interconnection models, thus relieving the vertical industry from specifying its slice details. A template including the information provided by a vertical is called Vertical Service Descriptor (VSD), and can be either based on basic components and interfaces to compose the service, yielding to a service graph similar to a forwarding graph from NFV, or be based on a set of essential services used as building blocks to compose more complex services. The VS is therefore in charge of mapping the high-level requirements and placement constraints of the slice template into a set of one or more VNF/VA graphs and service function chains (SFCs).

The *Service Orchestrator (SO)* is the main decision point of the system. It manages the allocation and monitoring of all virtual resources to all slices (from vertical industries and others, such as Mobile Virtual Network Operators – MVNOs). Depending on the slice requirements and network context, the SO may interact with other SOs belonging to other administrative authority domains to take decisions on the end-to-end service (de)composition of virtual resources and their most suitable execution environment. This can be a single or multiple administrative domains depending on resources availability and characteristics. The resources can be pre-defined in the Network Service Descriptor (NSD) or dynamically selected by the SO. All resources will be characterized through descriptors and templates that follow a common information model and will be made available in the different federated domains through unified catalogs.

Finally, the *Mobile Transport and Computing Platform (MTP)* manages the underlying physical mobile transport network and computing infrastructure. It evolves the 5G-Crosshaul solution to integrate MEC resources from multiple domains, and provide support for 5G-TRANSFORMER concept of slicing. It enforces slice requirements coming from the SO and provides physical infrastructure monitoring and analytics services.

Fig. 2 shows the high level workflow for instantiation of a vertical service through these modules. During service onboarding the VS defines a set of vertical services in a vertical service catalog offered to the vertical tenants through service advertisement. To request a vertical service, the tenant sends a service request to the VS, which includes the selection of one or multiple services from the provided catalog including a generic high-level service description. Then the VS translates the high-level service requirements to a service graph, which can be understood as a NFV network service forwarding graph. It can be described by a NSD with specified deployment flavors, including the composition of a set of VNFs/VAs chained with each other to build a nested service (i.e., SFCs) and the resources requirements. To request the instantiation of a service, the VS sends to the SO the service instance instantiation request including the requested service graph. Then, the SO maps the service graph to an MTP network slice by means of orchestration of virtual resources to this slice. This is based on the abstraction provided by the local and federated MTPs

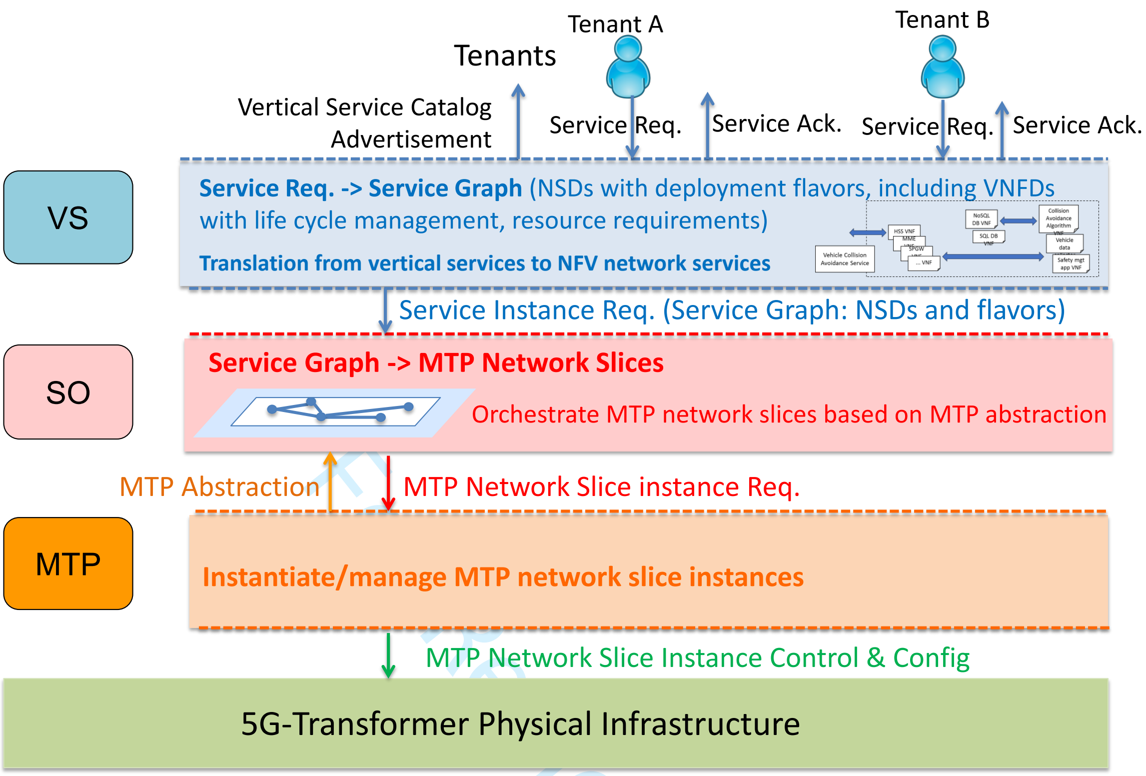


Fig. 2. 5G-TRANSFORMER high level workflow for instantiation of a vertical service

(whenever federation is needed). The orchestration decision for an MTP slice consists of the placement of VNFs over a virtual network as well as deciding the resources to be allocated. The SO will then request the MTP to instantiate the MTP network slice instance. The MTP is responsible for the actual allocation/instantiation/control/configuration of virtual resources (including networking, computing and storage resources) over the underlying physical infrastructure.

The interworking of these modules is presented in a simplified system view in Fig. 3. A key challenge is to define the interfaces and abstractions (adequate level of details) at different levels in the system. To do so, 5G-TRANSFORMER defines four different Service Access Points (SAPs): VS-SAP, SO-SAP, SOSO-SAP, and MTP-SAP.

The *VS-SAP* interfaces between each vertical slice (described in its slice template) and the vertical slicer (VS) which will do the arbitration between the different vertical slices, and map each slice description into VNF graphs and SFCs.

The VS module then interfaces through *SO-SAP* with the Service Orchestrator (SO) module. The SO-SAP provides the requirements of each slice in terms resource allocation and monitoring. Note that for non-vertical slices, e.g., MVNO slice, the slice interfaces directly through SO-SAP with the SO (i.e., it does not go through the VS module).

The SO module manages the allocation and monitoring of all resources to all slices. It provides an end-point for federation of resources from multiple providers and multiple domains, including its own domain. The SO initially interacts with the VS to get the resource allocation and monitoring requirements and functional description of the vertical slice to be created and deployed. Upon receiving these requirements, the SO will interact with other SOs to provide end-to-end network service delivery. The interfacing to other SO domains is done through the *SOSO-SAP* interface.

The SO module next sends its instructions for resource allocation and monitoring to the underlying MTP module. This is done through the *MTP-SAP* interface. The MTP instantiates and controls the VNFs and MEC resources over physical substrates and optimizes their placement and migration. The MTP also exposes an abstract view of its context through analytics service to the SO for context-aware decisions by the SO.

III. System Design and Key R&D Challenges

A. System Design

5G-TRANSFORMER proposes a novel design of the global system architecture including the functions and pro-

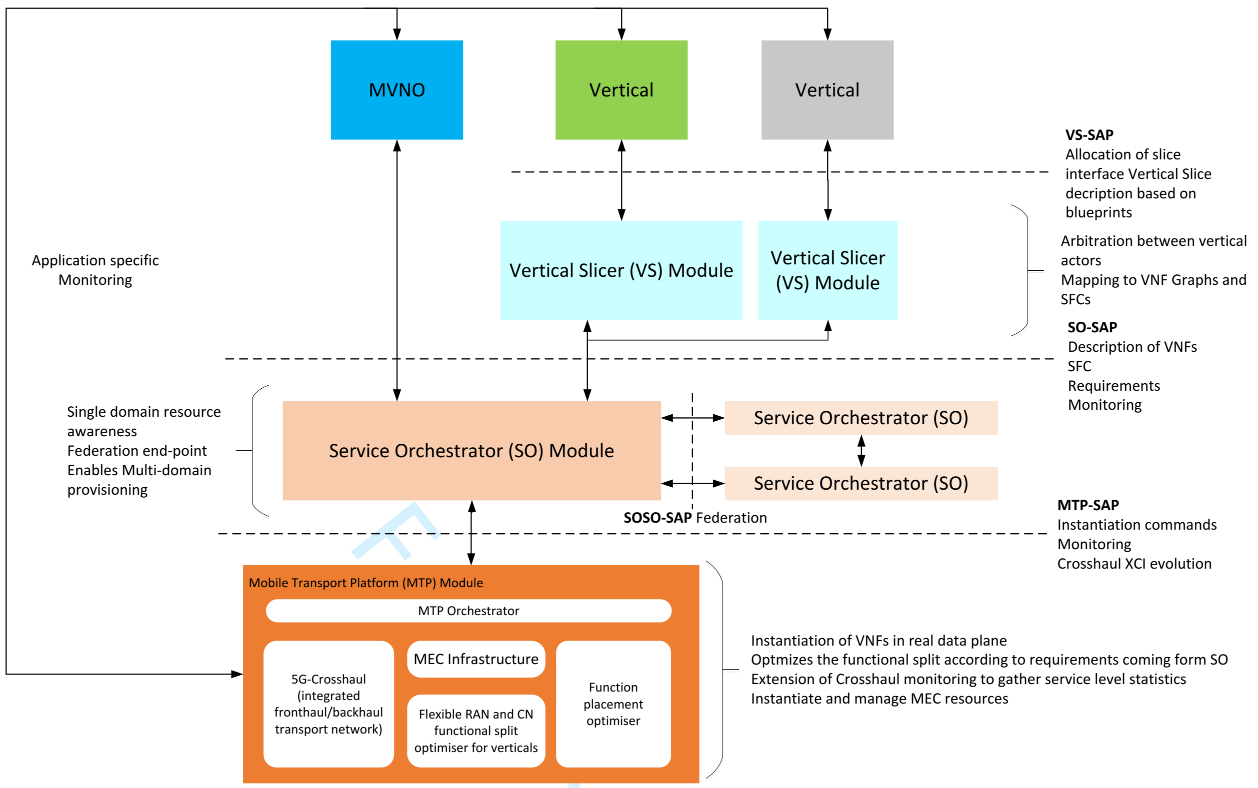


Fig. 3. 5G-TRANSFORMER System View

cedures for creating and managing slices including MEC infrastructure. Beyond an evolved 4G/MEC architecture, 5G-TRANSFORMER proposes an open and flexible transport and computing platform at the "5G Edge" tailored for verticals. It provides different levels of abstractions and ways for the composition and orchestration of services on individual network slices. Moreover, it leverages on the concept of network slicing and virtualization together with native SDN and NFV control to flexibly distribute VNFs in MEC and Cloud platforms. Abstractions levels allow "*as a service*" resources provisioning for verticals' applications; slicing creation with required network functions and SLA; and processed/filtered monitoring features. To this end, we are considering the design of different levels of resources and service abstractions, their inter-relations, interfaces and APIs, instantiation mechanisms and orchestrating verticals suppliers' services like if they would have managed a dedicated infrastructure. In order to build such an architecture, our idea is to extend the ETSI MANO [1] base design adding new functional building blocks, namely the Vertical Slicer (VS, Section III-B) and the Service Orchestrator (SO, Section III-C) interworking with the Mobile Transport Platform (MTP, Section III-D). Such a system will be able to allow the creation of vertical suited slices including integrated fronthaul/backhaul and computing resources (e.g., MEC/Cloud Services). At the same time, this architecture will enable new business models around the trading of network slices to verticals.

B. Vertical Slicer

The VS is a new component on top of the SO to create customized slices based on blueprints. Thereby, verticals can reduce significantly the time to create services. This approach requires complex mechanisms for automatic service decomposition to translate a blueprint into a set of network graphs and requirements, algorithms for the dynamic and flexible placement of vertical functions and abstract monitoring mechanisms to enable SLA verification to verticals.

The main target of the vertical slicer is to provide an easy-to-use interface to the vertical sectors for deploying their tailored services.A vertical describes its services through service templates or blueprints, which include the definition of service graphs, vertical functions, traffic flows, and connection points. As an example, an LTE IoT service may be defined as such a blueprint. These templates must be designed in a way understandable by verticals, i.e., use their domain-specific terminology, and may be integrated with essential services provided by the platform. The deployment and orchestration of vertical services is therefore based on such templates, namely vertical service descriptors. After defining such VSD, the VS contacts the SO to deploy the service on the transport platform. The VS is also in charge of among services of different verticals and resources at deployment stage and throughout the lifetime of services via continuous service monitoring.

We expect only few verticals to have the technical expertise to create the VSDs for deployment and orchestration on their own. Proper guidance is hence required and two approaches are considered:

(1) Basic interfaces (e.g., ONF Transport API [10]) compose the services. The result is a service graph similar to a forwarding graph from NFV. Given the higher level of details required, such an approach is more suited to verticals willing to orchestrate their own services.
(2) A set of essential services are used as building blocks to compose more complex services. To simplify service graph development, templates or blueprints can be used by a vertical. This approach is more suited to verticals not being experts in NFV.

Both approaches require the extension of existing orchestration mechanisms. Additional parameters will be used to describe the service graphs for verticals, such as required service availability, real-time computation capabilities, or low latency communication. In addition, when deploying a new service on a large geographical scale, there is no guarantee that the required resources are available throughout the area. In such a case, the VS needs to arbitrate the resource contention among different vertical services. The VS relies on an abstracted view of the infrastructure and deployed services provided by SO and MTP to prevent duplicate or conflicting resource allocations.

C. Service Orchestrator

The SO is in charge of end-to-end Service Orchestration and Federation of transport networking and computing resources across one or multiple MTP domains and manages their allocation to different MTP slices. The SO receives the service requirements via the SO-SAP interface from M(V)NOs and/or vertical industries. The SO provides E2E network service delivery according to the network service requirement provided by the VS or MVNOs through deciding the optimal resource allocation and VNF/VA placement and in turn instructing the configuration of resources of the local MTP and federated MTP domains.

Service orchestration is focused on managing, instantiation, and migrating VNFs/VAs at local, edge and cloud level. The problem of placing VNFs/VAs to select the nodes over the path that minimizes the overall latency can be tackled by heuristics and mathematical programming techniques.

SDN techniques are a valuable tool to support orchestration, especially in the case of highly mobile users. As a case in point for the sake of providing an intuitive validation of some of these concepts, we consider a sample network scenario (shown in Fig. 4) featuring an SDN-based backhaul network interconnecting Points of Access (PoA) on the RAN. A vertical requests a virtual CDN service with enhanced mobility support. The CDN service is provided through VNFs deployed on compute nodes connected to the SDN-based backhaul. A Distributed Mobility Management (DMM) service monitors the movements of the UEs and, if a change of PoA is detected, it (*i*) instantiates a new CDN node nearer to the new PoA and (*ii*) it reconfigures the SDN backhaul to route the flow to the new CDN node. In a legacy network, this procedure would be accomplished using Proxy

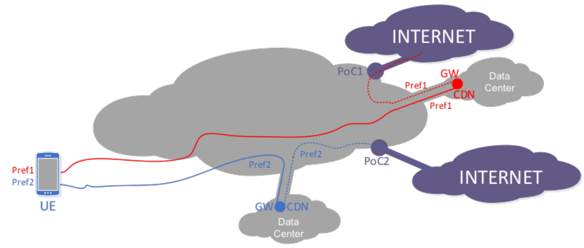


Fig. 4. Emulated scenario

Mobile IPv6 (PMIPv6) [11], a tunnel-based solution with well-known scalability issues.

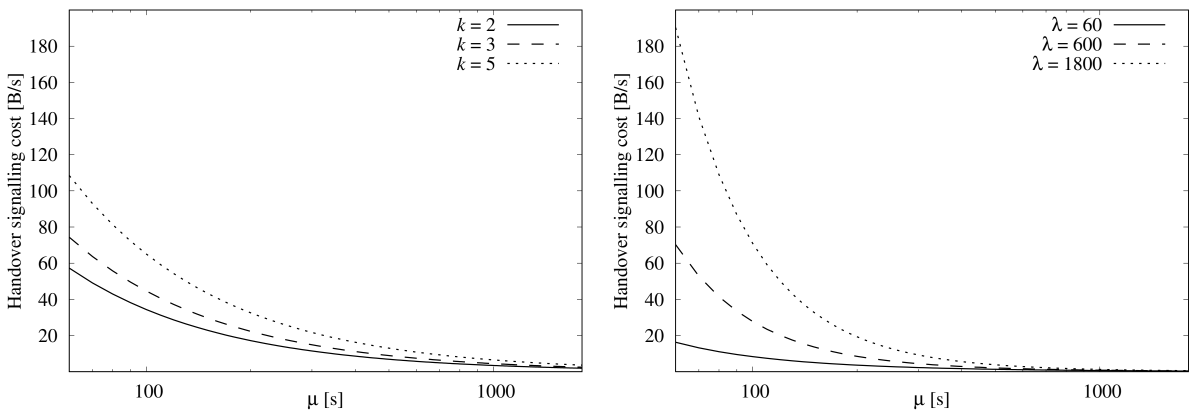
We have emulated the scenario using a set of interconnected OpenFlow Ethernet switches with a WLAN interface working as Point of Access [12]. The forwarding is based on a direct modification of flow tables using standard OpenFlow rules. Results show that the SDN-based solutions lowers the handover signaling cost compared to the PMIPv6 solution. Fig. 5(a) highlights a minimal performance degradation as the number of SDN switches (k) increases (μ represents the mean of the exponential time between MN handovers). If PMIPv6 is used – see Fig. 5(b) – the handover cost ramps up as handovers are more frequent, for different values of λ, the mean of the exponential interval that a tunnel remains active.

Moreover, automatic network service management and self-configuration algorithms (e.g., failure recovery) are also required to adapt to network changes and special events triggered by the monitoring platform [13].

In case that the SO detects that one MTP domain alone has no enough infrastructure resources to orchestrate the required service, it interacts with other SOs via the SOSO-SAP interface to compose service federation across multiple administrative domains. In this case, the SO will dynamically discover the available administrative domains by exchanging the view with the SOs of the neighboring domains, and negotiate with them to decide which administrative domains can be federated together to provide an end-to-end service orchestration ensuring the desired SLAs.

Finally, to ensure the service requirements to be fulfilled, a flexible monitoring platform is required to collect and process consolidated monitoring data from multiple MTPs to monitor end-to-end infrastructure services to support vertical service management at run time. It will operate over multiple domains acting as a consumer of the monitoring services exposed by the MTPs. To collect the monitoring data, service aware methods for multi-domain infrastructure monitoring are used. These methods, include procedures for periodic, on-demand or per-subscription collection of the monitoring data, according to vertical-specific requirements. The platform will offer a set of APIs for verticals to acquire monitoring data and expose it to the service part, integrating vertical-specific analytics algorithms.

In terms of possible implementation, the SO can be devel-



(a) SDN-based solution

(b) PMIPv6-based solution

Fig. 5. Handover signaling cost

oped by extending existing open source MANO platforms (such as OSM [3], ONAP [4], Cloudify [5]). The monitoring platform can be developed by extending existing open source monitoring tools (e.g., Prometheus [6] Zabbix [7]) and integrating further components for efficient storage and access of distributed data (e.g., Cassandra databases).

D. Mobile Transport Platform

The MTP consists of the actual infrastructure (physical or virtual) over which vertical slices are created. The MTP solution is based on the ETSI NFV Management and Orchestration (MANO), to support vertical services as described next:

- Receiving service requirements including MEC service parameters (e.g., amount of processing, bandwidth, latency of the services, resource availability and hardware characteristics) from the SO.
- Identifying the geographical location of servers working on a suitable abstraction view that allows cross optimization of mobile, transport, and computing. To deal with user mobility, the selection of servers will be based on a novel method that considers the geographical area where the user accesses the service and accordingly enables a dynamic placement of servers.
- Triggering the Virtual Infrastructure Manager (VIM) for configuration of servers in data-centers having radio and transport resources for connectivity and, if necessary, extend the VIM configuration process to include the information about the connectivity among the data-centers provided by radio and transport.
- Configuring the Virtual Function (VF) and, when needed, also the radio and transport resources by triggering the corresponding controllers.

In the following lines, we present the details on the operation of the MTP and its relation with the VS and the SO. The MTP exposes to the SO a suitable abstract view of the processing and storage available resources, allowing the SO to select them according the requirements received from the VS. The abstracted view exposed to the SO by the MTP, includes not only the processing and storage resources allocated to the Vertical, but also the virtual links used to connect those resources. With this abstracted view, the MTP is able to translate it to the corresponding requirements for the radio/mobile and transport composing the selected virtual links. In a second step, the MTP selects and configures the related physical resources. Given that the chain of the nodes composing the mobile communication (e.g., the Distributed Unit and the Centralized Unit in a functional split) are connected by transport links/networks, the selection of the current physical resources within the MTP is based on an implementation-dependent cross-optimization among mobile and transport resources.

The presented 5G-TRANSFORMER architecture allows the vertical to ignore the detailed requirements of the infrastructure that provides the services (i.e., the mobile-transport infrastructure), while simplifies the operations on the mobile and transport infrastructure that can be operated as separated layers interacting in a sort of client server relationship. Moreover they can evolve independently to each other in future releases; and they can belong to different owners/providers.

[3]Open Source MANO, https://osm.etsi.org/
[4]ONAP, https://www.onap.org/
[5]Cloudify, https://cloudify.co/
[6]Prometheus, https://prometheus.io/
[7]Zabbix, https://www.zabbix.com/

IV. Summary and Outlook

5G systems gives rise to a wide range of vertical industries with very diverse and stringent service requirements. To enable this vision, the 5G-TRANSFORMER approach proposed in this paper is to blend together SDN, NFV and MEC technologies to create logical infrastructures for meeting the networking and computing requirements of vertical industries. In particular the ones requiring low-latency such as automotive, eHealth and media. The 5G-TRANSFORMER solution therefore builds on three pillars: (*i*) Virtualization of the mobile transport network infrastructure; (*ii*) Network Slicing enabling per-slice management of the virtualized resources; and (*iii*) Integration of MEC to enable the deployment of low latency services and VNFs at the edge.

The 5G-TRANSFORMER solution combines three novel building blocks, namely:

1) Vertical Slicer as the logical entry point for verticals to support easy creation and management of the slices.
2) Service Orchestrator for end-to-end service orchestration, federation of transport networking and computing resources from multiple domains, and their allocation to slices.
3) MTP as the underlying unified transport stratum for integrated fronthaul and backhaul networks.

The design of these three building blocks together with the global system architecture are the main research challenges tackled. The targeted solution includes: (*i*) procedures for creating and managing slices including MEC infrastructure; (*ii*) the definition of vertical service descriptors based on blueprints and an easy-to-use interface for verticals to deploy them on the slices of the underlying platform; (*iii*) the design of Network Service Descriptors in the SO and its interfaces to VS, MTP and other SOs; (*iv*) novel service orchestration and federation algorithms to optimize resource allocation across one or multiple MTP domains, tailored for different slices; (*v*) focusing on transport abstractions supporting efficient functional splits of virtualized radio software stacks.

The proposed 5G-TRANSFORMER solution will be developed, validated and demonstrated with 5G use cases from three vertical industries: automotive, eHealth and media & entertainment.

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