A Mobile Transport Platform Interconnecting VNFs over a Multi-Domain Optical/Wireless Network: Design and Implementation

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***Abstract*—Vertical industries see 5G networks as an appealing context to enhance their offered services, capabilities, and products. In the 5G context, such services are formed by a set of Virtual Network Functions (VNFs), likely deployed across distributed datacenters (DCs). The interconnection of remote VNFs is done over a wide area network (WAN) transport infrastructure. In a generic scenario, the transport network may entail heterogenous technologies such as optical, packet, and wireless. Hence, the goal is to provide the orchestration mechanisms being able to dynamically compute, select and configure the different kind of needed resources to effectively accommodate NSs while satisfying their specific requirements. This problem has been investigated in the EC 5G-TRANSFORMER (5GT) project. One of the outcomes of this project was to provide a unified platform providing the automatic deployment of NSs for different verticals over a shared infrastructure. A key element of this 5GT system is the Mobile Transport and Computing Platform (5GT-MTP), which provides the means to allocate heterogenous (network and cloud) resources to roll out targeted NSs. Herein we describe and experimentally validate an implementation of the 5GT-MTP controlling a multi-layer network infrastructure combining optical, packet, and wireless technologies connecting VNFs distributed into two NFVI-Points of Presence.**

***Index Terms*—5G, NFV/SDN, optical-wireless transport network, automation, interfaces**

I. Introduction

5G network capabilities entail high dynamic, agile and programmable network services (NSs) with specific and tailored requirements (e.g., bandwidth, latency, etc.). Indeed, this is transforming the traditional telco ecosystem, opening the door to new stakeholders. Among them, we find the *vertical industries* (e.g., automotive, media, eHealth, etc.), which are eager to leverage the envisaged benefits of 5G networks. The understanding of the vertical needs over the 5G infrastructure is receiving significant attention in both the industrial and research communities. In this context, the EC 5G-TRANSFORMER (5GT) project [1] investigated, deployed and validated a platform to seamlessly support multiple verticals services. To this end, the 5GT project exploits the concepts of both Software Defined Networking (SDN) and Network Function Virtualization (NFV). Thereby, the goal of the 5GT project is to provide the control and orchestration functionality to deploy multiple vertical services into a common underlying infrastructure composed by different datacenters/NFV Infrastructure (NFVI)-Points of Presence (PoPs) interconnected by heterogeneous technological transport domains (e.g., optical, packet, and wireless).

The 5GT platform consists of four key building blocks [2]. The Vertical Slicer (5GT-VS) is the entry point for the vertical industries to request specific services, which are mapped to network slices and network services. The Service Orchestration (5GT-SO) coordinates the end-to-end (E2E) deployment and the lifecycle management of NSs according to the available resources (i.e., compute, storage and network). The Mobile Transport and Computing Platform (5GT-MTP) coordinates the programmability of both the transport stratum and the NFVI-PoP computing, networking and storage resources. In addition to resource allocation, the 5GT-MTP applies abstraction mechanisms, creating *its view* of the available resources [3]. These abstractions homogenise different kind of resources, e.g, optical or wireless links at the transport network, easening the orchestration functions of the 5GT-SO. Finally, the Monitoring Platform (5GT-MON) is in charge of collecting and providing monitored information of the infrastructure and the deployed elements (e.g., Virtual Network Functions -VNFs -, network links, etc.) to the other 5GT elements such as the 5GT-SO and 5GT-MTP. This allows the 5GT platform to ensure the expected service requirements and adopt the required actions to preserve them.

Herein, we focus on the 5GT-MTP element and its supported functions and interactions with other 5GT architectural elements to automatically select the (compute and network) resources when deploying requested NSs. To do that, we rely on our open source implementation of the 5GT-MTP called *mobilE tranport pLatform for multi-tEChnology neTwoRk infrAstructure* (ELECTRA)[1]. ELECTRA has been developed explicitly to design and validate the networking functionalities needed by the 5GT-MTP building block. Specifically, this work addresses *(i)* the architectural design description and *(ii)* the experimental validation of the *ELECTRA* 5GT-MTP implementation aiming at automatically orchestrating networking resources in different NFVI-PoPs and in a multi-layer transport network combining optical, packet and wireless domains [4]. Such an orchestration is needed when VNFs of

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[1]https://gitlab.cttc.es/cttc-cnd/ELECTRA.git

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an NS are distributed in different NFVI-PoPs.

In this regard, the interconnection of NFVI-PoPs through a transport network infrastructure in an SDN/NFV context has been object of study in contemporary EC projects such as Metro-Haul [5] and 5G-TANGO [6]. Examples of these approaches are found at [7] and [8], respectively. A difference between these approaches and ours stems of the fact that the other approaches present a high degree of integration with the used Management and Orchestration (MANO) platform. However in our case, in the 5GT architecture, the 5GT-SO and the 5GT-MTP are decoupled and interact via the interfaces defined in the ETSI NFV IFA005 [9] specification and the recommendations available at ETSI NFV IFA022 [10] report. Hence, the 5GT-MTP is agnostic of the MANO platform used by the NS orchestrator element, the 5GT-SO in our scheme.

The rest of this paper is organized as follows. Section II provides the description of the 5GT-MTP ELECTRA module. Section III focuses on describing the workflows between the 5GT-SO and the 5GT-MTP to deploy interPoP connectivity during the NS instantiation procedure. Next, in section IV, it is reported the experimental validation of the devised 5GT-MTP functions, operation and interfaces. Finally, Section V draws the main conclusions with remarks for future work.

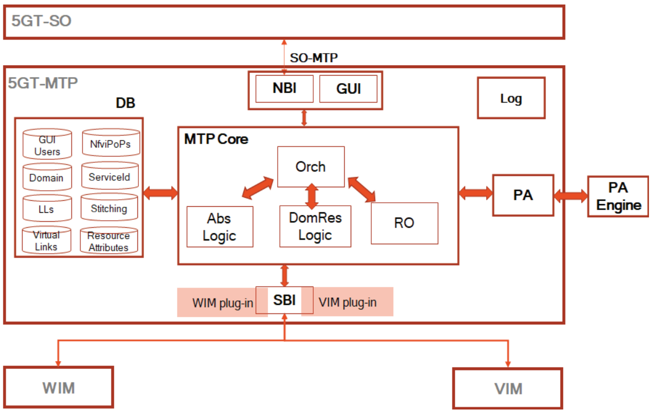

Fig. 1. ELECTRA Software architecture

II. 5GT-MTP Software Implementation: ELECTRA

Fig. 1 presents the software architecture of ELECTRA. This implementation of the 5GT-MTP building block shows that the 5GT architecture is sufficiently generic and flexible to accept different MTP implementations as long as external interfaces are respected, e.g, Northbound Interface (NBI). Hence, infrastructure providers could reuse its existing physical resource managing systems to interact with the 5GT stack. ELECTRA presents the following building blocks:

•MTP Core module: it implements the management and configuration of network resources at the underlying Virtual Infrastructure Manager (VIM) and Wide Area Infrastructure Manager (WIM) entities. It contains four sub-modules:

◦ *Orchestrator* (Orch): it is in charge of controlling the workflow of operations inside the 5GT-MTP.

◦ *Domain Resource Logic (DomRes Logic)*: it retrieves the physical resources for both networking and computing elements from the WIM and VIM entities. Then, it combines this information with the stitching information available in the database (DB) module and transforms it into graphs elements to be processed by other sub-modules.

◦ *Abstraction Logic (Abs Logic)*: this sub-module implements the logic required to pass from a detailed physical representation of resources to a *simplified* view, which allows hiding specificities of the underlying infrastructure [3]. An example of this operation is the transformation of sets of chained transport network links sharing some aggregated characteristics (e.g, bandwidth, latency) into logical links (LLs) that represent point-to-point links interconnecting NFVI-PoPs.

◦ *Resource Orchestrator (RO)*: this sub-module implements the methods to create/modify/remove the actual resources in VIM/s and WIM/s, supporting the NS lifecycle phases (instantiation, modification, termination ,...). It also interacts with the Placement Algorithm (PA) module.

•NorthBound Interface (NBI) and GUI: this module receives and validates the requests from the 5GT-SO. These requests follow the ETSI GS NFV-IFA005 specification [9] to handle requests related with VIM operations (e.g., creation of VNF, creation and allocation of network resources to support VLs), and are inspired in the ETSI GR NFV-IFA022 report [10] to handle requests related with WIM operations, such as the configuration of interconnections of NFVI-PoPs through the underlying transport network. This NBI is implemented as a Python REST server using Swagger. The classes included in this REST framework allow the creation of a web GUI to access the 5GT-MTP functionalities.

•SouthBound Interface (SBI) module: it implements the logic to communicate with the underlying VIM and WIM entities. In particular, ELECTRA is prepared to use OpenStack software [11] as VIM entity and a transport SDN controller using Control Orchestration Protocol (COP) [12] as WIM entity. Other VIM/WIM entities could be supported through a wrapper system, as the 5GT-SO does to support multiple open source MANO platforms, like OSM or Cloudify [13].

•Database (DB) module: this module manages the different DBs containing the system information. Currently, the available databases are:

◦ *Domain List*: it includes the registries of the WIM, VIM entities in the underlying infrastructure and their corresponding IP addresses and access credentials.

◦ *Nfvi PoPs*: it contains association information between NFVI-PoPs and the registered VIMs they belong to.

◦ *Resource Attributes*: it includes resource data in terms of RAM/CPU/storage for each registered VIM/NFVI-PoP.

◦ *Logical Links (LLs)*: it includes the description of the available link abstractions representing the available interconnections between registered NFVI-PoPs.

◦ *ServiceId*: it contains the identifiers of all active interNFVI-PoP connections.

◦ *Stitching*: it registers the connections between the transport network managed by the WIM and the available NFVI-PoPs of a VIM and the connections between the transport networks managed by different WIMs.

◦ *Virtual Links (VLs)*: it includes information related to the networks created in the different VIMs to support the virtual links expressed in the network service descriptor (NSD) according to the VNF distribution determined by the placement algorithm at 5GT-SO. Between this information, this DB keeps tracks of the used VLAN identifier, the Classless InterDomain Routing (CIDR) value, and IP addressPools[2].

○ *Users*: it contains the credentials of allowed users.

• Placement Algorithm (PA) module: this module is in charge of requesting the calculation of physical paths in the underlying transport network satisfying the requirements expressed in the request done by the RO sub-module. It communicates with the *PA Engine*, an external process doing the actual path calculation, through a predefined API. Herein, the used baseline algorithm in the PA Engine is based on a K-shortest paths (modifying the Yen algorithm) to jointly optimize a set of additive performance objectives such as number of hops, overall distance, etc.

• Logging (Log) module: this module registers all the operations done in the different processes of the 5GT-MTP.

III. INTERCONNECTING NFVI-POPS THROUGH 5GT-MTP

This section presents the operations performed by the 5GT-MTP block related to networking resources in the datacenters and in the WAN to achieve the interconnection of VNFs deployed in different NFVI-PoPs. These operations are two: *(i)* the creation of intraPoP networks at the VIM level to attach allocated VNFs, and *(ii)* the instantiation of connectivity services between NFVI-PoPs performed at the WIM level. These operations are done in different moments of the NS instantiation workflow followed by the 5GT-SO [13].

Fig. 2 presents the workflow followed by the 5GT-MTP to create intraPop networks supporting the VLs expressed in the NSD. The 5GT-SO makes an *Allocate Virtualised Network Resource operation* request to the 5GT-MTP following the format specified at IFA005 [9] (message *[1]* of Fig.2). This request is done previous to the VNF allocation operation triggered by the 5GT-SO to the MANO platform. Between other parameters, the 5GT-SO specifies a network name and a VIM where the required intraPop network needs to be created. This network name is unique for the combination NS instance and VL (to allow simultaneous instances of the same NS). This request arrives to the *Resource Orchestrator* sub-module. It checks whether this network name entry is present in the DB, and if not, it determines the VLAN identifier, the CIDR and the adressPool parameters to use in this VIM to instantiate the network (operation *[2]* of Fig.2). If the network name is present in the DB, then it retrieves the parameters from the DB and creates the network at the specified VIM.

Differently to [7], the 5GT-MTP uses the same VLAN id in all NFVI-PoPs for the same intraPoP network mapping the VL. This avoids swap operations of VLAN ids in the transport network, simplifying the configuration of forwarding operations and the forwarding operations themselves. For each NFVI-PoP sharing the same *network name*, the 5GT-MTP assigns a different addressPool, which serves to avoid IP address collision because network DHCP clients are configured in disjoint sets of IP addresses at the different involved VIMs.

[2]In ELECTRA, the addressPool is represented as an integer value determined by the 5GT-MTP Orchestrator sub-module representing a set of IP addresses within a CIDR

Fig. 3 presents a simplified workflow followed by the 5GT-MTP to create interPop connectivity between NFVI-PoPs sharing intraPop networks with the same *network name*. In this case, after the VNFs have been allocated, and its ports have been attached to the previously created intraPoP networks, the 5GT-SO sends a request to the 5GT-MTP with an array of LL descriptions demanding the interconnection of those VNFs sharing a VL and placed in different NFVI-PoPs (message *[1]* of Fig.3). Listing 1 presents this request, which has been defined within the context of the 5G-TRANSFORMER project based on the IFA022 report because the IFA005 specification only relates to the *Orchestrator-VIM* interface, not covering networking aspects with WIM entities. Listing 2 presents the response to this request (message *[13]* of Fig. 3).

```
Request: InterPop Connectivity creation
URL =  "http://5gt-mtp_ip:port/
5gt/mtp/v1/abstract-network-resources"
body: { "logicalLinkPathList": [
            "logicalLinkAttributes": {
                "srcGwIpAddress": string,
                "dstGwIpAddress": string,
                "localLinkId": string,
                "remoteLinkId": string },
            "reqBandwidth": string,
            "reqLatency": string,
            "metaData": {
                {"key": "srcVnfIpAddress",
                "value": string},
                {"key": "dstVnfIpAddress",
                    "value": string},
                {"key": "networkName",
                    "value": string} }
            ],
        "interNfviPopNetworkType": string,
        "networkLayer": string,
        "metadata":{
            "key": "ServiceId",
            "value": string }  }
```

Listing 1: 5GT-SO request to 5GT-MTP to establish interPoP connectivity

Next, we comment three aspects with respect to the workflow of Fig.3 and the request triggering the interPop connectivity. First, the content of *metadata* field in the interPoP connectivity request contains the source and destination IP addresses of the VNF ports it connects and the network name they share. Thanks to the network name, the 5GT-MTP is able to recover from its DB the associated parameters of the intraPoP network (VLAN Id, CIDR and addressPool) and verifies that the specified IP addresses are within the registered CIDR, hence validating the request. Second, once the request is validated, the 5GT-MTP incorporates in the subsequent request to the involved WIMs, not only the VLAN Id but also, the specified IP addresses of the VNFs to configure the forwarding elements (FEs) available in the transport network (message *[10]* of Fig.3). Thanks to the use of these two parameters (VLAN Id and IP addresses), the 5GT platform supports the location of VNFs of the same NS in more than two NFVI-PoPs interconnected by LLs which are mapped to partially overlapped physical paths. Third, the 5GT-MTP generates four requests (message *[10]* of Fig.3) to the involveld WIMs for each element of the *logicalLinkPathList* in the interPoP connectivity request, allowing bidirectional ARP and IP traffic.

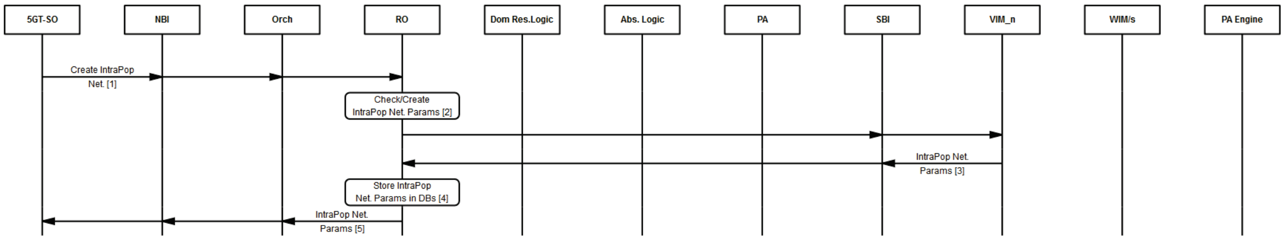

Fig. 2. 5GT-MTP Workflow for the interconnection of NFVI-PoPs: intraPop network creation

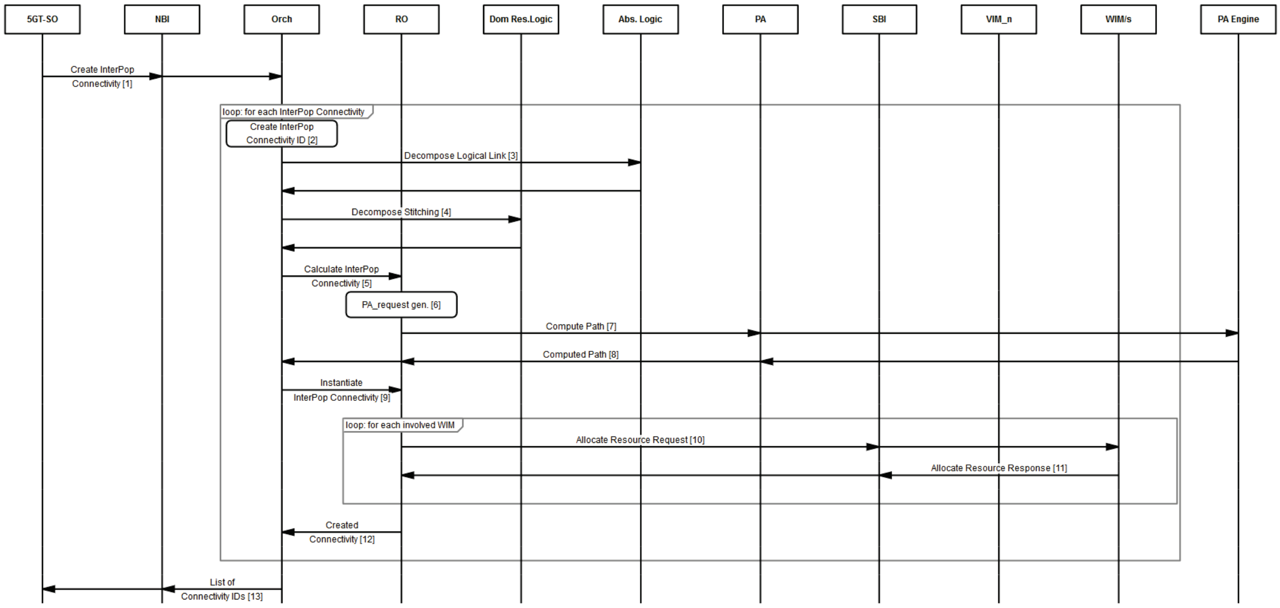

Fig. 3. 5GT-MTP Workflow for the interconnection of PoPs: interPop connectivity creation

```
Request: Response to interPop Connectivity
body: { [ { "key": "interNfviPopConnectivityId",
            "value": string },
          { "key": "interNfviPopNetworkSegmentType",
            "value": string } ] }
```

Listing 2: 5GT-MTP InterPoP connectivity response

IV. Experimental validation

This section describes the infrastructure managed by the 5GT platform, in which we demonstrate how the ELECTRA prototype manages the interconnection of VNFs allocated in NFVI-PoPs placed at both ends of a multi-technology transport network. In the presented validation, interconnected VNFs belong to different nested NSs, as the 5GT platform is able to handle composite NSs [14].

Fig. 4 shows the real experimental setup. The 5GT platform, and more specifically the presented *ELECTRA (5GT-MTP)* block, manages two NFVI-PoPs controlled by independent instances of OpenStack (Devstack all-in-one Queens Release) acting as VIMs. The NFVI-PoPs are interconnected by a multi-technology transport network combining a wireless mmWave/WiFi (IEEE 802.11ad/802.11ac) ring of four elements with a multi-layer network combining optical and packet switching technologies. This multi-layer network consists of first, three aggregation packet-switched Ethernet networks with tunable optical interfaces as edge nodes. Second, an all-optical DWDM mesh network counting with two colorless Reconfigurable Optical Add/Drop Multiplexers (ROADM) and two Optical Cross-Connect (OXC) nodes, interconnected through five bidirectional optical links.

A hierarchy of SDN controllers manages this multi-technology transport network. On top of it, the parent controller acts as Wide Area Infrastructure Manager (WIM), performing the E2E SDN transport orchestration. The parent controller follows the IETF Application-Based Network Operation (ABNO) [15] architecture. Each of the mentioned *segments* is controlled by its dedicated technology-aware SDN controller, acting as child controller. The different elements in the control hierarchy use a unified interface both at the NBI/SBI, the COP protocol [12], a precursor of the ONF T-API [16]. Child controllers are based on open source SDN solutions like Ryu or OpenDayLight using a COP-based plugin to interact with the parent controller. More details of this transport network and its managing SDN system can be found at [4].

On top of Fig. 4, we can observe the composite NS used to validate the proposed approach. The composite NS consists of

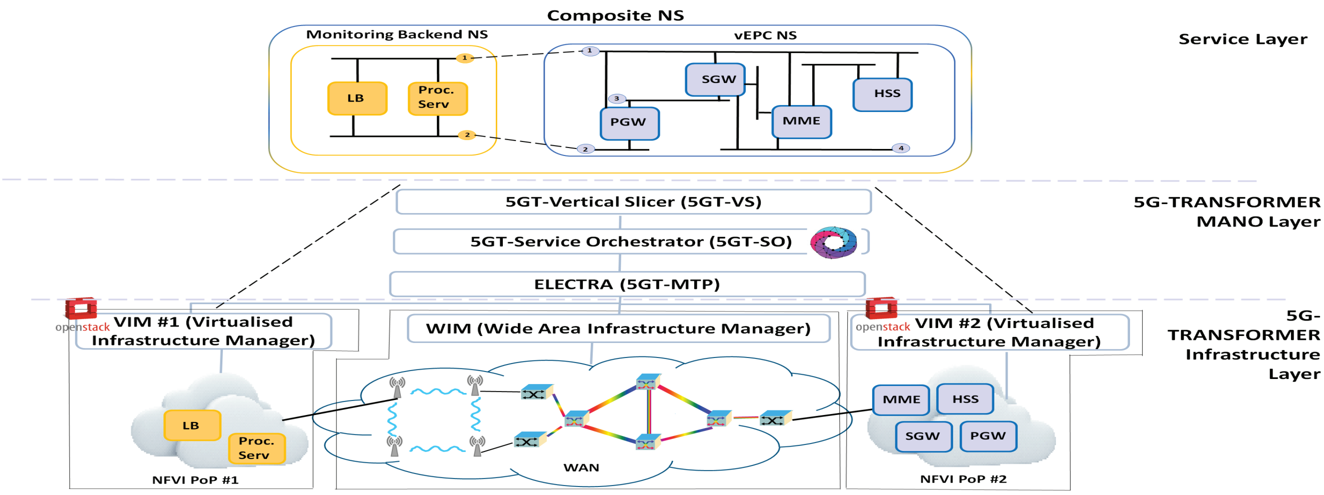

Fig. 4. Experimental Setup for Interconnection of NFVI-PoPs using the 5G-TRANSFORMER platform and deployed composite NS

two nested NSs. First, a NS emulating a Virtualized Evolved Packet Core (vEPC). This NS consists of four VNFs, namely MME, HSS, SGW and PGW. The second nested NS is a monitoring backend NS consisting of two VNFs, namely a load balancer (LB) and a processing server (Proc. Serv).

Fig. 5 depicts an extract of exchanged messages between the 5GT-SO and 5GT-MTP and between the 5GT-MTP and the WIM controller (i.e., pABNO) to allocate resources in an LL interconnecting the two available NFVI-PoPs. These messages are exchanged towards the end of the composite NS deployment process as part of the composite NS instantiation workflow [14]. They serve to set the required interconnection between VNFs of the different nested NSs. As it can be seen in Fig. 4, LLs traverse the multi-layer optical and the wireless networks. In this experimental validation both the 5GT-SO and the 5GT-MTP run in the same host. Message labeled as 1 in Fig. 5 issues the request from the 5GT-SO to the 5GT-MTP (message *[1]* of Fig.3). The message includes the description (JSON-encoded) of the list of selected LLs as presented in Listing 1. This is reflected in the details of message 1 in Fig. 5, showing for a given LL the *src* VNF IP address, the bandwidth and latency to be guaranteed, the service Id, etc. In the described scenario, the 5GT-MTP manages a *logicalLinkPathList* array of ten elements to interconnect the set of VNFs in the nested NSs according to the scheme presented on top of Fig. 4.

The pair of messages labeled as 2 provide the interactions between the 5GT-MTP and the WIM controller (pABNO). The purpose is to update the WAN infrastructure vision (i.e., topology and resource availability) kept at the 5GT-MTP DBs. This information is used as an input to trigger the PA mechanism. The PA triggering is made by the request message numbered as 3 in Fig. 5 (message *[7]* of Fig.3). The PA algorithm running at the PA Engine seeks for both a feasible WAN path and available resources (i.e., packet, optical, etc.) to accommodate resources at targeted LLs ensuring their requirements in terms of bandwidth and latency. If the PA succeeds, the computed WAN resources supporting this LL are allocated. This is handled relying on the COP-based request issued by the 5GT-MTP to the pABNO (message labeled as 4 in Fig. 5), which corresponds to message *[10]* of Fig.3. The goal is to configure the involved FEs via the pABNO controller. Between the parameters included in this call, the 5GT-MTP includes the *VLAN Id* tag, which is not present in the message labeled as 1. The 5GT-MTP has determined this tag previously when creating the IntraPop network. This tag can be easily retrieved from the DB thanks to the *networkName* metadata parameter present in message 1. The payload of this 5GT-MTP - pABNO request message (labeled as 4) is detailed in Fig. 5. In the details of this message, we can see how the commented *VLAN Id* tag is included in the *match* object field. For the sake of completeness, forty 5GT-MTP - pABNO requests are sent to accomplish the required data flow configurations requested by the message labeled as 1. The flow configurations specify how to handle at each network FE the ARP and IP traffic in both directions. Actually, message 4 of Fig. 5 shows that it corresponds to an ARP request. Then, the pABNO segments the configuration requests sent by the 5GT-MTP and forwards them to the corresponding child controller. Recall that a child controller governs a specific set of FEs within a particular technology-transport network segment.

The total elapsed time to configure the transport network according to these forty requests between 5GT-MTP and pABNO is of 40.1 seconds. These results are aligned with those presented in [4]. However, that work evaluated a simpler case only dealing with the interconnection of a less complex set of virtual computing resources (VMs) through the described transport network but without integrating the operations into the complete instantiation process of an NS. Hence, we validate that the generic design of ELECTRA allows the integration of the mentioned previous work [4] into the 5GT platform. In this way, we show that infrastructure providers could reuse its existing physical resource managing systems to interact with the 5GT stack.

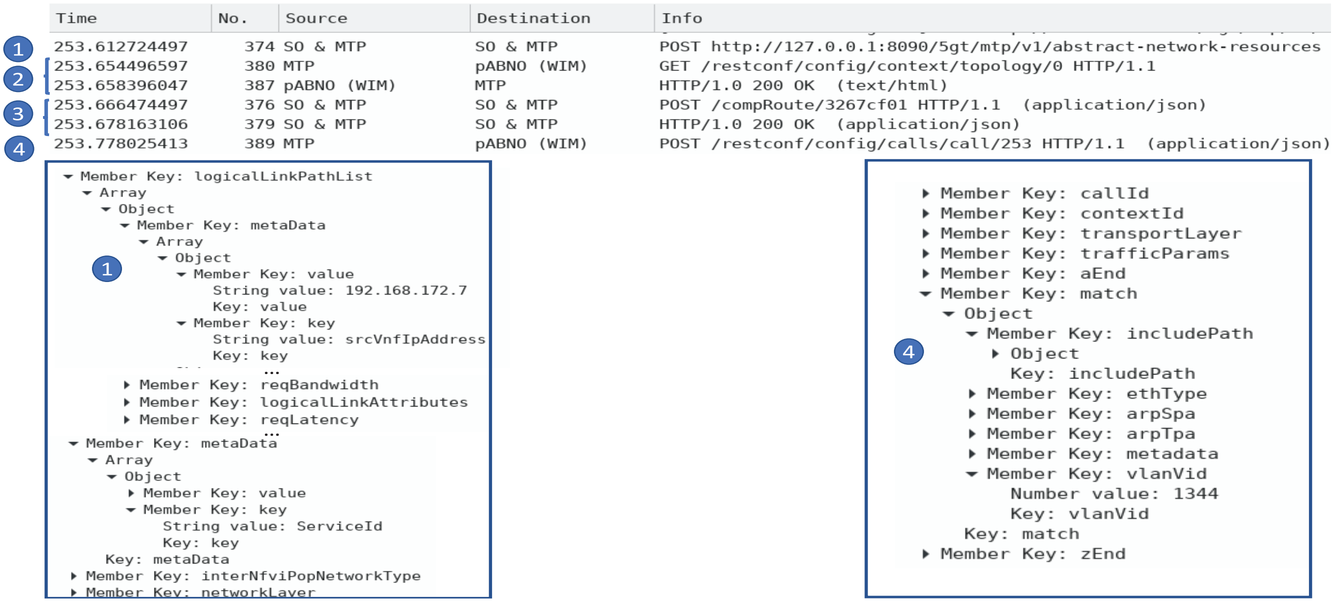

Fig. 5. Captured control messages for both SO-MTP and MTP-pABNO (WIM) APIs

V. Conclusions

This paper presents the design of the ELECTRA module, implementating the 5GT-MTP block of the 5GT platform. ELECTRA focuses on the required networking procedures to achieve the automatic interconnection of VNFs deployed in different NFVI-PoPs. The followed design allows a flexible NS deployment, whose objective is to provide a better use of computing/networking resources while satisfying the requirements of vertical industries. The design of the interfaces of the 5GT-MTP building block is based on the ETSI NFV work, namely, the ETSI NFV IFA005 specification and the ETSI NFV IFA022 report. Based on the latter, this paper presents the workflow and the designed API to request the interconnection of VNFs in different NFVI-PoPs through the underlying transport network. ELECTRA has been validated in a multi-technology transport network featuring a multi-layer optical network and a wireless domain interconnecting two different NFVI-PoPs placed at both edges of the transport network. Around forty seconds are needed to establish a total of 40 requests (accounting bidirectional ARP and IP traffic) interconnecting the VNFs of different nested NSs belonging to the same composite NS according to the network scheme expressed in the associated network service descriptor. This value is in line to contribute with the 5G target of reducing the service creation time from days/hours to minutes. Due to its generic design, ELECTRA is going to be further developed in the context of the EC 5Growth project [17] to include Radio Access Network (RAN) capabilities.

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