Control and Orchestration Solutions for End-to-End Time Sensitive Services in Future 6G Networks

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ABSTRACT
The provisioning of time sensitive end-to-end services in future 6G networks imposes multiple technical challenges, spanning from the data plane to the control and orchestration planes. In particular, the automation of the provisioning and maintenance of connectivity services with deterministic constraints over multiple technology/administrative domains requires control and orchestration solutions able to assure the strict time service requirements. In line with that, the paper investigates some requirements imposed to the control and orchestration planes and it also shows potential enabling architectures for end-to-end service guarantees.
Keywords: Time Sensitive Networks, SDN, control and orchestration, 6G networks.

1. INTRODUCTION

The rise of applications with stringent requirements in latency boundaries and device synchronization, such as augmented reality and Industrial IoT, has led to the development of Time Sensitive Networking (TSN) as a key concept in future 6G networks [1]. In light of this, standardization bodies responsible for various network technologies are working on defining solutions to implement the TSN concept. While the 3GPP is currently defining protocols and data models to implement TSN service configuration over the current 5G infrastructure [2], the IEEE 802.1 standards family focuses on enabling deterministic capabilities to Ethernet, and the IETF is producing several RFCs and drafts to standardize the support of deterministic capabilities over network layers 2 and 3 [3]. To provide end-to-end (E2E) time sensitive services, it is necessary to keep these capabilities between TSN domains. This is the case, for example, of distributed factory floors, where a single application is responsible for controlling production lines placed in different premises, and augmented reality applications, where the image processing is moved from the user device to a data centre. In such scenarios, optical transport networks, with their high bandwidth and by-design deterministic capabilities [4], appear as a promising solution to interconnect TSN domains. However, a proper E2E control and orchestration environment is needed. In this paper, we discuss on extensions to the SDN-based control and orchestration planes to support time sensitive service provisioning across multiple technological domains. While some approaches pull for intent-based mechanisms [5], we propose here a complete architecture where the orchestration layer uses abstracted information about the multiple domains to compute optimized latency-bounded E2E connectivity services. The paper is organized as follows: Section 2 presents the scenario under study and the architectural control and orchestration solution highlighting the required extensions in support of TSN capabilities; section 3 describes the proof of concept (PoC) of the proposed architecture; and section 4 draws some conclusions.

2. CONTROL AND ORCHESTRATION ARCHITECTURE IN SUPPORT OF E2E TIME SENSITIVE SERVICE PROVISIONING

In this paper, a scenario where different TSN domains are interconnected through an optical transport network (Fig. 1) is considered. Emphasising on a particular use case, we assume that deterministic connectivity services need to be established to support the distributed automated production lines of two spare factory floors.

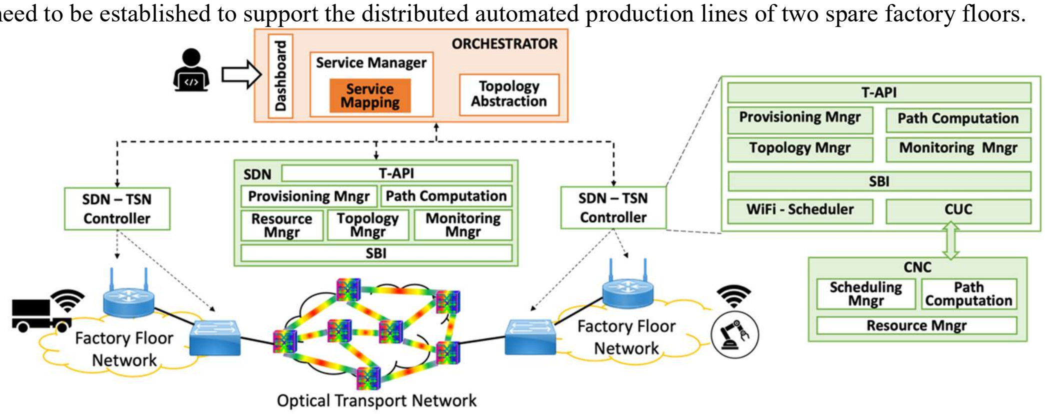

Figure 1. Scenario under study and proposed control and orchestration architecture.

At the data plane level, the factories implement state-of-the-art WiFi and Ethernet TSN-capable access technologies, and are interconnected by a WDM network. In particular, for experimental demonstration purposes, we assume the WiFi and wired Ethernet devices presented in [6] and [7], respectively. For the control plane, an SDN approach is proposed for the different domains involved in the E2E service provisioning. In the factory floor network, an SDN layer sits on top of the TSN-capable data plane. The optical transport network is operated by means of an SDN controller, which has been extended here to cope with the bounded latency requirements posed by the TSN services. On top of the architecture, the orchestrator is responsible for computing the E2E TSN connectivity service deployment across the different technological domains, as well as for supervising the complete provisioning process.

The sub-sections below describe the control and orchestration modules involved in the presented architecture, particularly focusing on the extensions required at each level to meet the requirements imposed to support time sensitive connectivity services.

2.1 SDN-enabled TSN Controller

The IEEE 802.1Qcc defines a control framework for Ethernet-based TSN flows configuration. The main entity of such framework is the Centralized Network Configuration (CNC), which is responsible for scheduling the flows according to their priority and time interval. To enable external entities for the configuration of TSN flows, the CNC implements a Northbound interface (NBI), which is used by the so-called Centralized User Controller (CUC). Hence, the CUC collects the application requirements and enforces data plane configurations via the CNC's NBI.

In order to provide the TSN controller with SDN capabilities, we have designed an SDN controller wrapper (Fig. 1, right). The specific modules residing on the top of the controller, which are devoted to provide the SDN flavour to the control of the factory floor, are: The NBI, the Provisioning Manager (PM), the Path Computation Manager (PCM), the Topology Manager (TM), and the Monitoring Manager (MM).

The NBI collects the connectivity service requests from the orchestration layer. In our case, this interface is implemented by means of the Transport API (T-API [8]), which allows to create enriched connectivity requests, for example conveying latency requirements. The PM receives the connectivity service request and coordinates the provisioning process. First, the PM needs the computed path. Two options are available in this regard. On the one hand, the PM can request a path that meets the requested latency requirements to the PCM. The PCM, in turn, uses the topological information collected by the TM. On the other hand, the orchestrator can send a pre-computed path within the connectivity request. As it will be further detailed, this is the operation mode used in this work. Once the route has been computed, the PM configures the data plane by means of the Southbound interface (SBI). To satisfy the TSN configuration requirements, the SBI implements a CUC that allows for the wired TSN Ethernet flow configuration. The SBI is also equipped with a client to the configuration API of the WiFi access points. In the current version of the controller, topological information is statically configured since topological data collection is not available yet in the APIs of the data plane devices. Such topological information is used by the TM to build a network graph, where the nodes are enriched with information about the size of the queues and their latency capabilities. The occupation of the queues is maintained locally in the controller. To enable the E2E path computation at the orchestration layer, the TM sends summarized topological information to it through the T-API.

2.2 TSN-capable SDN Controller for Optical Transport Network

To enable the TSN capabilities at the control layer of the optical transport network, we have extended our SDN controller [9] to consider the data plane characteristics that impact on the transmission delay, such as the length of the optical links and the switching time of the optical switches. Hence, the SBI of the SDN controller has been extended to collect these parameters. In addition, the TM summarizes such information and sends an abstracted topology containing the information of the transmission delay associated to each link and node, so latency-bounded lightpaths can be properly computed in the optical network domain. As in the case of the SDN-TSN controller, the abstracted topology is sent to the orchestrator through the T-API.

2.3 TSN-enabled Connectivity Service Orchestrator

The provisioning of E2E connectivity services across multiple technological domains that fulfil the requested latency boundaries requires the operation of an upper layer entity, that is, the orchestrator. In this context, the orchestrator is responsible for deploying the requested TSN connectivity service request across the different domains that interconnect each end of the service (e.g., two spare factories in a metropolitan area). To do this, the orchestrator composes an abstracted topology graph of the multi-technological domain scenario and maps the requested service over it targeting to meet the latency requirements. It is worth noting here that different policies can be used to implement such mapping. In this work, we use the orchestration framework presented in [10].

From an implementation point of view, the orchestrator receives the TSN connectivity requests formatted in a JSON template through a REST interface. Such template is used to create a service instance that contains, among other information, the latency requirements associated to the E2E service. The request arrives to the Service Manager (SM) that implements the mapping logic. In this case, the goal is to maximize the number of services to be deployed over the system, and to minimize the usage of the lowest latency queues of the TSN domains [10], assuming that traffic flows with different latency requirements have to be provisioned. The topological information needed to realize such mapping is collected by the Topology Abstraction Manager (TAM) through the T-API, which implements in this case the SBI. Once the service has been mapped, the orchestrator sends the resulting connectivity sub-services into the corresponding technological domain to enforce the required configurations.

3. E2E TIME SENSITIVE SERVICE PROVISIONING WORKFLOW AND PROOF OF CONCEPT

In this section, we experimentally assess the implementation of the extensions presented in section 2. It is worth highlighting here that both the TSN data and control planes standardization for Ethernet and WiFi are still a work in progress, therefore, the control extensions required for these technologies are still not consolidated.

Following a top-down approach, we first illustrate the performance of the orchestrator. In this regard, Fig. 2 depicts a portion of the service template, which contains the clients' information (i.e., the TSN domains) and the type of the service, and the connectivity service details (such as E2E latency are provided). The template is sent by the client to the orchestrator through an ad-hoc designed REST interface.


```
PUT    http://192.168.3.201:65108/serviceo/catalog/serviceTemplate
"vertical":"Vertical1",
"serviceType":"IIoT",
"sliceTemplates":[
    {
        "sliceType":"Ultra-Reliable Low-Latency Communication",
        "EndPoints":[
            {"client_ip_network":"10.1.4.0/24", "border_ip_network":"10.1.5.0/24", "border_mac_address":"08:00:27:70:6a:98"},
            {"client_ip_network":"10.1.6.0/24", "border_ip_network":"10.1.7.0/24", "border_mac_address":"08:00:27:8a:e4:d5"}
        ],
        "coverage":"MEDIUM", "latency":20.0, "bitrate":50
    }
```


Figure 2. Service template with requested bounded latency.

Figure 3 shows the abstracted topology of the multi-technological domain scenario used by the orchestrator to map the service into the different domains according to a defined policy. Such abstraction is formatted in JSON and keeps a graph where each TSN client domain is treated as a node with a set of priority queues each providing a specific bounded latency. For the optical domain, each optical switch is a node of the graph and the optical links are parametrized with the length (the *cost* parameter in the figure). The switching time of the optical nodes, and the optical link propagation delay is kept for the orchestrator to compute the latency associated to the computed lightpaths. We assume no extra delay in the links between the TSN and the optical domains.


```
"network":{
    "nodeDelay": "1",
    "linkDelay": "0.005",
    "wavelengthCapacity": "40000",
    ...
    "nodes":[{"nodeId": "0","type": "opticalNode"}, {"nodeId": "1", "type": "opticalNode"},{"nodeId": "2","type": "opticalNode"},
    ...
    {"nodeId": "14","type": "clientDomain","queues": [{"priority": "4","delay": "1","capacity": "15"},
                                                      {"priority": "3","delay": "10","capacity": "15"},
                                                      {"priority": "2","delay": "40","capacity": "15"},
                                                      {"priority": "1","delay": "120","capacity": "15"},
                                                      {"priority": "0"}]},
    ...
    {"linkId": "39","srcId": "11","dstId": "10","cost": "102","type": "opticalLink","numWavelengths": "40"},
    {"linkId": "40","srcId": "12","dstId": "0","cost": "0","type": "interdomainLink"},
    ...
```


Figure 3. E2E topology abstraction at the orchestrator.

Once the service has been split into the connectivity requests associated to the different domains, the orchestrator contacts each one through the T-API. Figure. 4 illustrates the request sent from the orchestrator to the SDN controller of the optical domain. The figure shows the route computed by the orchestrator, and the capacity and latency requirements for that domain. Note that the formatting of the northbound interface is common for both the SDN-TSN controller and the SDN controller of the optical transport network.


```
"topology-constraint": [
    {
        "include-path":"{\"srcId\":\"14\",\"dstId\":\"15\",\"wavelength\":\"1\",\
        \"pathSequence\":[{\"linkId\":\"44\"},{\"linkId\":\"12\"},{\"linkId\":\"33\"},{\"linkId\":\"47\"}]}",
    }],...
"end-point": [{"connectivity-service-end-point-local-id": "10.1.5.0/24"}
    {"capacity": {"total-size": {"value": 50,"unit": "MBPS"}
    {"server-connectivity-service-end-point": {"connectivity-service-uuid": "14"}},
        ...
    "connectivity-service-end-point-local-id": "10.1.6.0/24"},
    "server-connectivity-service-end-point": {"connectivity-service-uuid": "15"},
"routing-constraint": {"latency-characteristic": [{"fixed-latency-characteristic": "6"}]}
```


Figure 4. T-API connectivity service request to the optical domain SDN controller.

Finally, the SDN controller configures the underlying data plane according to the request received from the orchestrator. Figure 5 depicts, on top, the T-API connectivity request from the orchestrator to the SDN-TSN controller, and the client interface that has been preliminary implemented to configure the TSN domain (i.e., the factory floor network) through the CNC at the bottom. In such configuration, the latency associated to the TSN segment (1ms in the T-API request) is configured in the *vlan_prio* parameter of the TSN switch.


```
"end-point": [{"connectivity-service-end-point-local-id": "10.1.4.1/24"}

    {"capacity": {"total-size": {"value": 50,"unit": "MBPS"}

    {"service-interface-point": {"service-interface-point-uuid": "08:00:27:70:6a:98"}

    {"connectivity-service-end-point-local-id": "10.1.7.1/24"}
    {"service-interface-point": {"service-interface-point-uuid": "08:00:27:8a:e4:5d"},

"routing-constraint": {"latency-characteristic": [{"fixed-latency-characteristic": "1"}]}
```

```
{"addr":"08:00:27:70:6a:98","vlan_id":10,"vlan_prio":4,"filter_en":0,"mac_addr":"08:00:27:8a:e4:d5",
"ip":"10.1.4.1","has_dest":0,"redundant":0}
```


Figure 5. T-API request to the SDN-TSN controller (top), Configuration interface of the TSN switch (bottom).

4. CONCLUSIONS

In this paper, we have presented a control and orchestration framework able to support E2E time sensitive services over a multi-technology scenario. In particular, we have focused on the extensions needed both at control and orchestration level for the provisioning of latency-bounded connectivity. From top to bottom, we have extended the topology manager of the orchestrator to be able to compose an abstracted topology enriched with latency capabilities information, and we have designed a service mapping module able to apply different policies to deploy the E2E service across multiple technological domains. At the control layer, we have defined a set of extensions to enable the SDN control at the TSN domain, and we have extended the SDN control of the optical transport network to consider the latency requirements posed by the upper layer to configure the lightpaths that support the time sensitive connectivity service. In the future work, we will tackle additional dimensions of the deterministic services, such as jitter and reliability.

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