Hierarchical SDN Orchestration of Wireless and Optical Networks with E2E Provisioning and Recovery for Future 5G Networks

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Abstract: This paper proposes the hierarchical SDN orchestration of heterogeneous wireless/optical networks. End-to-End connectivity services are provisioned through different network segments by means of a Transport API. The hierarchical approach allows scalability, modularity and more security.
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1. Introduction

Future 5G networks will have to be highly flexible to serve multiple services with stringent requirements such as ultra-low latency, ultra-high bandwidth, but also in terms of deployment flexibility (e.g., multi-tenancy or network density) in order to deliver End-to-End (E2E) services. These requirements can be met by efficiently integrating heterogeneous wireless and optical network segments (radio access/backhaul, aggregation, and core) and massive computing and storage services, delivered by means of Cloud/Fog computing [1].

On the one hand, a wireless SDN architecture has been proposed in [2], where a wireless SDN controller is responsible for the network control of the wireless nodes and links (e.g., mmWave, LTE, WiFi, 5G). Currently, ONF is in the process of standardizing OpenFlow (OF) extensions for wireless. On the other hand, a hierarchical SDN orchestrator has been previously introduced in order to provide an efficient solution to the network orchestration of different control plane technologies. A parent/child SDN orchestrator architecture has been previously validated for E2E multi-layer (packet and optical) and multi-domain provisioning across heterogeneous control domains (SDN/OF and GMPLS/AS-PCE) employing dynamic domain abstraction based on virtual node aggregation. The hierarchical SDN orchestrator is based on the IETF Applications-Based Network Operations (ABNO) architecture.

It is in this context where hierarchical SDN Orchestration is proposed in this paper as a feasible solution to handle the heterogeneity of wireless and optical network domains, technologies, and vendors. It focuses on network control and abstraction through several control domains, whilst using standard protocols and modules. The need of hierarchical SDN orchestration is justified not only to enable a multi-(technology, domain, and vendor) environment: but also for scalability, modularity, and security purposes.

In order to offer E2E transport service provisioning and orchestration across multiple hierarchical network segments, we propose to use a simplified Transport API [3], such as the one currently being standardized at ONF [4]. We use this Transport API as the SouthBound Interface (SBI) of a parent SDN orchestrator in order to provision E2E services towards a child SDN orchestrator, which also uses this Transport API as a NorthBound Interface (NBI).

This paper presents an architecture for hierarchical SDN orchestration of wireless and optical transport domains, using a hierarchy of SDN orchestrators. In particular, it provides an experimental evaluation of E2E provisioning and E2E recovery procedures in a multi-domain network integrating EXTREME wireless and ADRENALINE optical networking testbeds.

2. Proposed hierarchical SDN orchestration architecture for wireless/optical integration

Fig.1.a shows the proposed hierarchical SDN architecture for the integration of wireless and optical transport networks. In the wireless segment, a wireless SDN controller is in charge of the programming of the wireless mesh backhaul network, which is formed with Small Cells (SCs). This wireless SDN controller tackles the specificities of the wireless medium, implementing the proper extensions to control wireless devices. In the wired transport segment, two SDN-enabled MPLS-TP aggregation networks and a core network are controlled. The latter uses an Active Stateful PCE (AS-PCE) on top of a GMPLS-controlled optical network.
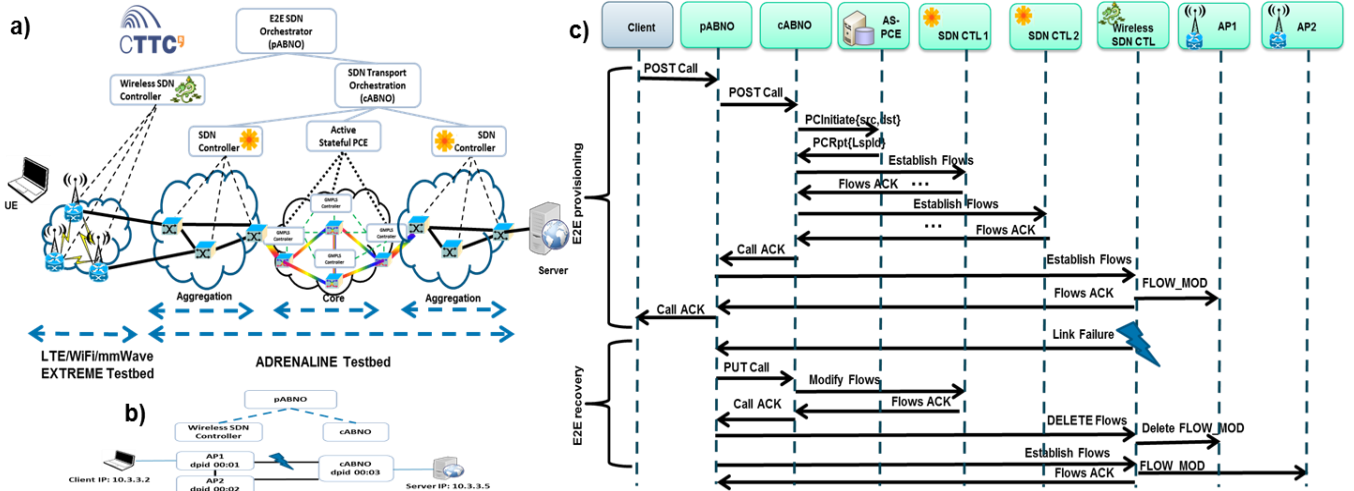
Fig.1. a) Hierarchical SDN orchestration architecture b) Network Topology view at the E2E SDN orchestrator, c) Message exchange workflow for E2E provisioning and recovery connectivity services.

In the proposed architecture, we introduce an E2E SDN Orchestrator, responsible for the provisioning of E2E connections across different network segments. It has been implemented using the parent ABNO (pABNO) in [5]. The pABNO is able to orchestrate several network segments: an SDN-enabled wireless segment and an optical transport network segment controlled by a child ABNO (cABNO). The cABNO provides the underlying network domains abstracted as a single node. The wireless SDN controller provides the underlying wireless network elements, as well as the inter-domain links. Fig.1.b shows the topological view seen from the perspective of the E2E SDN Orchestrator.

The hierarchical ABNO architecture has been described in [5]. In addition to ABNO controller, provisioning and topology managers, VNTM and PCE, the hierarchical ABNO introduces the Abstraction Manager (AM), which is the component of a cABNO responsible for the abstraction of the underlying network resources. The proposed AM is able to provide several types of hierarchical abstraction levels, such as node or link abstraction. Node abstraction offers to the higher level of hierarchy the underlying domains/segments as an abstract node, with the input/output ports of the underlying domains/segments as ports of each abstracted node. A common Transport API, described in [3], acts as a pABNO SBI and as a cABNO NBI. This API enables the necessary hierarchical architecture in order to offer E2E connectivity, topology, and path computation services.

Fig.1.c shows the proposed message exchange between a pABNO and a wireless SDN controller/cABNO. Two different scenarios are presented: E2E provisioning and E2E recovery. In the first scenario, it can be observed that an E2E connection is requested (POST Call) to the pABNO. The pABNO computes the involved network controllers (Wireless SDN/cABNO) and requests the underlying connection. The request sent to the wireless SDN controller is directly translated into OF commands sent to the wireless SCs. Moreover, we can observe how the workflow follows inside a cABNO, which is responsible for another level of hierarchical SDN orchestration, as presented in [6]. The cABNO first requests an optical lightpath to the AS-PCE and, once the lightpath has been established, the different flows are established towards the underlying packet SDN controllers. In the second scenario, an inter-domain link failure is detected by the wireless SDN controller. The link failure is notified to the E2E SDN orchestrator, that computes a new E2E path, and, following a "break-before-make" strategy, it first deletes or modifies the old connections and then establishes the new computed recovery connections.

3. E2E provisioning and recovery results in a multi-domain multi-technology wireless/optical testbed

The EXTREME SDN wireless testbed is based on 12 programmable SCs based on PC (Intel core i7 and 32GB RAM). Each SC is equipped with up to three Compex WLEV900X 802.11ac Atheros cards (ac/a/b/g/n) and Ethernet ports, also used to set up inter-domain links. Each SC runs xDPd as software switch and the wireless SDN controller is based on Ryu. Two SCs are interconnected to different packet switches, providing two inter-domain links between the EXTREME and ADRENALINE testbeds (Fig.1.a). The ADRENALINE Testbed consists of two packet SDN/OF domains based on Ethernet transport technology and an optical transport network. Each packet domain consists of 2 OF switches deployed using COTS hardware and running OVS. Each OF border switch includes a 10 Gb/s XFP tunable transponder. The transport network consists of a GMPLS-controlled WSON centrally managed by an AS-PCE.

a)

Time	Source	Destination	Protocol	Info
REF	pABNO	pABNO	HTTP	POST /restconf/config/calls/call/1 HTTP/1.1 (application/json)
0.009835	pABNO	pABNO-PCE	PCEP	PATH COMPUTATION REQUEST MESSAGE
0.017500	pABNO-PCE	pABNO	PCEP	PATH COMPUTATION REPLY MESSAGE
0.073936	pABNO	W-SDN-CTL	HTTP	POST /stats/flowentry/add HTTP/1.1 (application/json)
0.076621	W-SDN-CTL	pABNO	HTTP	HTTP/1.1 200 OK
0.104657	pABNO	cABNO	HTTP	POST /restconf/config/calls/call/00002 HTTP/1.1 (application/json)
REF	pABNO	cABNO	HTTP	POST /restconf/config/calls/call/00002 HTTP/1.1 (application/json)
0.017858	cABNO	cABNO-PCE	PCEP	Path Computation Request
0.089537	cABNO-PCE	cABNO	PCEP	Path Computation Reply
0.192055	cABNO	AS-PCE	PCEP	Initiate
0.413193	AS-PCE	cABNO	PCEP	Path Computation LSP State Report (PCRpt)
0.595911	cABNO	AS-PCE	PCEP	Initiate
0.818264	AS-PCE	cABNO	PCEP	Path Computation LSP State Report (PCRpt)
2.226984	cABNO	SDN-CTL-1	HTTP	PUT /controller/nb/v2/flowprogrammer/default/node/OF/00:00:00:1e:67
2.228431	cABNO	SDN-CTL-1	HTTP	PUT /controller/nb/v2/flowprogrammer/default/node/OF/00:00:00:1b:21
2.391473	cABNO	SDN-CTL-2	HTTP	PUT /restconf/config/opendaylight-inventory:nodes/node/openflow:116
2.398850	cABNO	SDN-CTL-2	HTTP	PUT /restconf/config/opendaylight-inventory:nodes/node/openflow:130
2.421527	cABNO	pABNO	HTTP	HTTP/1.1 200 OK (application/json)
2.526387	cABNO	pABNO	HTTP	HTTP/1.1 200 OK (application/json)
2.551317	pABNO	pABNO-PCE	PCEP	PATH COMPUTATION REQUEST MESSAGE
2.558513	pABNO-PCE	pABNO	PCEP	PATH COMPUTATION REPLY MESSAGE
2.617861	pABNO	cABNO	HTTP	POST /restconf/config/calls/call/00003 HTTP/1.1 (application/json)
3.024554	cABNO	pABNO	HTTP	HTTP/1.1 200 OK (application/json)
3.053772	pABNO	W-SDN-CTL	HTTP	POST /stats/flowentry/add HTTP/1.1 (application/json)
3.056336	W-SDN-CTL	pABNO	HTTP	HTTP/1.1 200 OK
3.065708	pABNO	pABNO	HTTP	HTTP/1.1 200 OK (application/json)

b)

Time	Source	Destination	Protocol	Info
REF	W-SDN-CTL	pABNO	TCP	**WS: LINK Failure Notification**
0.028197	pABNO	cABNO	HTTP	DELETE /restconf/config/calls/call/00003 HTTP/1.1
0.028396	pABNO	cABNO	HTTP	DELETE /restconf/config/calls/call/00002 HTTP/1.1
0.540708	pABNO	cABNO	HTTP	DELETE /stats/flowentry/clear/1 HTTP/1.1
0.550885	pABNO	cABNO	HTTP	POST /restconf/config/calls/call/4 HTTP/1.1 (appl
0.551236	pABNO	cABNO	HTTP	POST /restconf/config/calls/call/5 HTTP/1.1 (appl
3.094941	pABNO	W-SDN-CTL	HTTP	POST /stats/flowentry/add HTTP/1.1 (application/j
3.101028	pABNO	W-SDN-CTL	HTTP	POST /stats/flowentry/add HTTP/1.1 (application/j
3.107895	pABNO	W-SDN-CTL	HTTP	POST /stats/flowentry/add HTTP/1.1 (application/j
3.113219	pABNO	W-SDN-CTL	HTTP	POST /stats/flowentry/add HTTP/1.1 (application/j
3.495740	cABNO	pABNO	HTTP	HTTP/1.1 200 OK (application/json)

c)

Time	Source	Destination	Protocol	Info
REF	10.3.3.2	10.3.3.5	ICMP	Echo (ping) request id=0x2385, seq=3918/19983, ttl=64 (reply in 4009)
0.002444	10.3.3.2	10.3.3.5	ICMP	Echo (ping) reply id=0x2385, seq=3918/19983, ttl=64 (request in 4008)
0.002483	10.3.3.5	10.3.3.2	ICMP	Echo (ping) request id=0x2385, seq=3919/20239, ttl=64 (no response found!)
0.012550	10.3.3.5	10.3.3.2	ICMP	Echo (ping) request id=0x2385, seq=3920/20495, ttl=64 (no response found!)
...				
3.686449	10.3.3.5	10.3.3.2	ICMP	Echo (ping) request id=0x2385, seq=4286/48400, ttl=64 (no response found!)
3.696515	10.3.3.5	10.3.3.2	ICMP	Echo (ping) request id=0x2385, seq=4286/48656, ttl=64 (no response found!)
3.706581	10.3.3.5	10.3.3.2	ICMP	Echo (ping) request id=0x2385, seq=4287/48912, ttl=64 (reply in 4383)
3.716646	10.3.3.5	10.3.3.2	ICMP	Echo (ping) request id=0x2385, seq=4288/49168, ttl=64 (reply in 4385)
3.726712	10.3.3.5	10.3.3.2	ICMP	Echo (ping) request id=0x2385, seq=4289/49424, ttl=64 (reply in 4386)
3.736777	10.3.3.5	10.3.3.2	ICMP	Echo (ping) request id=0x2385, seq=4290/49680, ttl=64 (reply in 4388)
3.746842	10.3.3.5	10.3.3.2	ICMP	Echo (ping) request id=0x2385, seq=4291/49936, ttl=64 (reply in 4389)
3.749384	10.3.3.2	10.3.3.5	ICMP	Echo (ping) reply id=0x2385, seq=4287/48912, ttl=64 (request in 4378)

Fig.2. a) E2E provisioning wireshark captures at pABNO and cABNO, b) E2E recovery wireshark captures at the pABNO, c) Data plane E2E recovery between UE and Server.

The implementation of the ABNO uses Python for most of the components and C++ for PCE component. Several internal REST interfaces are offered between the different components. In this paper we have used the Transport API to interact between pABNO and cABNO. The Transport API information model is described in YANG, and it uses RESTconf as transport protocol. RESTconf allows using the Transport API as an HTTP REST API. As a REST API does not allow notifications, websockets have been introduced (as described in RESTconf) in order to send notifications of nodes and links status.

Fig.2.a shows the wireshark captures of the exchanged messages at both the pABNO and cABNO. The bidirectional E2E service call request is received at the pABNO. The pABNO PCE is responsible for computing an E2E path. The pABNO VNTM decomposes the computed E2E path in order to request a call service to the cABNO. The cABNO is responsible for SDN orchestration towards the underlying network domains (SDN-CTL-1, AS-PCE, and SDN-CTL-2). After the cABNO provisions the requested call service, the pABNO requests the necessary flows to the wireless SDN controller. The setup delay for an E2E service call is around 3.06s.

The E2E recovery message exchange is shown in Fig.2.b. The wireless SDN controller receives the OF port down message in an inter-domain link and notifies the pABNO of the link failure through an open websocket. The pABNO computes the E2E recovery path and it first removes the previously provided connections. Then, it establishes the new connections between the wireless nodes.

Fig.2.c. shows the data plane connectivity between a User Equipment (UE) connected through a wireless SC and a server running at the aggregation network. ICMP ping messages (with a message interval of 10ms) are exchanged between both hosts. We emulate a link failure by disconnecting one of the inter-domain ports. When the E2E recovery is applied, the ICMP request messages are recovered and replied. The resulting E2E recovery time from the data plane perspective is around 3.7s.

4. Conclusions

We have presented E2E provisioning and recovery use cases in an integrated optical/wireless testbed by means of hierarchical SDN orchestration. Experimental results suggest that certain levels of hierarchy can cope with the upcoming network heterogeneity from a multi-(technology, domain, and vendor) perspective.

5. Acknowledgments

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