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Field Trial of Multi-Layer Slicing Over Disaggregated Optical Networks Enabling End-to-End Crowdsourced Video Streaming

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Abstract We present a field trial of NFV Orchestration over multi-layer packet and disaggregated optical network testbed to demonstrate crowdsourced video streaming use case. We show the average service creation time is under 5 minutes, which meets the KPI as defined by 5G PPP.

1. Introduction

The next generation of networks (5G and beyond) is aimed at supporting new services with stringent requirements. A Crowdsourced Live Video Streaming (CLVS) is an example of such Network Service (NS), in which thousands of users attending an event (sports, concert, etc) stream video from their smartphones to a CLVS platform. The content from all the users is edited in real time, producing an aggregated video, which can be broadcasted to a large number of viewers.

In order to support new vertical applications, Metro-Haul project^[1] has designed and built a cost-effective, agile, disaggregated packet-optical metro infrastructure with compute capabilities at the network edge, addressing the capacity increase and characteristics such as low latency and high bandwidth. Metro-Haul control plane consists of the Control, Orchestration and Management (COM) system^[2], based on the principles of ETSI NFV framework and a hierarchical SDN control plane, which facilitates the deployment of multilayer end-to-end network slices, including Virtual Network Functions (VNFs) in multiple datacentres (with multiple Virtual Infrastructure Managers) and simultaneously dedicates packet and optical network resources, including Layer 2 (L2) VPNs and photonic media channels.

In this paper, we present the experimental demonstration of CLVS NS using Metro Haul infrastructure, with NFV orchestration using COM system implemented over a disaggregated optical network testbed in UK. The service creation procedure, from planning to service deployment is shown and measured against the Key Performance Indicators (KPIs) defined by 5G PPP.

2. Crowdsourced live video streaming Network Service

In the past few years, videos streamed on CLVS platforms have generated a staggering amount

of traffic: 3.8 million people broadcasted live-streaming videos^[3] in Feb. 2020 on Twitch^[4], a CLVS platform. This amount of traffic^[5] requires a high capacity network with low latency network paths for multiple video streams. Furthermore, a CLVS-based NS may also require compute resources to process the video traffic^[6]. A reference CLVS NS, shown in Fig. 1, consists of CLVS traffic as multiple video streams in different VLANs, from access network being processed by a Deep Packet Inspector (DPI) VNF for traffic analysis. Via a metro-optical network, the CLVS traffic is forwarded to a Firewall (FW) VNF which can block any video stream per VLAN based on some criteria. Following this, the CLVS traffic is forwarded to core network for upload to a CLVS platform.

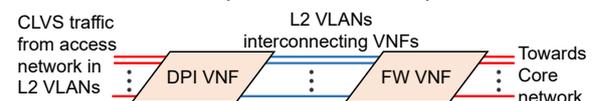


Fig. 1: ETSI-NFV network service targeting CLVS use case

CLVS use case can benefit from Metro-Haul infrastructure, since its COM system can rapidly provision a slice on top of the end-to-end (E2E) compute/network resources and support the high capacity and low latency requirements.

3. Metro-Haul testbed for CLVS use case

We describe the Metro-Haul testbed supporting the CLVS use case including both the data plane and control plane. as presented in Fig. 2.

3.1 Data plane

Metro-Haul data plane nodes are SDN/NFV enabled with compute servers to host applications as VNFs and multi-layer packet and optical networking capabilities. They comprise *Access Metro Edge Node (AMEN)* connected to the metro and access network; and *Metro Core Edge Node (MCEN)* connected to the metro and core network^[7]. AMENs may host VNFs close to the access network for low latency to end user. AMEN and MCEN are connected together by a

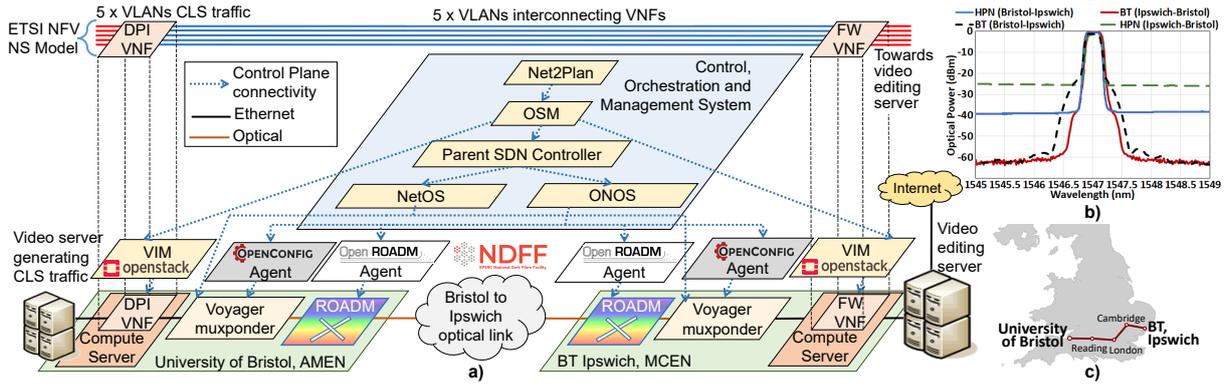


Fig. 2: a) Testbed for CLVS application, b) optical spectrum Bristol-Ipswich link, c) UK optical connectivity: Bristol-Ipswich

metro optical network. At each node, the compute server is connected to a multi-layer Voyager muxponder^[8], which can switch VLAN-tagged Ethernet traffic on a client port towards the optical network on a DWDM coherent transponder (line port). The Voyager muxponder is further connected to a ROADM at each node for optical switching. We adopt vendor neutral OpenConfig^[9] and OpenROADM^[10] based YANG data models and agents to control the Voyager muxponder and ROADM devices respectively to enable disaggregated optical networks^[11].

We demonstrate the CLVS use case where the AMEN and MCEN are hosted at HPN lab, University of Bristol (Bristol, UK) and BT Research Labs (Ipswich, UK). These sites are interconnected via two optical fibre infrastructures: the National Dark Fibre Facility (NDFF) connects Bristol to Cambridge, and a second fibre-link connects Cambridge to Ipswich with a total length of 1060 km (530 km unidirectional) of standard single mode fibre. DWDM filtering at Cambridge and Ipswich limits the ASE noise generated by the EDFAs in the links. A server at HPN generates video streams, emulating CLVS traffic, on multiple VLANs towards the AMEN where it is received by a video editing server at BT after traversing the VNFs and the metro network. The video editing server aggregates the received CLS video streams and broadcasts to Twitch via internet.

3.2 Control plane

The Metro-Haul control plane includes the COM system^[2] to enable flexible service provisioning. It requires an NS described using ETSI standard Network Service Descriptor (NSD) template consisting of VNF Descriptors (VNFDs) and Virtual Links (VLs) interconnecting VNFs^[12]. VNFDs include the required resources (CPU, RAM, storage) per VNF. The COM system provisions a slice of overall resources based on the NSD by mapping each VNF and VL into actual deployed Virtual Machines (VMs) and connectivity over the metro network respectively, using a hierarchy of services. These include i) network planning service, fulfilled by Net2Plan^[13]:

an open-source planning tool widely used in networking demonstrations; ii) E2E slicing service, fulfilled by an extended version of Open Source MANO (OSM)^[14] as the reference NFV Orchestrator (NFVO); iii) E2E connectivity service, fulfilled by Parent SDN Controller (PSC) which is a hierarchical SDN controller; and iv) optical connectivity service, fulfilled by an ONOS SDN controller. These services are explained with detail in next section.

4. Network Service deployment workflow

We present the CLVS NS deployment workflow (depicted in Fig. 3) using the Metro-Haul COM services. First, a CLVS application administrator requests a CLVS NS from Net2Plan^[13], which provides the *network planning service*. Net2Plan gathers the NS network/compute resources, latency and bandwidth requirements. It then executes a resource allocation algorithm producing NSD and VNF locations as output. Here, the location of DPI VNF and FW VNF is decided as Bristol AMEN and BT MCEN respectively. Net2Plan uses this output to deploy the network slice by instantiating the CLVS NS using an NFVO.

The OSM NFVO offers the *E2E slicing service* to deploy the NS using the NSD; this service includes both VNF deployment as well as interconnecting VNFs. OSM deploys the VNFs as VMs on the compute servers using OpenStack. as the reference Virtual Infrastructure Manager (VIM). Once the VNFs are active, OSM requests an L2 based *E2E connectivity service* offered by the PSC to interconnect the VNFs.

PSC is a hierarchical SDN controller which implements IETF L2SM model as Northbound API (NBI)^[15], where OSM specifies the AMEN and MCEN network endpoints and VLAN ID while requesting connectivity. The PSC first connects the AMEN and MCEN at the optical layer using the *optical connectivity service* offered by ONOS SDN controller. We have implemented Transport API (TAPI) v2.1 photonic media layer extensions on the ONOS NBI, for the PSC to request a connectivity service (optical channel - OCh)) be-

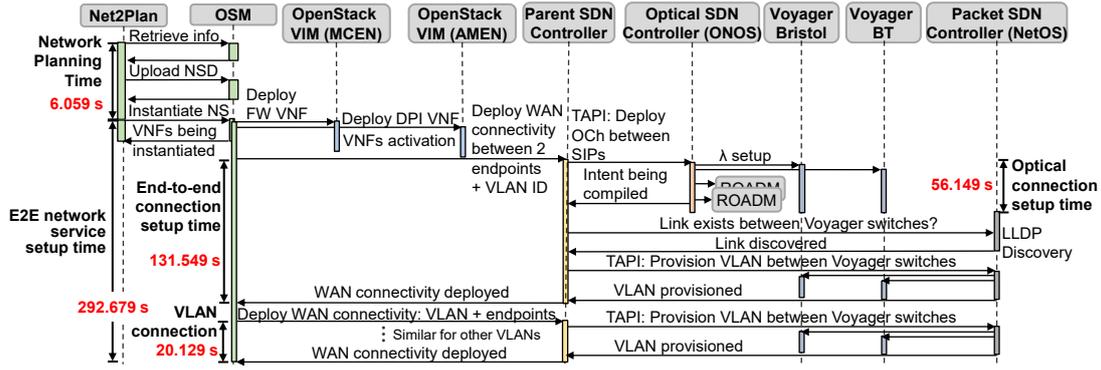


Fig. 3: Crowdsourced live video streaming NS deployment workflow

tween Voyager muxponder line ports. Also, device drivers (using NETCONF/YANG) for Voyager muxponder (OpenConfig terminal-device model) and ROADMs (OpenROADM device model)^[11] are implemented to configure the line ports and network media channels respectively.

Once the optical connectivity is deployed, the PSC deploys the L2 VLAN-based packet connectivity between the ethernet client ports of the Voyager muxponder using NetOS packet SDN controller^[16]. NetOS exposes the topology via TAPI context to the PSC, where the optical link between Voyager muxponders is discovered using LLDP. To interconnect the Voyager muxponder client ports, NetOS configures the VLAN on both the client and line ports, which are internally connected to the same bridge on the Voyager muxponder. As a VLAN is deployed, the E2E connectivity is established. Finally, OSM requests connectivity for each VLAN between the VNFs.

5. Results

We repeat the CLVS use case NS deployment for 30 times, and collect the setup times for Metro-Haul COM system services. The average setup time with 95% confidence intervals in Tab. 1 and Fig. 3 show that the whole network service is deployed within ≈ 5 minutes (even when considering the network planning as part of the whole E2E network service). From those 5 minutes, ≈ 56 s are taken by configuring the optical connection, ≈ 131 s by the VMs instantiation and control plane orchestration, and ≈ 6 s by the network planner, whereas the remaining time by establishment of the 5 VLANs.

Furthermore, the obtained times are dependent on the number of links, nodes, and VLANs between the VNFs in the NSD. Since the configuration of the optical equipment i.e., ROADMs and muxponders, is performed in parallel, the addition of extra devices does not impact the obtained results in any meaningful way. On the other hand, since the VLANs are configured in series, the total number of VLANs do increase the overall establishment time in a linear fashion. As Tab. 1 shows, each extra VLAN allocated on top of an already

existing optical connection adds ≈ 20 s. When comparing these results against the 5G PPP KPI service creation time of 90 minutes^[17], it is clear that the presented solution can meet the specification if the number of VLANs needed by a given service does not exceed ≈ 270 VLANs. Moreover, the performance of each VLAN was measured using iperf with UDP traffic between the two VNFs. The maximum throughput achieved was approximately 1 Gbps per VLAN, due to the limitation of VirtIO based VNF Ethernet interfaces, and can be increased if SR-IOV NICs are used^[18].

Tab. 1: Metro-Haul average service setup times

Service	Avg. setup time (s)
Network planning	6.059 \pm 0.283
E2E network service	292.679 \pm 6.056
E2E connection	131.549 \pm 5.241
Optical connection	56.149 \pm 0.649
VLAN connection (no optics)	20.129 \pm 0.710

Finally, the optical connection was implemented by the Voyager muxponders, with the channels centred at 1547 nm wavelength, using PM-QPSK modulated signals resulting in 100 Gbps data rates (Fig. 2b). The measured pre-FEC BER was 1.33×10^{-3} for Ipswich-Bristol link and 4.257×10^{-5} for Bristol-Ipswich link. The FEC in the Voyager muxponders was set at 25%, sufficient to correct errors during the transmission in both links. The measured L2 latency (RTT) between Ipswich and Bristol was 5.5ms.

6. Conclusions

We presented a demonstration of crowdsourced live video streaming use case, benefiting from a multi-layer slice provided by Metro-Haul project's packet and disaggregated optical network infrastructure and SDN/NFV enabled control plane in a UK-based testbed. The average service setup creation time for the CLVS use case shows that it meets the 5G PPP KPI.

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