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Field Trial of Remotely Controlled Smart Factory based on PON Slicing and Disaggregated OLT

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Abstract *Field trial of remotely controlled 5G smart factory was demonstrated by PON slicing and disaggregated OLT, for the first time. PON slicing is realized by interworking of SADIS, vOLT, and slicing app in vPON.*

Introduction

Recently, there are a lot of new services requiring fast-response, high-capacity, and on-demand connection in optical access networks such as smart factory, tactile internet, immersive media, mobile data, and 3D augmented reality. Time-division multiplexed- passive optical network (TDM-PON) is attractive solution to support ever increasing traffics in optical access network due to its cost-effective optical connection. In order to meet these rapidly changing new applications and various service-specific characteristics, TDM-PON with flexibility for adding/replacing new functions as well as guaranteed low-latency for time critical applications play an important role.

Up to nowadays, there have been substantial efforts to converge time-critical applications with non-time-critical applications in the same optical distributed network (ODN) [1-3]. These include low-latency oriented dynamic bandwidth allocation (DBA) differentiating class of traffic [1] and co-operative DBA (CO-DBA) exchanging scheduling information between optical and mobile equipment [2], disaggregating TDM-PON into physical PON (pPON) and virtual PON (vPON) [3], and PON slicing [4]. PON slicing divides a single physical network into multiple logical networks according to application-specific requirements such as bandwidth (BW) and latency would be effective solution to accommodate time-critical applications within the existing ODN. However, the previous demonstrations mostly focused on DBA scheme itself, removing vendor dependency, or proof-of-concept of slicing in lab environment.

We demonstrate in this paper, for the first time, field trial of remotely controlled 5G smart factory by PON slicing and disaggregated OLT. The higher priority slice for 5G smart factory is logically isolated from other slices, and the performances of smart factory slices isn’t affected by other traffic conditions. 5G smart factory is successfully controlled from 279 km away with PON slicing and TSN/DetNet switch.

PON Slicing architecture

Figure 1(a) shows PON slicing architecture. TDM-PON system is disaggregated into vPON and pPON. vPON composed of hardware abstraction (VOLTHA) with open OLT/ONU adapters and SDN controller based on open networking operating system (ONOS) with vPON applications (App), while pPON is based on XGS-PON white-box OLT. PON slicing is realized by interworking with three vPON applications as

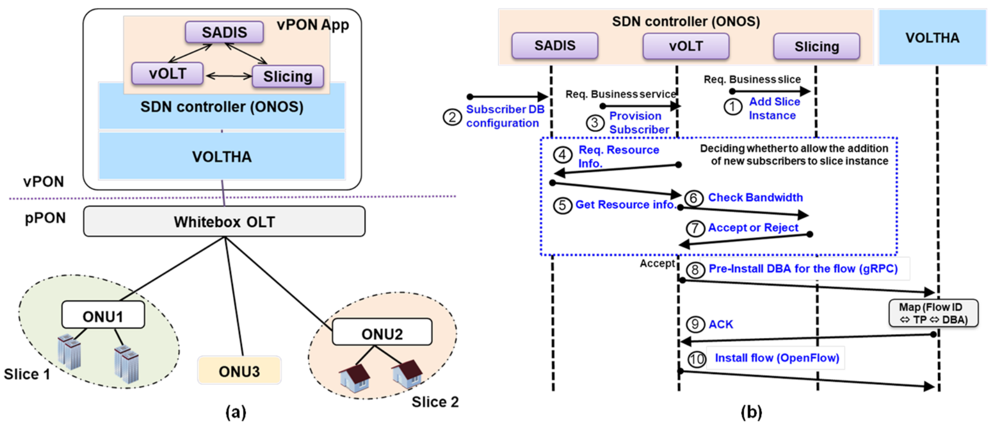


Fig. 1: (a) PON slicing architecture and (b) PON slice workflow for business services.

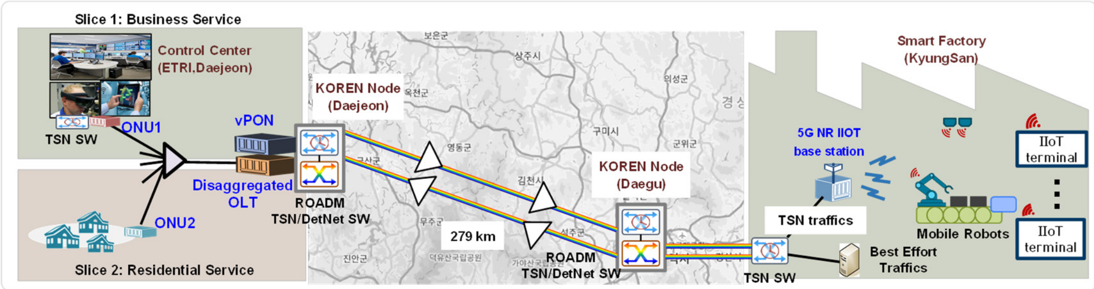


Fig. 2: Field trial configuration of PON slicing for remotely controlled 5G smart factory. IIoT: industrial IoT.

shown in Fig. 1: subscriber/access device information service (SADIS), vOLT, and slicing. SADIS is database to keep all the provisioning information relevant to subscribers such as bandwidth as well as slice profile for different types of services. After modelling service type specific attributes such as maximum and guaranteed BWs, slice priority, and latency class identified by DBA, slice profiles is stored in SADIS app. Slicing app retrieves physical device information from VOLTHA, and then initializes all the PON ports to have a single slice instance with an allowable bandwidth (i.e., entire PON channel capacity) by default. After the initialization, an operator can add a different slice instance such as business/residential/mobile application by specifying the slice name, PON port, guaranteed BW, and DBA algorithm to be used. Figure 1(b) shows the workflow for generating new slice for business services. When new slice request is inputted to slice app, SADIS loads subscriber profile such as bandwidth profile, VLAN, logical device information, and so on. vOLT app maps information to the slice profile and then provisions subscriber. In steps ④ ~ ⑦, slicing app determines whether the requested BW can be accommodated by the designated slice instance. When the request is accepted, vOLT app pre-installs DBA for the flow and creates an OpenFlow (OF) message with the corresponding information to the subscriber referred from SADIS, and the OF message is sent to VOLTHA.

During the operation, slicing instance can be added or deleted through slicing app. When the operator provisions additional slicing instances, the default slice instance is divided into multiple slices based on the requests of the type of service, guaranteed BW, and DBA requirements. Conversely, when slice instances are deleted, its bandwidth is merged with the remaining default slice instance.

Experimental Setup and Results

Figure 2 shows field trial configuration of PON slicing for remotely controlled 5G smart factory. The testbed is composed of TDM-PON and core network. The XGS-PON whitebox OLT and two

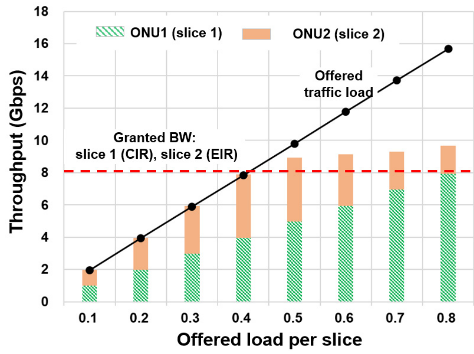
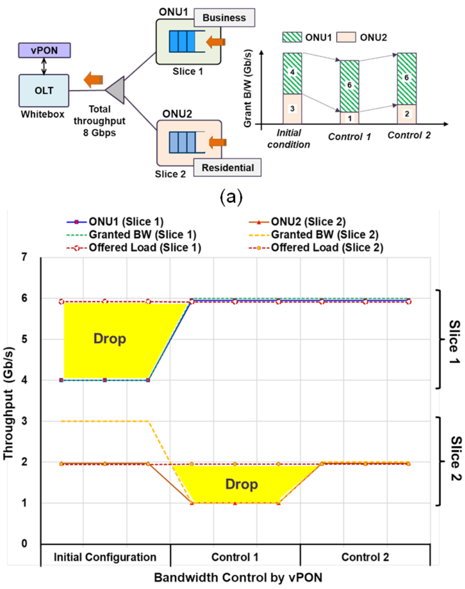


Fig. 3: Measured throughput of slice 1 and slice 2.

ONUs were placed at the access network. One ONU was used for smart factory control centre, whereas the other ONU was connected to typical residential application. The traffic for control and monitoring of 5G industrial IoT (IIoT) were connected to TSN/DetNet switch, and then was transmitted over 279 km over Korea advanced research network (KOREN) composed of ROADM, EDFA, DP-QPSK base 100 Gbps coherent transceiver. At the smart factory site, the IIoT traffic went to 5G NR IIoT base-station via TSN switch, and then connected to mobile robots in the factory. The best effort traffic and residential traffic were utilized to test the performance of TSN switch and PON slicing, respectively.

First of all, we measured the performance of PON side enabled by slicing. The vPON made two slices for smart factory and residential applications by interworking with SADIS, vOLT, and slicing app. In addition, the vPON configured bandwidth profile of ONU1 to have committed information rate (CIR) 8 Gbps and excess information rate (EIR) 2 Gbps. ONU2 was set to be EIR of 8 Gbps. Figure 3 shows the measured throughput of each slice according to the traffic load. Before connecting to the real-time control packet of smart factory, packet generator/analyser was connected to each ONU. The packet size was 1518-byte for ONU1 and random size (64- to 1518-byte) for ONU2. There is no packet drop when the offered load is less than the granted bandwidth. As the offered load increases, the congestion occurred and the



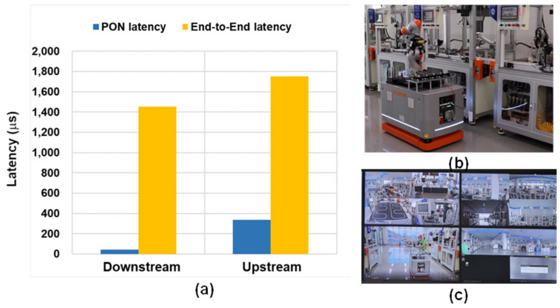
(a) (b)

Fig. 4: Measured throughput of re-allocating bandwidth between slice 1 and 2 by vPON.

throughput was saturated. However, ONU1 could successfully provide service within the guaranteed BW (i.e., CIR), whereas ONU2 had packet loss.

Figure 4 shows performance of bandwidth re-allocation of each slice enabled by vPON. Initially, the guaranteed BW of each slice for ONU1 and ONU2 were set to be 4 Gbps and 3 Gbps, respectively. The offered load to ONU1 and ONU2 were 6 Gbps and 2 Gbps respectively. By monitoring the packet loss of slice 1 (i.e., ONU1), the vPON increased CIR for slice1 from 4 Gbps to 6 Gbps, whereas CIR for slice2 decreased from 3 Gbps to 1 Gbps. In the case of packet loss of slice 2, vPON could increase slice 2 from 1 Gbps to 2 Gbps. Thus, we can observe that both slice1 and slice2 have no packet loss. The vPON could flexibly control bandwidth of each slice.

For the remote control of smart factory, the overall network latency was measured, as shown in Fig. 5(a). The end-to-end latency of slice 1 including fibre delay was measured to be 1,752 μs and 1,455 μs for upstream and downstream, respectively. These latency values include the latency of PON side of 340 μs and 43 μs for upstream and downstream. Because we have set the control traffic for smart factory to have high-priority slice profile by vPON, the measured latency wasn't affected by traffic condition of slice 2 for residential application. In addition, TSN switch within the smart factory successfully guaranteed the latency for 5G NR IIoT base station regardless of best-effort traffics. With PON slicing, TSN/DetNet switch, 5G NR IIoT base station, we could successfully control smart



(a) (b) (c)

Fig. 5: 5G IIoT smart factory control and management (a) measured latency (b) manufacturing facility and robot at remote site (c) monitoring screen at control centre.

factory from 279 km away such as process monitoring with virtual reality HMD, remote control of manufacturing mobile robot, control of production facility by touch panel, and so on, as shown in Fig. 5(b).

Conclusions

We demonstrated, for the first time, field trial of remotely controlled 5G smart factory by PON slicing and disaggregated OLT. The virtual PON could support various demands by flexibly configuring bandwidth and slice profiles per slice instance. The higher priority slice for 5G smart factory was logically isolated from other slices, and the performances of smart factory slices wasn't affected by best-effort traffics. As a result, 5G smart factory was successfully controlled from 279 km away with PON slicing and TSN/DetNet switch. The results confirmed that PON slicing could flexibly configure logical network structure to meet various service requirements.

Acknowledgements

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