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Proposal on Virtual Edge Architecture Using Virtual Network Function Live Migration with Wavelength ADM

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***Abstract*—We propose a virtual network edge architecture with a novel wavelength channel add/drop multiplexer configuration using virtualized network functions (VNFs) to save processor and bandwidth resources. The feature of this architecture is VNF live migration with wavelength-division-multiplexing/time-division multiplexing photonic switching technology to use metro network resources efficiently. To reduce the computation of reallocation, the live-migration of a VNF is limited to part of the VNF that contains a larger number of subscribers.**

Keywords—Virtual edge, PON, NFV, WDM, ADM

I. INTRODUCTION

Network convergence among mobile networks and fixed line networks is progressing; therefore, various media services, such as Internet access, IP telephony, video on demand, and streaming, can be provided. The service admission functions for these services are deployed intensively at the carrier network edge for the user-and-network interface and network-and-network interface.

Network function virtualization (NFV) [1] has enabled carrier networks to use emerging virtualization technologies in Internet data centers that contain not only virtualization of application software servers but also virtual switches and routers with a wire-rate speed of up to 10 Gbit/s. The NFV of routers and switches is expected to reduce cost by the efficient use of hardware resources and fast service delivery on demand by adding or changing the virtual function.

On the other hand, progress in optical network technology has enabled the development of Tbit/s-order long-distance transmission systems with wavelength-division-multiplexing (WDM). For metro area optical networks that connect access equipment, such as a passive optical networks (PONs), mobile base stations, and service nodes, several network technologies have been proposed such as a WDM/time-division multiplexing (TDM)-PON [2, 3] and packet optical ADM [4], which uses wavelength path switching. In addition, an elastic path was proposed, which enables path capacity change of wavelength paths to depend on the traffic demand and save wavelength resources [5]. Due to these wavelength technologies, variable-bandwidth path circuit can be provided.

In this paper, we propose a virtual edge architecture in which processor resource management and bandwidth control of aggregated user traffic at the virtual edge are performed independently. In our architecture, live migration of a VNF is performed with wavelength-channel switching by using an add/drop multiplexer (ADM) to select a wavelength channel.

II. EDGE ROUTER IN METRO NETWORK

In a conventional metro network, the edge router concentrates user flows from several particular access networks such as 10-Gigabit Ethernet-PONs (10GE-PONs) [6]. We propose a virtual edge architecture instead of dedicated edge routers. Figure 1 shows a schematic of the relationship between subscribers of the virtual edge L and network resources. This virtual edge offers two types of network services, A and B (such as Web browsing, video streaming, and IP telephony), to subscribers. Some subscribers use only one service and other subscribers use multiple services. The ratios of in-service subscribers of A and B are denoted as η_A and η_B, respectively. We assume that the required processor capacity and user flow bandwidths are constant when a subscriber uses A or B services, which is denoted as P_A, P_B, W_A, and W_B. The total required processor and bandwidth are $\eta_A L_A P_A + \eta_B L_B P_B$ and $\eta_A L_A Wx + \eta_B L_B W_B$. Sufficient hardware resources should be prepared to satisfy these required resources. In a real network service, P and W are not constant. Therefore, resource demand variation is large. When the local traffic demand is biased, resource shortage may occur, even though the total amount of network resource is sufficient.

To solve this problem, resource reallocation by live-migration of virtual edge and dynamic bandwidth allocation are conducted followed by participation and withdraw of subscribers and peak service usage.

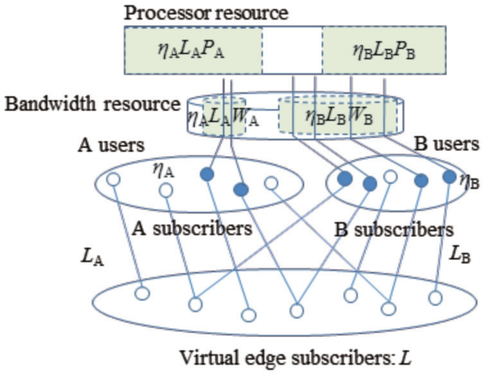


Fig. 1. Proccessor and bandwidth demand of service users.

III. VIRTUAL EDGE ARCHITECTURE WITH ADM CONFIGURATION

A. Virtual Edge with VNFs correnponding to OLTs

Figure 2 shows a schematic of the logical configuration between VNFs and optical line terminals (OLTs) of a 10GE-PON. The important feature is that the virtual network function (VNF) [7] has a one-to-one correspondence to the dedicated OLT. The total number of VNFs is equal to the number of 10GE-PONs. The user flow of an OLT is connected only at the VNF. The edge servers (ESs) contain several VNFs, but the user flow is a simple point-to-point one. From the viewpoint of ESs, a simple star topology is constructed between OLTs.

The resource demand of a VNF depends on the number of OLT subscribers, which varies due to subscriber participation and withdrawing. This VNF resource demand also varies due to various service usages and changes rapidly based on the service-usage duration. The physical resources of an ES of a CPU and network NIC are divided into a virtual CPU (vCPU) and virtual NIC (vNIC) for each VNF to use these resources efficiently. If demand exceeds the physical resources of bandwidth and processor in the ES and resource shortage occurs due to peak service usage that, some of the VNFs are live-migrated to another ES that has excess resources.

In the virtual edge, the packet flows should be transmitted without service session interruption and with bandwidth allocation for service quality guarantee. Even though live migration of VNFs is effective for saving server processor resources, it might lead to service interruption and bandwidth shortage of service flows. In this architecture, the volume of a VNF is relatively small because an OLT contains only a small number of subscribers; up to 32/128. Therefore, a small-volume VNF can lead to in-service live-migration due to short migration time.

B. Live Migration of the Kth-largest-subscribers VNFs

There are still scalability problems due to the large number of VNFs. The important point is which VNFs move. The second feature of this proposed architecture is that only VNFs that contain a large number of subscribers can be live-migration candidates because the processor and bandwidth demand change is the larger. The number of VNFs where live-migration is permitted is denoted as *K*. If all VNFs are candidates for live-migration, the live-migration control requires a large amount of computation time or computation resources in cooperation with the numbers of live-migration candidate VNFs because there is a huge number of VNFs, which is equal to the number of OLTs. The candidates of live migration VNFs are reselected in larger-subscriber order when the number of subscribers varies due to participation and withdrawal. Server resource reallocation is done within an internal ES and then the resource allocation of vCPUs and vNICs are changed.

For evaluation of live-migration: in a metro network, the number of ESs that have 10-Gbit/s network interface cards (NICs) is N=100, and the number of 10GE-PONs is M=2500. The number of field 10GE-PON subscribers actually varies between 0 and 32. For evaluation, we assumed that the average number of subscribers in a 10GE-PON is 16, then this network contains a total of 40000 subscribers and an average of 25 VNFs. The distribution of subscribers in OLTs is uniform, binominal, and a combination of both. In these distributions, accumulating subscribers via OLTs in decreasing order is shown in Fig. 3. More than a quarter of subscribers are covered by the largest 500 VNFs. If K=500 VNFs, the number of live-migration subscribers is 10,000 and 14,000 for binominal and uniform distributions, respectively. At each edge server, the 5 largest VNFs lead to the migration of 100 subscribers on average.

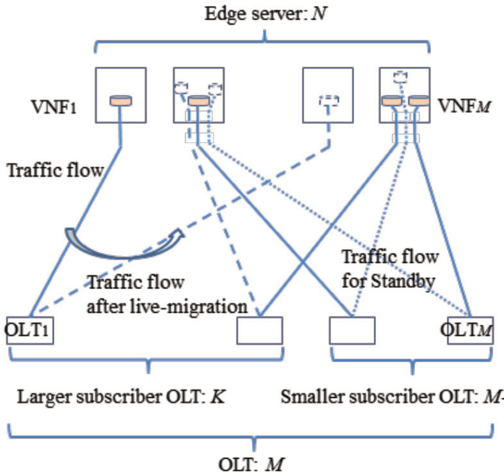


Fig. 2. Schimatic of proposed virtual edge architecture.

We now discuss the number of traffic flows connecting OLTs and VNFs. The OLTs up to the *K*th most subscribers are connected by the active traffic flows to the edge server that contains the corresponding VNFs selected for live migration and by the N-1=99 potential traffic flows to the other edge servers. The rest of the M-K OLTs have two logical paths, each for the active flow and standby flow for failure recovery of the edge server. The total amount of logical paths is $KN+2(M-K)$ = 54,000 (bi-directional flows), which is less than the case in which all VNFs are candidates for live migration, NM=250,000. For the edge server, a total of 540 flows are set for the active paths of M/N=25 and for the reservation and standby paths of $K+(M-K)/N$=515. Table I compares the cases in which all the VNFs are candidates of live migration and the K-th largest-subscribers VNFs are candidates for migration.

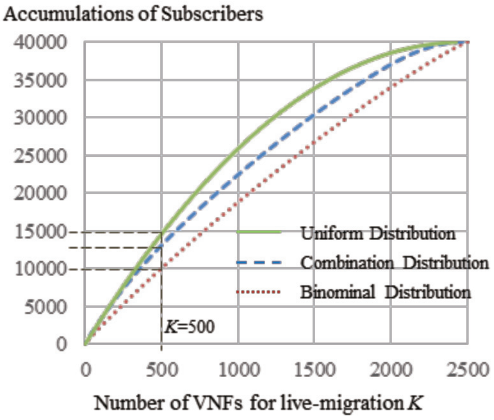


Fig. 3. Accumulation of subscribers in edge server.

TABLE I. CONTROL OBJECTS FOR LIVE MIGRATION OF VNFS

VNF Migration Candidates	**Number of management Object**	
	VNF management	***Flow management***
All VNF	M=2500	M=2500
Kth largest VNF	K=500	$2(M-K)/N$ $+K$=540
Reduction percentage	20%	21.6%

C. *Intra-Edge-Server Bandwidth Resouce Allocation*

In the virtualization of the network edge function, bandwidth resource confirmation should be considered according to service traffic utilization. Physical metro networks between OLTs and ESs, which also gather traffic, are geographically distributed. We adopted a wavelength path network like WDM-TDM PON[3] to achieve bandwidth resource reallocation.

Figure 4 shows the proposed wavelength path network configuration. There are two feature of this configuration: one is dynamic bandwidth allocation (DBA) control[8] to enable intra-edge-server bandwidth resource reallocation and the other is wavelength path switching by Add/Drop Multiplexer (ADM) to enable the live migration in the virtual edge. Each wavelength channel is shared among OLTs.

The number of wavelength channels is allocated to each ES. The notation ESi is the connected wavelength channel of λj. For the wavelength channel of an ES that contains the corresponding VNF, the optical power is partially dropped by the ADM and the rest is passed to the next ADM. With this method, a star-topology wavelength path is constructed between the ES and corresponding OLTs, as shown in Fig. 1.

The relationship between ES and OLTs in a certain wavelength channel is similar to a 10GE-PON where one OLT is shared among optical network unit (ONU) as shown in Fig 5. The transportation between an ES and OLTs can be adopted in the same way as a 10G-EPON. Downstream from the ES, the optical power is broadcasted, and each OLT receiver extracts only the signal for itself. In upstream, the burst signal is sent out at a designated time from the ES to prevent collision. The bandwidth to satisfy the traffic demand is assigned to both the upstream and downstream signals between the VNF and each OLT. This method, called DBA, mediates the traffic demand conflict among VNFs and OLTs. With DBA, bandwidth resource allocation is independently done in each wavelength channel.

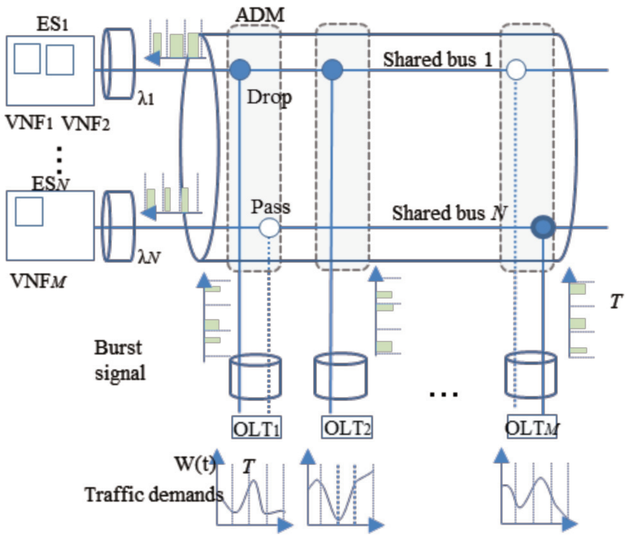
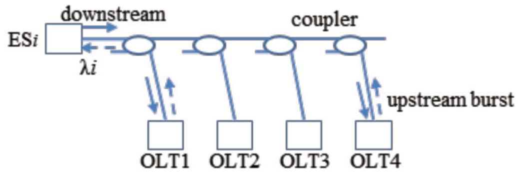
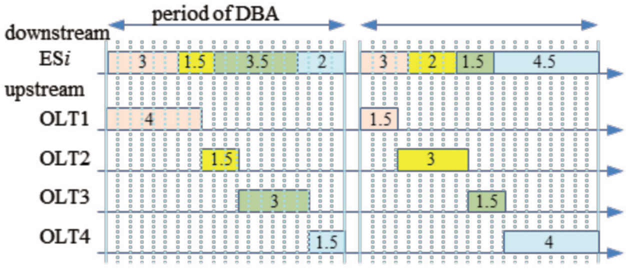


Fig. 4. Wavelength path network configration of edge servers and OLTs.



(a) Logical configuration at λi



(b) Example of bandwidth allocation

Fig. 5. Intra-Server bandwidth resource allocation by DBA.

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In a WDM/TDM-PON [3], all wavelength-channel signals are broadcasted to all the OLTs including the destinations that are not required to receive such signals. ADM can select only the required signal power drop.

Figure 6 shows the combination of ESs. An ES contains several VNFs. Each VNF and the corresponding OLT is connected by the logical path, for example a virtual local area network. A VNF has a vNIC, and the traffic from the vNICs are concentrated by the virtual switch in the ES and sent to the OLT through the physical path of the wavelength channel. Through a burst 10-G NIC, this wavelength path is shared among these logical paths from VNFs in a particular ES.

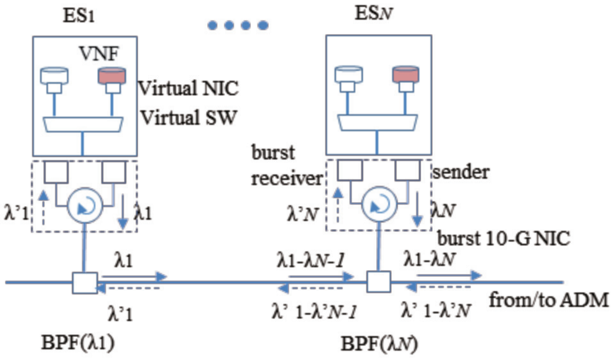

Fig. 6. Schimatic of the edge servers and shared fiber bus.

D. Wavelength switching by ADM to enable live-migration

The maximum bandwidth is a physical burst 10-G NIC of the ES, and DBA control among VNFs should be done within this bandwidth. If the total demand of VNFs exceeds the physical resources of the edge server, some of the VNFs are live-migrated into another ES that has excess resources, which means that in-service VNFs move. When live migration of a VNF occurs, the accommodation of the logical path between the VNF and OLT should be changed from the original ES to the destination ES in the physical path determined by shared fiber ports and wavelength channels. For this switching, we now describe the ADM configuration of the proposed architecture with several shared fiber ports.

Figure 7 shows the ADM configuration of the proposed architecture. This ADM can select an arbitrary wavelength channel by ADM. In this example, the number of wavelength channels is N=12. In a shared fiber port, WDM signals are transmitted because ESs have wavelength channels. In this ADM configuration, WDM signals demultiplxed in the wavelength router WR1 are sent to the tunable directional couplers (TCs). There are two TC statuses. One is "pass mode", where all the power is transmitted to the output of an ADM. The signals are multiplexed in WR3 and sent to the next ADM. The other is "drop mode", where some of the optical power is sent to the add/drop part and the rest is sent to the output of the ADM. The drop-side outputs of the TC are connected to WR3 for the add/drop output of the ADM and the selected signal is sent to the OLT. When TC3 is drop mode, wavelength channels of λ3 is selected at the output port of WR3, as shown in Fig. 6.

The divide ratio of a TC depends on the number of VNFs and the power of dropped wavelength channel signals is adjusted to equalize among OLTs. If the maximum drop is D, the divide ratio of a TC is $1/(D-i+1)$ where i-th dropped ADM. For example, when D=1, the first dropped ADM drops by a divide ratio of 0.05 and the 20th ADM drops all power. A Mach-Zehnder interferometer-type optical switch on the planner lightwave circuit [9], for example, is suitable for TC device selection because the coupling ratio can vary due to the input electrical current and easily integrated with wavelength multiplexers [10].

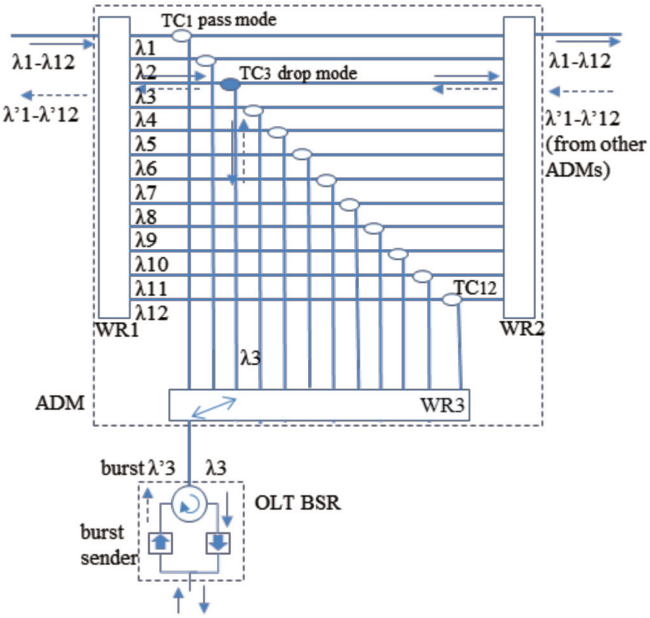

Fig. 7. Example of ADM configuration (N=12)

To avoid a reflection problem in bidirectional transmission, such as optical amplifier oscillation, different wavelength bands (e.g., C and L bands) are used for the upstream and downstream wavelength λ' and λ sets because the cyclic characteristics are the same at every free spectral range, as shown in Fig. 8. For WR1, WR2, and WR3 of this ADM configuration, an arrayed waveguide grating filter (AWGF) [12] is used, which has cyclic characteristics between input/output ports and wavelength channels [13]. In an N-port AWGF, when an optical signal is transmitted to the input port i, the wavelength channel of output port j is $\lambda i+j-1$ mod N.

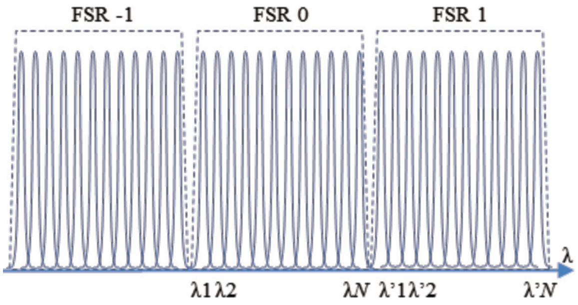

Fig. 8. Wavelength band selection for upstream and downstream.

IV. CONCLUSIONS

We proposed a virtual edge architecture with a partial – power-drop ADM configuration. We adopted the VNF corresponding to an OLT of a 10GE-PON, which leads to a simple physical star topology that is constructed due to a partial power drop in ADMs. The bandwidth allocation among VNFs is possible by dynamic bandwidth allocation and live migration accompanied with wavelength channel switching. The live migration of a VNF is limited to a part of the VNF that contains a larger number of subscribers. This architecture leads to a reduction in high-speed management computation time of live migration and DBA control, even though the number of VNFs is large.

REFERENCES

[1] ETSI, "GS NFV001 V1.1.1," Oct. 2013: http://www.etsi.org/technologies-clusters/technologies/nfv.

[2] F. T. An, K. S. Kim, D. Gutierrez, S. Yam, E. Hu, K. Shrikhande, and L. G. Kazovsky," SUCCESS: A next-generation hybrid WDM/TDM optical access network architecture," J-LT, vol. 22, no. 11, pp. 2557-2569, Nov. 2004.

[3] H. Nakamura, K. Taguchi, S. Tamaki, T. Mizuno, Y. Hashizume, T. Yamada, M. Itoh, H. Takahashi, S. Kimura, and N. Yoshimoto "40Gbit/s-class-λ-tunable WDM/TDM-PON using tunable B-Tx and cyclic AWG router for flexible photonic aggregation networks," Proc. *ECOC* 2012, Tu.4.B.3, Sep. 2012.

[4] I. Redpath, D. Cooperson, and R. Kline, "Metro WDM Networks Develop an Edge," Proc. *OFC/NFOFC* 2006, NThC1, March 2006.

[5] M. Jinno, H. Takara, B. Kozicki, Y. Tsukishima, Y. Sone, and S. Matsuoka, "Spectrum-Efficient and Scalable Elastic Optical Path Network: Architecture, Benefits, and Enabling Technologies," IEEE *Com. Mag.*, vol. 47, no. 11, pp. 66-73, Nov. 2009.

[6] IEEE Std 802.3.av, Oct.(2009)

[7] K. Mochizuki, H. Yamazaki, A. Misawa, "Bandwidth Guaranteed Method to Relocate Virtual Machines for Edge Cloud Architecture," Proc. *APNOMS*, TS8-3, Sep. 2013.

[8] M. Nakagawa, K. Hattori, N. Kimishima, M. Katayama, and A. Misawa, "Hierarchical Time-Slot Allocation for Dynamic Bandwidth Control in Optical Layer-2 Switch Network," IEICE *Trans. Commun.*, vol. E97-B, no. 7, July 2014, pp. 1303-1312.

[9] H. Nakamura, K. Taguchi, S. Tamaki, T. Mizuno, Y. Hashizume, T. Yamada, M. Ito, H. Takahashi, and N. Yoshimoto., "40Gbit/s-class-λ-tunable WDM/TDM-PON using tunable B-Tx and cyclic AWG router for flexible photonic aggregation networks," Proc. *ECOC* 2012, Tu.4.B.3, Sep. 2012.

[10] K. Suzuki, T. Yamada, H. Ishii, T. Shibata, and S. Mino, "High-Speed Optical 1 × 4 Switch Based on Generalized Mach–Zehnder Interferometer With Hybrid Configuration of Silica-Based PLC and Lithium Niobate Phase-Shifter Array," Photo. Tech. Lett., 19. 9, pp. 674-676, May 2007.

[11] I. Ogawa, F. Ebisawa, N. Yoshimoto, K. Takiguchi, F. Hanawa, T. Hashimoto, A. Sugita, M. Yanagisawa, Y. Inoue, Y. Yamada, Y. Tohmori, S. Mino, T. Ito, K. Magari, Y. Kawaguchi, A. Himeno, and K. Kato, "Loss-less hybrid integrated 8-ch optical wavelength selcector module using PLC platform and PLC-PLC direct attachment technique," in Proc. OFC '98, PD4-1, 1998.

[12] H. Takahashi, S. Suzuki, K. Kato and I. Nishi, "Arrayed-waveguide grating for wavelength division multi/demultiplexer with nanometer resolution," Electron. Lett., vol. 26, no. 2, pp. 87-88, 1990.

[13] A. Misawa, K. Habara, and T. Matsunaga, "Frequency-channel selector with multi-output ports for photonic ATM switches," in Proc. IOOC/ECOC '97, Edinburgh, Scotland, WE1A 1997