Stacked-VLAN-Based Modeling of Hybrid ISP Traffic Control Schemes and Service Plans Exploiting Excess Bandwidth in Shared Access Networks

Kyeong Soo Kim
Department of Electrical and Electronic Engineering
Xi’an Jiaotong-Liverpool University
Suzhou, 215123, P. R. China
Email: Kyeongsoo.Kim@xjtlu.edu.cn

***Abstract*—The current practice of shaping subscriber traffic using a token bucket filter by Internet service providers may result in a severe waste of network resources in shared access networks; except for a short period of time proportional to the size of a token bucket, it cannot allocate excess bandwidth among active subscribers even when there are only a few active subscribers. To better utilize the network resources in shared access networks, therefore, we recently proposed and analyzed the performance of access traffic control schemes, which can allocate excess bandwidth among active subscribers proportional to their token generation rates. Also, to exploit the excess bandwidth allocation enabled by the proposed traffic control schemes, we have been studying flexible yet practical service plans under a hybrid traffic control architecture, which are attractive to both an Internet service provider and its subscribers in terms of revenue and quality of service. In this paper we report the current status of our modeling of the hybrid traffic control schemes and service plans with OMNeT++/INET-HNRL based on IEEE standard 802.1Q stacked VLANs.**

***Index Terms*—ISP traffic control, excess bandwidth allocation, stacked VLANs.**

I. Introduction

The resource sharing in shared access networks — like cable Internet based on hybrid fiber-coaxial (HFC) networks or passive optical networks (PONs) — is a key to achieving lower infrastructure cost and higher energy efficiency. The full sharing of the bandwidth available among subscribers in a shared access network, however, is hindered by the current practice of traffic control by Internet service providers (ISPs), which is illustrated in Fig. 1; due to the arrangement of traffic shapers (i.e., token bucket filters (TBFs)) and a scheduler in the access switch, the capability of allocating available bandwidth by the scheduler is limited to the *traffic already shaped* per service contracts with subscribers [1], [2].

Even though the allocation of excess bandwidth in a shared link has been discussed in the general context of quality of service (QoS) control (e.g., [4]), it is recently when the issue was studied in the specific context of ISP traffic control in shared access [5], [6]. Based on the ISP traffic control schemes proposed in [5] and [6], we have been studying the design of flexible yet practical ISP service plans exploiting the excess bandwidth allocation in shared access networks under a hybrid ISP traffic control architecture in order to gradually introduce the excess bandwidth allocation while providing backward

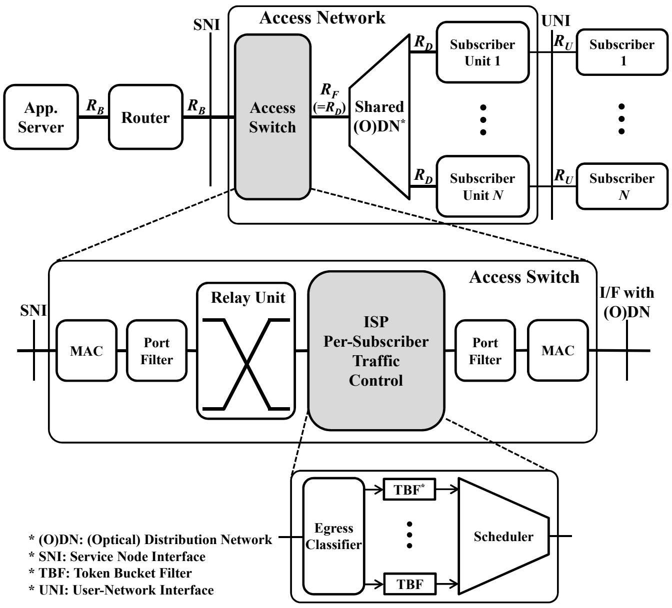

Fig. 1. Overview of current practice of ISP traffic control in shared access (shown for downstream traffic only) [3].

compatibility with the existing traffic control infrastructure [3]. To the best of our knowledge, our work in [3], [5], [6] is the first effort to study the issue of enabling excess bandwidth allocation among the subscribers, together with its business aspect, in the context of ISP traffic control in shared access.

In this paper, we report the current status of our modeling of the hybrid ISP traffic control schemes and service plans exploiting excess bandwidth in shared access networks with OMNeT++ [7] and INET-HNRL[1] based on the stacked virtual local area networks (VLANs) of IEEE standard 802.1Q [9].

II. Review of Hybrid ISP Traffic Control for Shared Access

In this section, we briefly review the hybrid ISP traffic control schemes and service plans for shared access that we

[1]A fork of INET framework (rev. INET-20111118) [8] and available at http://github.com/kyeongsoo/inet-hnrl, which requires OMNeT++ version 4.6 and later.

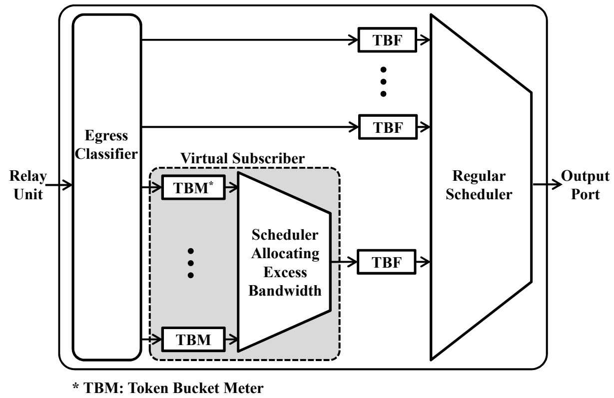

Fig. 2. Hybrid ISP traffic control for a flexible service plan exploiting excess bandwidth allocation [3].

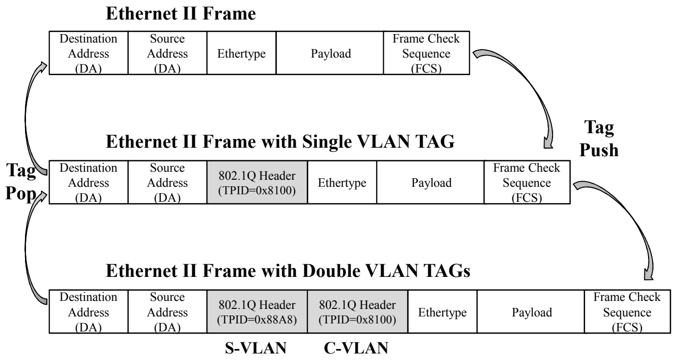

Fig. 3. Frame formats for VLAN stacking.

proposed in [3].

Fig. 2 shows the proposed architecture for hybrid ISP traffic control, where there coexist subscribers for the current flat-rate service plan and those for a new service plan fully sharing the bandwidth among them. For backward compatibility with the existing traffic control and pricing schemes, the new service plan subscribers are grouped together and treated as one *virtual* subscriber under the flat-rate service plan; at the same time, the traffic from each subscriber of the new service plan is individually controlled by an ISP traffic control scheme enabling excess bandwidth allocation within the group. The migration toward fully-shared access will be completed when all the subscribers of the flat-rate service plan move to the new service plan exploiting excess bandwidth allocation.

Note that, for the new service plan to be acceptable, it is desirable that there should be no disadvantage in adopting the new service plan for both ISP and its subscribers compared to the existing flat-rate service plan. In this regard, we can derive requirements for the new service plan to meet in terms of parameters for existing flat-rate service plans, including monthly price, token generation rate, and token bucket size. Interested readers are referred to [3] for details.

III. Modeling of Hybrid ISP Traffic Control Schemes and Service Plans Based on Stacked-VLANs

As discussed in [10], we have already implemented models of the shared access network shown in Fig. 1 based on VLAN as part of INET-HNRL, because we want abstract models that can provide features common to specific systems (e.g., cable Internet and Ethernet PON (EPON)), while being practical enough to be compatible with other components and systems of the whole network. In the VLAN-based shared access models, we use a VLAN identifier (VID) to identify each subscriber, which is similar to the service identifier (SID) in cable Internet and the logical link identifier (LLID) in EPON.

For the implementation of models for the hybrid ISP traffic control shown in Fig. 2, we can think of two distinct approaches, i.e., an integrated approach where we implement the whole scheduling as one system (e.g., based on the hierarchical token bucket (HTB) scheduler [4]) and a modular approach where we integrate separate schedulers (e.g., a scheduler based on TBF shaping and a DRR-based scheduler enabling excess bandwidth allocation [6]) into one. Considering the ease of the management of two separate groups of subscribers and the upgradability of the component scheduler allocating excess bandwidth independently of the traditional one based on TBFs, we have chosen a modular approach and again based our implementation on VLAN.

Unlike existing models based on a single VLAN tag per frame, we need two different ways of identifying frames from the subscribers for the new hybrid traffic control scheme and service plan: As for the existing TBF-based traffic control scheme, the whole frames from those subscribers need to be identified and treated as a group (i.e., one virtual subscriber) for traffic shaping and scheduling; as for the new excess-bandwidth-allocating traffic control scheme, on the other hand, the frames from each subscriber need to be identified and treated as a separate flow. Fortunately, this requirement of hierarchical identification of Ethernet frames under the new hybrid traffic control scheme can be met by the technique of *stacked VLANs* (also called *provider bridging* and *Q-in-Q*), which is now part of IEEE standard 802.1Q [9]. The change of Ethernet frame formats related with the VLAN stacking and two tag operations are shown in Fig. 3. Note that the tag protocol identifier (TPID) of the second service VLAN (S-VLAN) tag is set to a value of 0x88A8, different from the value of 0x8100 for the first customer VLAN (C-VLAN) tag.

Fig. 4 shows stacked-VLAN-based modeling of a shared access network with hybrid ISP traffic control, while Figs. 5 and 6 show the Ethernet switch module for ONUs, OLTs, and access switches, and the Ethernet MAC module implementing hybrid ISP traffic control, respectively; as for the traffic control schemes enabling excess bandwidth allocation, there are implemented two queue types, i.e., *CSFQVLANQueue5* for the algorithm based on core-stateless fair queueing (CSFQ) [5] and *DRRVLANQueue3* for the algorithm based on deficit round-robin (DRR) [6].

First, the “olt_c” access switch carries out individual traffic control based on the customer VID (C-VID) of a frame with a single C-VLAN tag, which is assigned to each subscriber, and sends resulting frames to the second access switch node

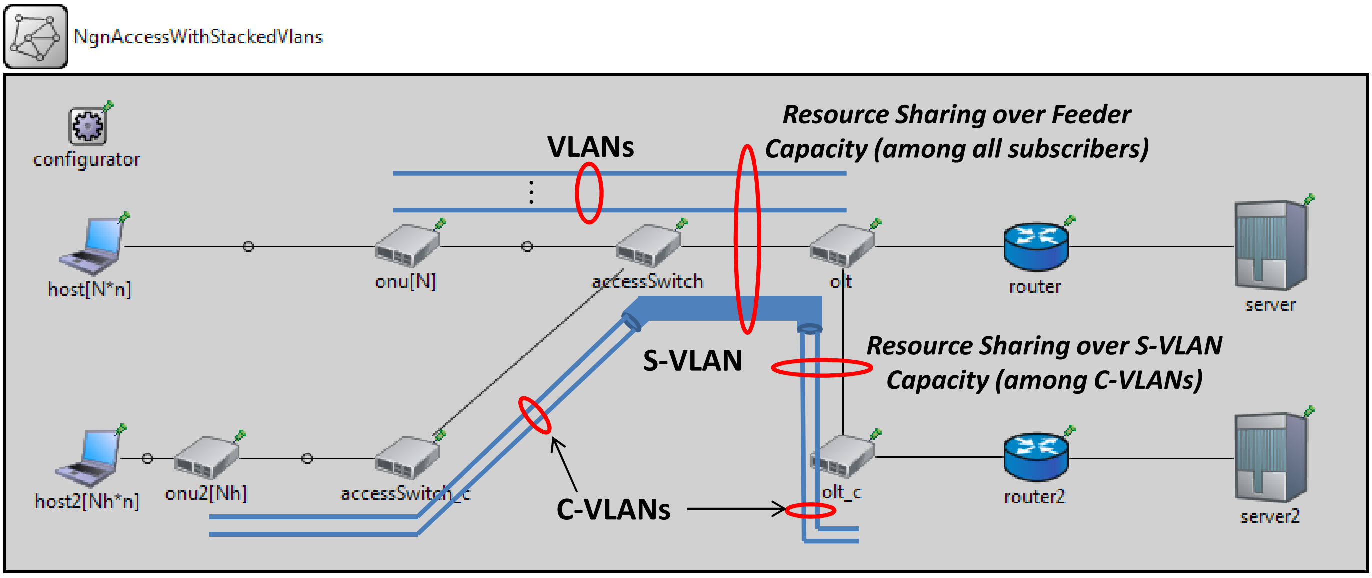

Fig. 4. Stacked-VLAN-based modeling of an access network with hybrid ISP traffic control.

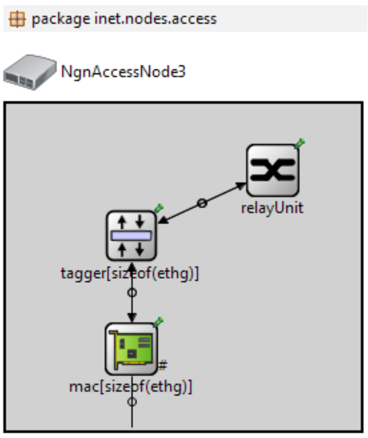

Fig. 5. Ethernet switch module (*NgnAccessNode3*) with stacked-VLAN capabilities (for ONUs, OLTs, and access switches shown in Fig. 4).

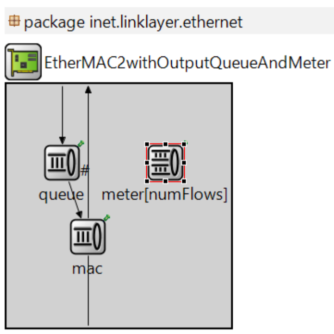

Fig. 6. Ethernet MAC (*EtherMAC2*) module with a queue and a traffic meter for modeling of hybrid ISP traffic control.

"olt". At the "olt", the C-VLAN frames are grouped together with the second S-VLAN tag (i.e., VLAN stacking) and go through another traffic control together with frames from other subscribers with normal (i.e., unstacked) VLAN tags. In this way, traffic for the subscribers of the new hybrid traffic control scheme and service plan goes through two stages of traffic control, i.e., one at the "olt_c" exploiting excess bandwidth allocation and the other at the "olt" based on traditional TBF-based traffic shaping.

In implementing models of the hybrid traffic control in shared access based on stacked VLANs, we tried to meet the following major requirements:

- *Backward compatibility* with the existing VLAN implementations in INET-HNRL, including
  - *EthernetFrameWithVLAN* message format
  - *MACRelayUnitNPWithVLAN* and *VLANTagger* modules
- *Expandability* to stack more than two VLAN tags

Consider the original definition of *EthernetFrameWithVLAN* message shown in Fig. 7 (a). Because the *MACRelayUnitNPWithVLAN* switching module is based on the *vid* field of the *EthernetFrameWithVLAN* message, which is directly accessible by the *getVid()* member function, we had to keep these fields in the new definition of *EthernetFrameWithVLAN* message. For stacking of VLAN tags, on the other hand, we need to introduce *innerTags* field based on the *stack* C++ type, which is shown in Fig. 7 (b) and ignored by the existing modules based on the original definition of *EthernetFrameWithVLAN* message, including *MACRelayUnitNPWithVLAN* module. In this way, we can meet both the requirements.

Note that in the current implementation of stacked VLANs, broadcasting is not allowed across the hierarchies of stacked VLANs. In the shared access network model shown in Fig. 4,

```
packet EthernetIIFrameWithVLAN extends EthernetIIFrame
{
    uint16_t tpid = 0x8100; // tag protocol identifier (16 bits; set to 0x8100)
    uint8_t pcp; // priority code point for IEEE 802.1p class of service (3 bits; 0 (lowest) to 7 (highest))
    bool dei; // drop eligible indicator (1 bit)
    uint16_t vid; // VLAN identifier (12 bits; 0x000 and 0xFFF are reserved, which allows up to 4094 VLANs)
}
```

(a)

```
cplusplus {{
#include <stack>
#include "VLAN.h" // define VLANTag struct
typedef std::stack<VLANTag> VLANTagStack;
}}

class noncobject VLANTagStack;

packet EthernetIIFrameWithVLAN extends EthernetIIFrame
{
    uint16_t tpid; // tag protocol identifier (16 bits; set to 0x8100 for C-TAG & 0x88A8 for S-TAG)
    uint8_t pcp; // priority code point for IEEE 802.1p class of service (3 bits; 0 (lowest) to 7 (highest))
    bool dei; // drop eligible indicator (1 bit)
    uint16_t vid; // VLAN identifier (12 bits; 0x000 and 0xFFF are reserved, which allows up to 4094 VLANs)

    // optional; IEEE 802.1Q-in-Q stacked VLANs.
    VLANTagStack innerTags; // based on std::stack
}
```

(b)

Fig. 7. Message definitions of Ethernet II frame with VLAN support: (a) Without and (b) with VLAN stacking.

for example, broadcasting is possible among normal VLANs or C-VLANs within the same S-VLAN. Broadcasting over the hierarchies of stacked VLANs requires the modification of the learning mechanism implemented in the current *MACRelayUnitNPWithVLAN* module.

IV. Summary

In this paper we discuss the issues in current practice of ISP traffic shaping and related flat-rate service plans in shared access networks and review alternative service plans based on new hybrid ISP traffic control schemes exploiting excess bandwidth. We also report the current status of our modeling of the hybrid ISP traffic control schemes and service plans with OMNeT++/INET-HNRL based on stacked VLANs.

In implementing models of the hybrid traffic control in shared access based on stacked VLANs, we maintain backward compatibility with the existing modules for Ethernet switching and VLAN tagging and yet enable the support of stacking of multiple VLAN tags by clever modification of the message definition for Ethernet frame with VLAN tags.

Acknowledgment

This work was supported by Xi’an Jiaotong-Liverpool University Research Development Fund (RDF) under grant reference number RDF-14-01-25.

References

[1] S. Bauer, D. Clark, and W. Lehr, “PowerBoost,” in *Proc. HomeNets’11*. New York, NY, USA: ACM, Aug. 2011, pp. 7–12.

[2] L. Farmer and K. S. Kim, “Cooperative ISP traffic shaping schemes in broadband shared access networks,” in *Proc. the 4th International Workshop on Fiber Optics in Access Network (FOAN 2013)*, Sep. 2013, pp. 21–25.

[3] K. S. Kim, “Toward fully-shared access: Designing ISP service plans leveraging excess bandwidth allocation,” in *Proc. ICTC 2014*, Busan, Korea, Oct. 2014, pp. 897–900.

[4] M. Devera. Linux HTB home page. [Online]. Available: http://luxik.cdi.cz/~devik/qos/htb/

[5] K. S. Kim, “On the excess bandwidth allocation in ISP traffic control for shared access networks,” *IEEE Commun. Lett.*, vol. 18, no. 4, pp. 692–695, Apr. 2014.

[6] ——, “On guaranteeing the quality of service of conformant traffic in excess bandwidth allocation for shared access networks,” in *Proc. IEEE Sarnoff Symposium 2015*, Aug. 2015.

[7] A. Varga, “The OMNeT++ discrete event simulation system,” in *Proc. the European Simulation Multiconference (PESM2001)*, Prague, Czech Republic, Jun. 2001, pp. 319–324. [Online]. Available: http://www.omnetpp.org/

[8] A. Varga *et al.* INET framework for OMNeT++ 4.0. [Online]. Available: http://inet.omnetpp.org/

[9] IEEE Computer Society, *IEEE Std 802.1Q^{TM}-2014, IEEE Standard for local and metropolitan area networks: Bridges and bridged networks*, IEEE Std., Nov. 2014.

[10] K. S. Kim, “The effect of ISP traffic shaping on user-perceived performance in broadband shared access networks,” *Computer Networks*, vol. 70, pp. 192–209, Sep. 2014.