Toward Fully-Shared Access: Designing ISP Service Plans Leveraging Excess Bandwidth Allocation

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

Abstract—Shaping subscriber traffic based on token bucket filter (TBF) by Internet service providers (ISPs) results in waste of network resources in shared access when there are few active subscribers, because it cannot allocate excess bandwidth in the long term. New traffic control schemes have been recently proposed to allocate excess bandwidth among active subscribers proportional to their token generation rates. In this paper we report the current status of our research on designing flexible yet practical service plans exploiting excess bandwidth allocation enabled by the new traffic control schemes in shared access networks, which are attractive to both ISP and its subscribers in terms of revenue and quality of service (QoS) and serve as a stepping stone to fully-shared access in the future.

Index Terms—Access, service plan, network pricing, resource allocation, Internet service provider (ISP), traffic shaping, quality of service (QoS).

I. INTRODUCTION

The current implementation and operation of traffic control schemes by Internet service providers (ISPs) for shared access (e.g., cable Internet or Ethernet passive optical network (EPON)) prevent subscribers from getting the benefits of full sharing of resources available in the network; due to the arrangement of traffic shapers and a scheduler in the access switch shown in Fig. 1, the capability of allocating available bandwidth by the scheduler (e.g., weighted fair queueing (WFQ)) is limited to traffic already shaped by token bucket filters (TBFs) per service contracts with subscribers. This means that, even though the network is shared access, it is being managed by ISPs as if it is dedicated access. With the current practice of ISP traffic control in shared access, therefore, we cannot expect any fundamental sharing of resources in the long term except for that in the short term controlled by the size of a token bucket [1], [2].

In fact, the allocation of excess bandwidth in a shared link has long been discussed in the context of quality of service (QoS) control in routers (e.g. [3]) and recently in the more specific context of ISP traffic control in shared access in [4] and [5]; the major goal of the latter discussions is to allocate excess bandwidth among active subscribers in a fair and efficient way while not compromising the service contracts specified by the original token bucket algorithm for conformant subscribers in all time scales and with practical implementation. The business aspect of the excess bandwidth allocation in ISP traffic control, however, is yet to be investigated because the flat-rate service plan — dominant one in current residential broadband access



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

market — is so tightly coupled with traffic shaping based on TBFs that it cannot exploit the excess bandwidth allocation.

In this paper we report the current status of our research on designing flexible yet practical ISP service plans leveraging the excess bandwidth allocation enabled by the recently proposed ISP traffic control schemes in shared access networks. We first consider an architecture for hybrid ISP traffic control to gradually introduce the excess bandwidth allocation while providing backward compatibility with the existing traffic control infrastructure and then discuss the requirements for a new service plan to provide benefits for both ISP and its subscribers compared to the existing flat-rate service plans. Then we provide a design example for a new service plan meeting the requirements derived in this paper and discuss the impact of key design parameters on ISP revenue and subscriber QoS.



* TBM: Token Bucket Meter

Fig. 2. Hybrid ISP traffic control for a flexible service plan leveraging excess bandwidth allocation.

II. DESIGNING SERVICE PLANS LEVERAGING EXCESS BANDWIDTH ALLOCATION

A. Hybrid ISP Traffic Control Architecture

Much of existing work on Internet pricing focuses on congestion pricing based on the game theory (e.g., [6]). As discussed in [7], however, the game-theory-based framework does not fit the current practice of ISP traffic control and dominant flat-rate service plans. Rather, a hybrid approach like the proposal for a flexible service plan based on both flatrate and usage-based ones in [8] seems more practical and appealing to ISPs and subscribers, which is still static in that there is no interaction between ISP and its subscribers during the operation.

Taking the current flat-rate service plan based on traffic shaping by TBFs as a starting point for our design of a new service plan, we propose an architecture for hybrid ISP traffic control shown in Fig. 2 in order to gradually introduce the excess bandwidth allocation in shared access. For backward compatibility with the existing infrastructure for traffic control and pricing, a group of subscribers for this new service plan is treated as one *virtual* subscriber (i.e., their traffic is collectively controlled by a single TBF and also under a flat-rate service plan during the plan design procedure); for a new service plan leveraging excess bandwidth allocation, on the other hand, the traffic from each subscriber belonging to this group is individually controlled by the new ISP traffic control scheme enabling excess bandwidth allocation within the group.

Note that the migration toward fully-shared access will be finished when those subscribers under traditional TBF-based traffic shaping and flat-rate service plans also move under new traffic control schemes enabling excess bandwidth allocation and new flexible service plans, where all the network resources are fully and efficiently shared among the subscribers.

B. Requirements & Design Guidelines for New Service Plans

For a new service plan to be acceptable, it is desirable to guarantee that there should be no disadvantage for both ISP and its subscribers compared to the existing flat-rate service plans. Here we discuss and derive requirements for a new service plan in terms of parameters for existing flat-rate service plans.

Consider the case of designing a new service plan based on the two existing flat-rate service plans specified as follows:

- Lower-rate flat-rate service plan (for the individual subscribers)
 - Monthly price: P_L
 - Token generation rate: TGR_L
 - Token bucket size: TBS_L
- Higher-rate flat-rate service plan (for the virtual subscriber)
 - Monthly price: P_H
 - Token generation rate: TGR_H
 - Token bucket size: TBS_H

Based on the arrangement of traffic shaper and new traffic control scheme enabling excess bandwidth allocation shown in Fig. 2, we are to provide a new service plan which is specified as follows:

- New hybrid service plan
 - Number of subscribers: N
 - Monthly price: P + P(u)
 - Token generation rate: TGR_L
 - Token bucket size: TBS_L

P is a fixed, minimum price, and P(u) is a usage-based price function where u is the usage of excess bandwidth (i.e., the amount of non-conformant traffic). Note that this group of Nsubscribers is considered as one virtual subscriber as for traffic management and pricing in deriving requirements for a new service plan in the following.

First of all, for this new service plan to be feasible in terms of subscriber QoS, the sum of token generation rates for lower-rate plan subscribers should be no greater than the token generation rate of higher-rate plan, i.e.,

$$N \times TGR_L \le TGR_H,\tag{1}$$

or

$$N \le \frac{TGR_H}{TGR_L}.$$
(2)

From ISP's perspective, the revenue from the new service plans should be no less than either of that from the higher-rate flat-rate service plan for the virtual subscriber or the sum of those from the lower-rate flat-rate service plan for individual subscribers, i.e.,

$$\sum_{i=1}^{N} \{P + P(u_i)\} \ge P_H,$$
(3)

$$\sum_{i=1}^{N} \{P + P(u_i)\} \ge \sum_{i=1}^{N} P_L,$$
(4)

where u_i is the usage of excess bandwidth by the *i*th subscriber.

From subscribers' perspective, on the other hand, the price for the new service plan should be no greater than that of the higher-rate flat-rate service plan and, when there is no usage of excess bandwidth, equal to that of the lower-rate one, i.e.,

$$P + P(u_{max}) \le P_H,\tag{5}$$

$$P + P(0) = P_L, \tag{6}$$

where u_{max} is the maximum amount of excess bandwidth that one subscriber can use for a month. u_{max} corresponds to the extreme case where only one subscriber uses all the available excess bandwidth for a whole month with all other subscribers inactive, i.e.,

$$u_{max} = (TGR_H - TGR_L) T_{month} + (TBS_H - TBS_L),$$
(7)

where T_{month} is a time period for a month. Considering the first term is usually much larger than the second term in (7), u_{max} can be approximated as follows:

$$u_{max} \approx (TGR_H - TGR_L)T_{month}.$$
 (8)

As for P(u), we assume that it is a monotone-increasing function with P(0) = 0, which gives $P = P_L$ from (6). In case of a simple linear function, i.e., $P(u) = \alpha u$ for a nonnegative constant α , we obtain the following from (3) and (5) using (8):

$$\alpha \sum_{i=1}^{N} u_i \ge P_H - N \times P_L,\tag{9}$$

$$\alpha \le \frac{P_H - P_L}{\left(TGR_H - TGR_L\right)T_{month}}.$$
 (10)

In (9), because $\sum_{i=1}^{N} u_i$ is bounded by u_{max} , it can be rewritten as follows:

$$\alpha \ge \frac{P_H - N \times P_L}{(TGR_H - TGR_L) T_{month}}.$$
(11)

Also, because the left-hand side of (9) becomes zero when $u_i = 0$ for $\forall i$, the right-hand side should be no greater than zero, i.e.,

$$P_H - N \times P_L \le 0, \tag{12}$$

or

$$N \ge \frac{P_H}{P_L},\tag{13}$$

Note that, given the two existing flat-rate service plans and a simple linear usage-based price function, (2) & (13) and (10) & (11) provide requirements for the the slope of linear price function (i.e., α) and the number of subscribers (i.e., N), respectively. The guidelines for designing a new hybrid service plan based on the results in this section are summarized in Table I.

C. A Design Example

To illustrate how to design a new service plan using the requirements and design guidelines described in Sec. II-B, here we provide a design example based on the flat-rate service plans from Virgin Media Cable Internet [9].

According to their service plans, the lowest tier provides up to 50 Mbit/s speed for $\pounds 26.50$ per month, while the highest tier

up to 152 Mbit/s speed for \pounds 39 per month. The flat-rate service plan parameters, therefore, can be summarized as follows:

- Lower-rate flat-rate service plan
 - Monthly price (P_L) : £26.50 per month

- Token generation rate (TGR_L) : 50 Mbit/s

- Higher-rate flat-rate service plan
 - Monthly price (P_H) : £39 per month
 - Token generation rate (TGR_H) : 152 Mbit/s

Note that token bucket sizes for both service plans are unknown, but they are not used in the requirements for design parameters as discussed in II-B. T_{month} (assuming 30 days per month) and u_{max} in this case become 2.592e+6 s and 2.644e+8 Mbit, respectively.

From Table I, we obtain

$$\frac{39}{26.5} \approx 1.472 \le N \le \frac{152}{50} = 3.04. \tag{14}$$

For this design example, we set N to 3, i.e., the maximum possible value. For the slope of linear usage-based price function, we obtain

$$0 \le \alpha \le 4.728 \text{e-8 \pounds/Mbit.}$$
(15)

If we take a maximum value for α to maximize the revenue of ISP, the resulting hybrid service plan is specified as follows:

- Hybrid service plan
 - Number of subscribers: 3
 - Monthly price: $\pounds(26.50 + 4.728e \cdot 8 \times u)$
 - Token generation rate: 50 Mbit/s

where u is the usage of excess bandwidth in Mbit.

With this new hybrid service plan, we consider two extreme cases of excess bandwidth utilization:

First, consider a case where only one subscriber is active and utilizes all the available excess bandwidth for the whole month (i.e., $u=u_{max}$). The revenue is £92, which is higher than either P_H or three times of P_L .

Second, consider another case where all three subscribers are active and evenly divide the available excess bandwidth (i.e., $u=\frac{152-3\times50}{3}\times2.592e+6$ Mbit). The revenue in this case is £79.745, which is still higher than either P_H or three times of P_L .

This design example demonstrates that the new hybrid service plan enables subscribers to enjoy benefits of both flatrate service plans through excess bandwidth allocation without much increase in monthly payments, while improving the revenue of ISP depending on the usage patterns of subscribers.

III. CONCLUDING REMARKS

In this paper we have discussed the issues in current practice of ISP traffic shaping and related flat-rate service plans in shared access networks and suggested alternative service plans based on new ISP traffic control schemes enabling excess bandwidth. We have proposed a hybrid ISP traffic control architecture to gradually introduce the excess bandwidth allocation in shared access, and, based on the proposed architecture,

Parameters	Flat-rate service plans		Hybrid service plan
	Lower rate	Higher rate	
Token generation rate	TGR_L	TGR_H	TGR_L
Monthly price	P_L	P_H	$ \begin{array}{ c c } P_L + \alpha u \\ \text{where } \alpha \geq \max\left(0, \frac{P_H - N \times P_L}{(TGR_H - TGR_L)T_{month}}\right) \\ \text{and } \alpha \leq \frac{P_H - P_L}{(TGR_H - TGR_L)T_{month}}. \end{array} $
Number of subscribers			where $\frac{P_H}{P_L} \le N \le \frac{TGR_H}{TGR_L}$.

 TABLE I

 Design guidelines for a new hybrid service plan

provided requirements for new service plans leveraging excess bandwidth allocation.

Note that the impact of aggregate traffic from the group of subscribers under a new service plan on metro and backbone networks is yet to be investigated because it is likely that the utilization of a group of subscribers is higher than that of a single subscriber under the higher-rate flat-rate service plan.

References

- 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] M. Devera. Linux HTB home page. [Online]. Available: http: //luxik.cdi.cz/~devik/qos/htb/
- [4] 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.
- [5] —, "Deficit round-robin-based ISP traffic control scheme enabling excess bandwidth allocation in shared access networks," Mar. 2014, *submitted to IEEE Communications Letters*. [Online]. Available: http://arxiv.org/abs/1403.5712
- [6] X.-R. Cao, H.-X. Shen, R. Milito, and P. Wirth, "Internet pricing with a game theoretical approach: Concepts and examples," *IEEE/ACM Trans. Netw.*, vol. 10, no. 2, pp. 208–216, Apr. 2002.
- [7] J. W. Roberts, "Internet traffic, QoS, and pricing," Proceedings of the IEEE, vol. 92, no. 9, pp. 1389–1399, Sept 2004.
- [8] J. Altmann and K. Chu, "A proposal for a flexible service plan that is attractive to users and internet service providers," in *Proc. INFOCOM* 2001, vol. 2, 2001, pp. 953–958.
- [9] Virgin media broadband service plans. Accessed: 2014-09-15. [Online]. Available: http://store.virginmedia.com/broadband/compare-broadband/ index.html