Peer-assisted Network Operator-friendly P2P Traffic Control Technique

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***Abstract*—In the existing network operator-friendly traffic control techniques, the network operator provides network information as a guidance to the peers so that the P2P traffic flows as it intends, thus, realizing unilateral interaction from the network operator to the peers. In this paper, we propose bilateral cooperation between the network operator and the peers, in short BiCo. In BiCo, both parties participate in the P2P traffic control actively to improve a network efficiency while solving the identified limitations of existing work. In a nutshell, we divide measurement work into two parts, letting the peers collect fine-grained traffic information and enabling the network operator to grasp macroscopic information in order to issue useful guidances (including allowable traffic volume missing in the existing work). Our simulation results show that BiCo improves the network efficiency by distributing the traffic evenly over intra-domain links and by trying to fully utilize inter-domain links with given constraints while showing similar download completion time compared to the existing unilateral interaction.**

I. Introduction

The network operators are now facing challenges by P2P applications that generate extensive cross-domain traffic [1], [2]. Although the network operators have attempted to exercise various traffic control techniques such as caching [2] and rate limiting [3] to control the P2P traffic, most of them are not practically satisfactory.

As one alternative way for the P2P traffic control, several informed peer selection (IPS) schemes [4]-[14] have been proposed. In this technique, the peers are supposed to select their communication partners by following the guidance issued by the network operators so that some of inter-domain traffic may be redirected within a local domain without sacrificing the P2P system performance. The existing work has shown that inter-domain P2P traffic can be successfully reduced, while the peers can actually achieve better performance with IPS than without it.

However, we observe that most existing network operator-supported IPS techniques [4], [6], [8], [10], [11] define *unilateral interaction* where only the network operators strive to generate the guidance beneficial to both the network operators and the peers. In other words, the existing work focuses on the IPS design only from the network operator perspective, while overlooking what the peers could contribute. For example, in the current unilateral interaction, the network operators need to take charge of collecting the required network information to issue the guidance. This may cause measurement and analysis overhead to acquire flow-level information. In addition, the guidance of most existing work can be used by the peers as the network operator does not intend. In other words, it does not contain enough information to limit the P2P traffic to certain amount on specific links while only providing relative preference values about links like cost map [8] and ranking [10].

In the light of this observation, we propose *bilateral cooperation* between the network operator and the peers, shortly BiCo, to improve the network efficiency by overcoming the limitations of existing work. In BiCo, we identify following technical challenges. (1) The first challenge is how to divide measurement burden so that each party can do its measurement job more efficiently than the other party. For this, we allow the network operator to measure network link-level information such as link utilization while letting the peers measure peer-level information such as their communication partners and the corresponding traffic volume. (2) The second challenge is how to utilize the collected information to generate beneficial guidances. To effectively utilize the collected information, we design the guidance including the traffic bound (that is an amount of allowable P2P traffic) in addition to the preference value utilized in the existing work. We distinguish the guided traffic—traffic following the guidance—and the non-guided traffic through the peer reports so that we can utilize the existing traffic estimation technique to set the traffic bound for the guided traffic.

Our contributions are three-folds. First, we propose a novel bilateral cooperation architecture that enables efficient network information collection. Second, in addition to the simple preference value of the existing work, we add the notion of traffic bound as another metric in the guidance, so that the peers can not only tell which other peers to communicate with, but also be instructed up to how much traffic to transmit to the others. Finally, we extensively evaluate our architecture through simulation and show that BiCo improves the network efficiency by distributing the traffic evenly over intra-domain links and by trying to fully utilize the inter-domain links with given traffic-related constraints while showing similar download completion time compared to the existing work.

The rest of the paper is organized as follows. Section II provides a high level overview and the detail of BiCo including information collection and guidance generation. Section III

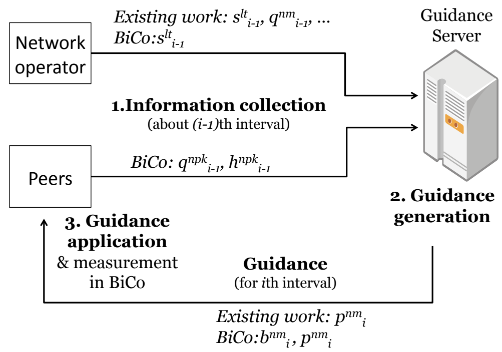


Fig. 1. Conceptual illustration of BiCo.

TABLE I
NOTATION

Parameter	Definition
p_k	peer k
d_m	network scope m
l_t	link t
c^{l_t}	link capacity of l_t
$s_i^{l_t}$	total traffic volume (*tv*) of l_t during *i*th interval
$q_i^{np_k}$ (q_i^{nm})	guided *tv* from d_n to p_k (to d_m)
$h_i^{np_k}$ (h_i^{nm})	# of p_k's (d_m's) neighbors belonging to d_n
a_i^{nm}	# of d_m's peers having d_n's peers as neighbors
$g_i^{l_t}$ ($ng_i^{l_t}$)	guided (non-guided) *tv* of l_t
$r_i^{l_t,nm}$	1 (if traffic from d_n to d_m passes l_t) or 0 (otherwise)
v_i^{nm}	potentiality of traffic generation from d_n to d_m
$v_i^{l_t}$	potentiality of traffic generation through l_t
$b_i^{l_t,nm}$ (b_i^{nm})	traffic bound from d_n to d_m through l_t (from d_n to d_m)
p_i^{nm} ($p_i^{l_t}$)	preference value from d_n to d_m (of l_t)
$f_i^{l_t}$	charging volume of l_t until *i*th interval
T	time interval for guidance generation

evaluates BiCo. Section IV presents related work and discussion issues and Section V concludes this paper.

II. BILATERAL COOPERATIVE P2P TRAFFIC CONTROL

A. Overview

Fig. 1 shows a high level overview of BiCo.[1] In BiCo, instead of solely relying on the network operator to collect the required information as in the existing work, we try to utilize the information from both parties, since they may collect different and useful information more efficiently than the other. Therefore, each party reports its measured information to the guidance server (that is managed by the network operator) periodically. Then, the guidance server generates the guidances including the allowable traffic bound in addition to the preference value to help the peers to apply the guidance effectively as the network operator intends. The generated guidances are about network scopes (NSes) from each NS perspective.[2] The guidance is about incoming traffic from other NSes, since the selected neighboring peers who belong to other NSes will send the guided traffic to peers who are in my NS. The peers select their communication partners based on the guidance during next time interval while measuring required information. Even though the network operator can collect the peer-level information by itself at cost of some measurement and analysis overhead, there may exist measurement errors by peers' reactions like dynamic port change and data encryption [15]. In addition, it is hard to measure some useful peer-level information like neighboring peer relationship that can be utilized for the guidance generation. We believe that the peer participation in BiCo enables us to overcome these limitations.

Peers are divided into two groups: guided peers (i.e., peers that follow the guidance) and non-guided peers (i.e., peers that do not follow the guidance). The traffic caused by the guidance is called guided traffic and otherwise non-guided traffic. The primary objectives of the network operator are to reduce cross-domain traffic while satisfying various requirements of inter-domain links and a reduced maximum link utilization (MLU) of its intra-domain links [8] and thus we focus on these two issues in this paper. We assume that every guided peer is innocent user that will not report false information and does not show misbehavior in following the guidance. For the sake of simplicity, we use d_m and d_n to indicate NS of current peers and counterpart NS of d_m, respectively.

[1]For parameters used in this paper, please refer to Table I.

[2]NS is a cluster sharing the same IP network prefix. For example, NS can be IP prefix in intra-domain and AS in inter-domain.

B. Information Collection

Every interval (e.g., (*i-1*)th interval), the guided peer p_k reports two kinds of information: network information ($q_{i-1}^{np_k}$) and neighboring peer information ($h_{i-1}^{np_k}$). The reports of guided peers are enough to calculate the flow-level traffic information, since the guided traffic is only generated by the requests of guided peers. Measuring $q_{i-1}^{np_k}$ may do not cause noticeable measurement overhead, since making a simple log about the received guided traffic is enough for the report. In addition, $h_{i-1}^{np_k}$ is usually managed by P2P application, which means there is no additional measurement overhead. The network operator can acquire $s_{i-1}^{l_t}$ by sending SNMP queries to its routers. This cooperative information collection may enable the network operator to collect the peer-level information with low measurement overhead.

C. Intra-Domain Traffic Control

BiCo tries to minimize MLU by distributing the P2P traffic evenly over intra-domain links. For this, BiCo calculates the guidances based on the network and neighboring peer information (Fig. 2). Here, NS can be regarded as IP prefix.

First, the guidance server processes the network information to estimate the allowable guided traffic volume through given intra-domain link for next (e.g., *i*th) interval as follows. The guidance server calculates the guided traffic volume ($g_{i-1}^{l_t}$) based on the reported guided traffic information ($q_{i-1}^{np_k}$) and the routing path information ($r_{i-1}^{l_t,nm}$) that can be given by the

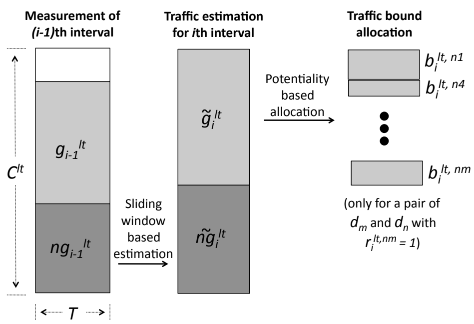


Fig. 2. Calculation and allocation of the traffic bound.

network operator.

$$q_{i-1}^{nm} = \sum_{k=1}^{|P|} q_{i-1}^{np_k}, \quad (1)$$

$$g_{i-1}^{l_t} = \sum_{n=1}^{|A|} \sum_{m=1, m \neq n}^{|A|} q_{i-1}^{nm} * r_{i-1}^{l_t,nm}, \quad (2)$$

where *P* is a set of guided peers of d_m and *A* is a set of NSes. Then, the guidance server calculates the non-guided traffic volume ($ng_{i-1}^{l_t}$) by subtracting $g_{i-1}^{l_t}$ from the total traffic volume ($s_{i-1}^{l_t}$).

$$ng_{i-1}^{l_t} = s_{i-1}^{l_t} - g_{i-1}^{l_t}. \quad (3)$$

With $ng_{i-1}^{l_t}$, the guidance server applies the traffic estimation techniques to estimate $\tilde{ng}_i^{l_t}$.[3] For example, with the sliding window of recent *N* intervals [9], $\tilde{ng}_i^{l_t}$ is $\frac{1}{N}\sum_{j=i-N}^{i-1} ng_j^{l_t}$. Finally, the guidance server estimates the allowable guided traffic volume ($\tilde{g}_i^{l_t}$) by subtracting $\tilde{ng}_i^{l_t}$ from $c^{l_t} * T$ (that is an allowable total traffic volume during *i*th interval).

$$\tilde{g}_i^{l_t} = c^{l_t} * T - \tilde{ng}_i^{l_t}. \quad (4)$$

The second step is to process the neighboring peer information to see a potentiality of guided traffic generation between NSes and of links. The results of this step are used to allocate the estimated guided traffic volume ($\tilde{g}_i^{l_t}$) to NSes as the traffic bound. The guidance server calculates following two values to see how many peers are related with each other in arbitrary two NSes (e.g., d_m and d_n).

$$h_{i-1}^{nm} = \sum_{k=1}^{|P|} h_{i-1}^{np_k}, \quad (5)$$

$$a_{i-1}^{nm} = \sum_{k=1}^{|P|} h_{i-1}^{np_k} / h_{i-1}^{np_k}, \quad (6)$$

(only for p_k with non-zero $h_{i-1}^{np_k}$). Intuitively the more number of neighboring peers, the more guided traffic that can be generated and there should be more relevant peers in both d_m and d_n for more guided traffic. Thus, the potentiality of the guided traffic generation is calculated as follows.

$$v_i^{nm} = \frac{h_{i-1}^{nm} * a_{i-1}^{nm}}{h_{i-1}^{nm} + a_{i-1}^{nm}}, \quad (7)$$

$$v_i^{l_t} = \sum_{n=1}^{|A|} \sum_{m=1, m \neq n}^{|A|} v_i^{nm} * r_i^{l_t,nm}. \quad (8)$$

As the final step, the guidance server allocates the allowable traffic bound ($b_i^{l_t,nm}$) from $\tilde{g}_i^{l_t}$ proportional to v_i^{nm}, since v_i^{nm} can be interpreted as the traffic volume can be generated.

$$b_i^{l_t,nm} = \tilde{g}_i^{l_t} * \frac{v_i^{nm}}{v_i^{l_t}}. \quad (9)$$

The minimum value among $b_i^{l_t,nm}$, where l_t indicates intra-domain links that transfer traffic from d_n to d_m, is used as the allowable traffic bound from d_n to d_m to avoid link congestion.

$$b_i^{nm} = min(b_i^{l_t,nm}). \quad (10)$$

In addition to the traffic bound, BiCo generates the preference value (p_i^{nm}).

$$p_i^{nm} = 1 - max(\frac{\tilde{ng}_i^{l_t}}{c^{l_t} * T}), \quad (11)$$

where l_t indicates intra-domain links that transfer traffic from d_n to d_m.

Basically, in BiCo, the guided peers select their communication partners based on the traffic bound until all the allocated traffic bound is consumed. Then, the guided peers use the preference value. In the intra-domain case, the guided peers try to generate the guided traffic from NSes proportional to corresponding guidances. This approach may enable the guided peers to distribute the guided traffic over the intra-domain links by reflecting the underlying network status.

D. Inter-Domain Traffic Control

Inter-domain links can be grouped into two types: peering (i.e., free to send traffic) and transit (i.e., has to pay corresponding fee to its provider providing Internet connection). In both cases, BiCo tries to fully utilize given link while satisfying the traffic-related requirements. Here, NS can be AS or network domain consisting of multiple ASes.

1) Transit Link: One of the primary objectives of transit link is to reduce the transit bill that customer network operator has to pay to provider network operator for transiting the traffic every month. Usually, the customer negotiates commit level (*C* Mbps) with the provider and the negotiated commit level affects cost per Mbps (T_C) and minimum monthly fee of the transit link l_t. For example, at its maximum, the monthly fee is $C * T_C$ even when no traffic is actually sent. Thus, the charging volume of l_t up to (*i*-1)th interval with *q*-th percentile charging method is calculated as follows:

$$f_{i-1}^{l_t} = max(max(qt(s_j^{l_t,IN}, q), qt(s_j^{l_t,OUT}, q)), C), \quad (12)$$

[3] The tilde means an estimated one of corresponding value.

where qt(V, q) is the q-th percentile of traffic volume vector V.[4] With $f_{i-1}^{l_t}$, the network operator allocates the traffic bound so that the charging volume is not exceeded during next interval.

$$\tilde{g}_i^{l_t,IN} = max(f_{i-1}^{l_t} * T - \tilde{ng}_i^{l_t,IN}, 0), \tag{13}$$

where $f_{i-1}^{l_t} * T$ is an allowable total traffic that does not increase the charging volume.

2) Peering Link: There exist some requirements for continuous peering relationship between NSes. Among various technical requirements of the peering link, Out:In ratio is considered as most important factor to be satisfied. Thus, we focus on this issue.

Given β:1 ratio: Given ratio $\beta : 1$ and a period for Out:In ratio calculation that is usually one month, the traffic bound of incoming traffic through peering link l_t is calculated as follows.

$$\begin{aligned}\tilde{g}_i^{l_t,IN} = max(&\sum_{j=1}^{i-1} \frac{(\frac{1}{\beta} * s_j^{l_t,OUT} - s_j^{l_t,IN})}{NUM} \\ &+ (\frac{1}{\beta} * \tilde{ng}_i^{l_t,OUT} - \tilde{ng}_i^{l_t,IN}), 0),\end{aligned} \tag{14}$$

where *NUM* is a number of remaining intervals of current Out:In ratio calculation period. In the equation, the first part indicates a cumulated difference between incoming and outgoing traffic up to (*i-1*)th interval and the second part indicates an estimated difference between incoming and outgoing traffic during *i*th interval. We divide the cumulated difference between incoming and outgoing by *NUM* so as to meet the ratio requirement by distributing an adjustment overhead over remaining intervals.

No explicit ratio: Some peering relationships do not require the explicit Out:In ratio for continuous peering relationship. In this case, the traffic bound is affected by link capacity and the estimated incoming non-guided traffic.

$$\tilde{g}_i^{l_t,IN} = max(c^{l_t} * T - \tilde{ng}_i^{l_t,IN}, 0). \tag{15}$$

In addition to the traffic bound of each inter-domain case, the preference value is calculated like the intra-domain case with one additional parameter.

$$p_i^{l_t} = (1 - \frac{\tilde{ng}_i^{l_t,IN}}{c^{l_t} * T})^{\delta}, \tag{16}$$

where δ (> 1) is an weighting factor. For example, if the transit link and the peering link coexist, much higher δ can be applied to the transit link than the peering link so that the peering link is used mostly. If several same type links coexist, different δ can be applied according to their characteristics like T_c or given β:1 ratio so that certain links (that are cheaper or have flexible Out:In ratio) can be utilized more than others.

The guided peers select their communication partners based on the traffic bound (without the traffic distribution requirements of intra-domain case) until all the allocated traffic bound is consumed. After consuming all the traffic bound, the guided peers try to generate the guided traffic proportional to corresponding preference values.

[4] *IN* and *OUT* indicate directions of corresponding traffic, i.e., incoming and outgoing, respectively.

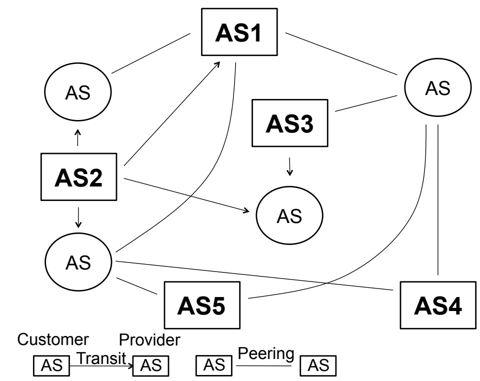


Fig. 3. Simulation topology.

E. Guided Peers

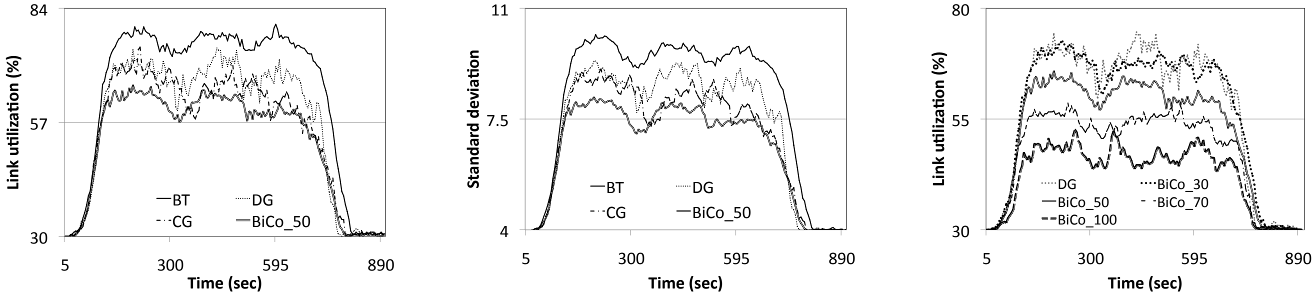
Whenever the guided peers want to select their communication partners, they check the guidances (e.g., remaining traffic bound) by accessing the entity that is managing the guidances on behalf of themselves. The role of the entity can be covered by the guidance server, the elected super peers, or the peer itself, but this is out of the scope of this paper. The guided peers select their communication partners among peers who can send the guided traffic through links with high preferential guidance. When the guided peers receive the guided traffic (e.g., one chunk in BitTorrent file sharing system), they report this to the entity so that the corresponding guidance is adjusted.

III. Evaluation

We utilize ns-2 simulator [19]. We run each simulation 10 times and show the average across the results together with standard deviation.

A. Simulation Setup

For the network topology, we have first collected the peer addresses by joining BitTorrent swarms with more than 350 torrents downloaded from IsoHunt. From the collected IP addresses and through Cymru AS mapping service [20] that maps an IP address to the AS that it belongs to, we have identified the AS with more than 200 peers. Among the ASes, we have chosen 5 ASes that belong to different network domains so that we can build a topology including various inter-domain link types (Fig. 3). ASes with number in Fig. 3 are the ASes we have chosen. For intra-domain topology of the chosen ASes, we utilize RocketFuel [21] data. As a background traffic, we generate different amount of constant bit rate flows on intra-domain links (from 0% to 30% of link capacity) and symmetric constant bit flows between ASes (i.e., 10% of link capacity). The non-guided peers generate variable non-guided traffic in addition to the constant background traffic. Given β:1 ratio for the peering link is 1:1.



(a) MLU (b) Standard deviation (c) MLU of BiCo

Fig. 4. Traffic distribution.

TABLE II
TRAFFIC OVERHEAD OF IPS APPROACHES

	BT	DG	CG	BiCo_50
InNS/OutNS	0.12 (0.04)	0.83 (0.1)	0.81 (0.16)	1.68 (0.28)
Average hops	1.38 (0.08)	1.4 (0.04)	1.38 (0.05)	1.25 (0.06)

TABLE III
TRAFFIC OVERHEAD OF BICO

	BiCo_100	BiCo_70	BiCo_50	BiCo_30
InNS/OutNS	4.73 (0.52)	2.6 (0.34)	1.68 (0.28)	0.83 (0.2)
Average hops	1.12 (0.03)	1.2 (0.05)	1.25 (0.06)	1.31 (0.06)

We use BitTorrent [18] (there are three initial seeders) and 25MB sized content. We use 1160 peers for all simulations. Peers join the swarm randomly from 0 to 10 seconds after simulation starts and leave the swarm after completing the download. We set download and upload capacity of all peers as 1500Kbps and 500Kbps, respectively. We divide the peers into the guided (50%) and the non-guided peers (50%) for baseline simulations. In addition, to study effect of peer cooperation in BiCo, we conduct simulations with different ratios of the guided peers to total peers (i.e., 100%, 70%, 50%, and 30%). From now on, BiCo_*GP* indicates BiCo with *GP%* of guided peers.

For performance comparison, we categorize the existing techniques into two groups: distance-based guidance (DG) and charging volume-based guidance (CG) [14].[5] Firstly, we implement BitTorrent without any guidance (BT) that is used as the basis of performance comparison. For DG, we design BitTorrent tracker so that it returns neighboring peers close to a newly joining peer in terms of AS hops instead of controlling peer communications based on network distance during BitTorrent swarming. By doing this, we try to provide sufficient connectivity required for good performance in content sharing while still allowing peers to communicate with peers close to themselves [16]. For enough connectivity with outside, the tracker returns 50% of peers from inside AS and 50% of peers from outside AS. For CG and BiCo, we follow the basic approach of DG while adding additional information, since the basic concept of IPS is to download a file from nearby peers. For both cases, we calculate the guidance at every 5 (i.e., T) seconds.[6] For the traffic estimation in both cases, we use the sliding window approach with window size of 10 [9]. In this paper, CG utilizes both the performance-related information and the charging volume-related information as the preference value. In other words, CG utilizes the link utilization for the intra-domain (i.e., p_i^{nm}) and the peering of inter-domain (i.e., $p_i^{l_t}$) and (C^{l_t} - $f_{i-1}^{l_t}$) as the preference value for the transit link of inter-domain. We apply same δ for same kind of inter-domain links. δ of transit link is 10 times larger than δ of peering link.

B. Intra-Domain

We now report the representative results of our simulations that are consistent with our observations from the five intra-domain topologies.

Table II and Table III show how much traffic is generated on intra-domain links. In the tables, *InNS* (*OutNS*) is amount of traffic that is generated within same NS (from other NSes) and *Average hops* is the average number of intra-domain links used for downloading the content from the other NSes. The absence of guidance in BT results in highest traffic overhead and longest content download path length. DG and CG show less guided traffic overhead than BT by enabling the peers to download chunks from close peers. CG, however, does not show noticeable performance improvement compared to DG although it utilizes additional information. On the other hand, BiCo shows lowest overhead (e.g., BiCo increases InNS by 52.5% and 18.5% compared to BT and CG, respectively) and shortest path length (which means that BiCo encourages the peers to communicate with the close peers). Although the traffic overhead increases as the ratio of guided peers decreases, BiCo_30 shows better performance than DG and CG. This result shows that BiCo utilizing the traffic bound

[5] We categorize the existing IPS techniques like this way instead of grouping them based on their architectures, since we believe that the guidance itself may have greater impact on performance. Note that same guidance can be generated by different IPS techniques.

[6] We use 5 seconds interval, since the simulation terminates around 1000 seconds. In real world, 5 min that is a usual interval for charging volume data collection can be used.

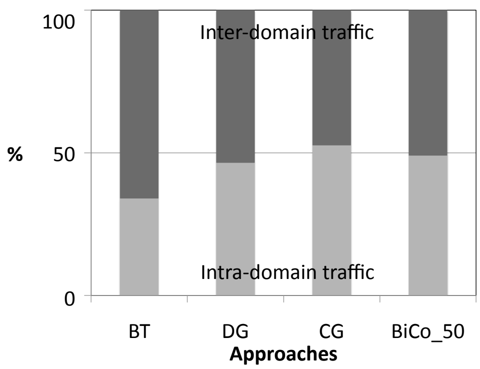


Fig. 5. Distribution of intra and inter-domain traffic.

TABLE IV
TRAFFIC THROUGH TRANSIT LINKS AND CHARGING VOLUME

	Transit link traffic (Mbits)	Charging volume (Mbps)
BT	64751 (446)	125.5 (0.93)
DG	52400 (432)	106 (0.86)
CG	47889 (582)	97.7 (0.34)
BiCo_30	53643 (423)	107.8 (0.64)
BiCo_50	48294 (475)	95.14 (0.83)
BiCo_70	40313 (411)	87.4 (0.72)
BiCo_100	32913 (521)	73 (0.86)

is more effective to reduce the traffic overhead than other approaches utilizing simple preference value.

Then, we examine how the traffic is distributed over intra-domain links by using MLU and standard deviation of the link utilizations (Fig. 4). BT has no guidance except its peering policy. As a result, the traffic is unevenly distributed over intra-domain links, which results in the highest MLU and standard deviation. DG and CG show better traffic distribution compared to BT by using their own guidances. CG shows further improvement compared to DG by reflecting networking status. On the other hand, BiCo shows lowest MLU and standard deviation by allowing the peers to distribute the guided traffic evenly over intra-domain links based on the traffic bound. In particular, BiCo reduces MLU by at most 29.4%, 17.3%, and by 15.7% compared to BT, DG, and CG, respectively. In addition, BiCo_100, BiCo_70, BiCo_50, and BiCo_30 reduce MLU by at most 43.9%, 39.1%, 29.4%, and 21.3% compared to BT, respectively. BiCo_30 shows better traffic distribution than DG. This result validates that the traffic bound is an effective way to distribute the traffic by limiting P2P traffic on certain link.

C. Inter-Domain

We first examine the distribution of intra and inter-domain traffic volume (Fig. 5). All three IPS approaches reduce the cross-domain traffic by over 20% compared to BT. In addition, CG and BiCo reduce the cross-domain traffic by 11.4% and 4.8% compared to DG. BiCo, however, shows slightly larger amount of cross-domain traffic than CG. This will be discussed later.

TABLE V
TRAFFIC DISTRIBUTION OVER TRANSIT AND PEERING LINKS

	Transit/Total	Charging volume	Transit traffic
BT	0.32 (0.008)	17.7 (0.67)	14291 (635)
DG	0.474 (0.072)	17.6 (0.51)	13676 (435)
CG	0.317 (0.009)	17.4 (0.51)	13376 (798)
BiCo_50	0.287 (0.008)	14.8 (0.7)	12401 (637)

TABLE VI
OUT:IN RATIO OF EACH PEERING LINK

		BT	DG	CG	BiCo_50
AS4	Link 1	0.65 (0.02)	0.86 (0.06)	0.91 (0.06)	1.08 (0.07)
	Link 2	1.14 (0.06)	1.31 (0.06)	1.26 (0.05)	1.29 (0.06)
AS5	Link 1	1.14 (0.02)	1.13 (0.03)	1.07 (0.02)	1.01 (0.06)
	Link 2	1.4 (0.03)	1.3 (0.05)	1.29 (0.05)	1.27 (0.04)

Now, we examine how the cross-domain traffic affects the charging volume that is calculated based on the 95th-percentile charging model (Table IV). IPS techniques reduce the traffic through transit links by over 19% and the corresponding charging volume by over 15.5% compared to BT. In addition, CG and BiCo reduce the traffic through transit links and the charging volume further compared to DG. This result shows that the simple traffic localization of DG is not so effective in reducing the charging volume. One interesting observation is that BiCo shows lower charging volume than CG even though BiCo shows larger amount of traffic through the transit links. Even BiCo_30 even shows similar charing volume with DG while BiCo_30 shows slightly larger amount of traffic through transit links traffic than DG. This result shows that BiCo can utilize the transit links better than CG and DG without increasing the charging volume by using the traffic bound.

To study the traffic distribution over inter-domain links when both transit and peering links exist, we examine AS3 with both transit and peering link. Table V shows a ratio of traffic through transit link to total cross-domain traffic, the charging volume, and amount of the traffic through transit link. DG (CG) shows higher (similar) ratio of the traffic through transit link compared to BT. They also show similar charging volume with BT even though they show smaller amount of traffic through transit links than BT. This result shows that DG and CG are not enough to utilize the peering link effectively and to reduce the charging volume in this case. On the other hand, BiCo encourages the guided peers to utilize (free) peering link more than (non-free) transit link and thus results in the lowest charging volume.

To examine Out:In ratio of each peering link, we choose AS4 and AS5 with two peering links (Table VI). BT and DG that do not reflect the dynamic networking status show somewhat uneven Out:In ratio in most cases. On the other hand, CG and BiCo that reflect the networking status show improved Out:In ratio. This result shows that the adoption of networking status improves Out:In ratio by adjusting the guidance to existing non-guided traffic. In addition, we examine how the traffic is distributed over two peering links in AS4 and AS5 (Table VII). Table VII shows a ratio of traffic through

TABLE VII
TRAFFIC DISTRIBUTION OVER PEERING LINKS

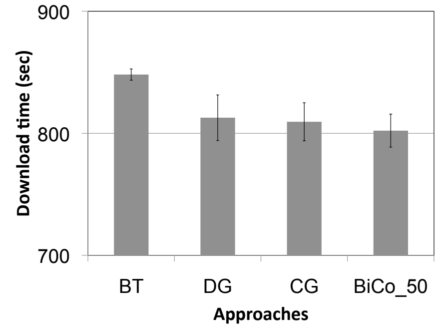
	AS4	AS5
BT	0.702 (0.01)	0.763 (0.005)
DG	0.715 (0.004)	0.717 (0.003)
CG	0.688 (0.006)	0.694 (0.009)
BiCo_30	0.722 (0.015)	0.737 (0.006)
BiCo_50	0.681 (0.01)	0.685 (0.01)
BiCo_70	0.642 (0.012)	0.651 (0.029)
BiCo_100	0.523 (0.02)	0.529 (0.008)

one peering link to total traffic volume. For example, high ratio indicates that much traffic is generated through one link, which means uneven traffic distribution over two peering links. The result shows that CG and BiCo show improved traffic distribution compared to BT and DG. In addition, BiCo shows slightly improved performance compared to CG. BiCo_100 shows the ratio that closes to 0.5, which means that the traffic is distributed evenly over two peering links. Above observations show that BiCo is enough to meet given Out:In ratio requirement of each peering link while distributing the traffic evenly over the peering links.

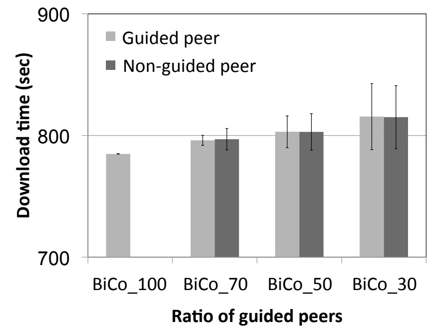
D. Download Completion Time

Fig. 6 shows download completion time. IPS approaches reduce the download completion time by around 50 seconds (5%) compared to BT. Three IPS techniques do not show noticeable difference between them. We conjecture that main factor for improving download completion time is the traffic localization that is common in IPS techniques as also shown in existing work [8], [12]. The performance improvement by IPS techniques is not much in our study. We believe that the performance improvement heavily depends on the underlying network topology as well as number and ratio of guided peers [12]. Therefore, we anticipate that the performance may increase further with larger network topology and larger number and higher ratio of guided peers than current setting.

Fig. 6(b) shows the download completion time of guided and non-guided peers with the various ratios of the guided peers. One interesting observation is that the guided peers and the non-guided peers show similar performance. Even though we only control the traffic generation of guided peers, it does not degrade the performance of non-guided peers. It rather increases the performance of the non-guided peers. The guided peers can select both the guided and non0guided peers, since the guidance is about not the peer type, but the networking status. Due to this reason, the non-guided peers may be able to communicate with the guided peers with good performance, even though they do not follow the guidance.



(a) IPS approaches



(b) Various ratio of guided peers in BiCo

Fig. 6. Download completion time.

IV. RELATED WORK AND DISCUSSIONS

A. Related Work

There exist several research efforts for P2P traffic control from the network operator perspective. In P4P [8], each peer has a PID that represents its network position like AS. The pDistance indicates the distance between a pair of PIDs and can be used as the guidance. For example, the network operator can assign the pDistance based on BGP preferences. The basic idea of [10] and [11] is to provide a list of the ordered peers or the paths according to the predefined criteria. When a peer sends the list of possible neighbors to the network operator, the network operator ranks them according to certain criteria such as high bandwidth links. Some approaches focus on verification of existing bilateral cooperative approach under real environment and its improvement. In [4], they show the win-win approach of the network operator-friendly technique is hard to achieve under real environment where peers are non-uniformly distributed. Then, they propose refinements of current proposals, allowing all users of P2P networks to be sure that their application performance is not reduced. In [6], the authors show that transmission cost of P2P streaming with ALTO guidance can be reduced. They also show that the network operator has to be careful not to over-localize traffic, for particularly delay-sensitive applications. If peers connect to too many peers which are in the same AS but have low upload capacity, chunk loss increases considerably resulting in poor video quality. Related to the bilateral cooperation, there is also a similar work [7]. [7] presents an architecture to enable the cooperation between the application providers, the peers, and the network operators so that the quality of experience of the peers is improved and network traffic optimized.

Some research tries to achieve the P2P traffic control without the network operator's help. In [5], they try to answer some fundamental questions raised by in using existing locality mechanisms (e.g., how far can we push locality?). In particular, they evaluate the impact of locality (in the peer matching of BitTorrent) on inter-domain links traffic and peers download completion time. In [12], each peer resolves the DNS names of CDN servers for multiple times and calculates the ratio map showing a distribution of DNS redirections. When a peer tries to choose its communication partner, it calculates the *cosine similarity* between the ratio map of itself and those of candidate peers and uses the results as the guidance. [13] tries to minimize the inter-domain cost and then minimize the intra-domain cost by calculating an AS path between arbitrary two peers and using it as the guidance .

The network operator-supported approach has a flexibility in selection of network information and thus can satisfy various traffic control objectives. But, it requires corresponding network measurement and analysis overhead. On the other hand, the peer-driven approach is simple and scalable. However, it may not be enough to satisfy the various traffic control objectives, since the availability of the information determines the scope of its application. We believe that the peer-assisted measurement in BiCo may ensure the flexibility by following the network operator-driven approach and the scalability by utilizing the peer participation.

B. False Report

The malicious peers may be able to report more guided traffic volume than real one so that other guided peers may face link congestion due to incorrect traffic bound estimation (i.e., larger amount of estimated traffic bound than actual available traffic bound). For safe deployment, we may be able to utilize existing work that employs a cryptographic fair-exchange mechanism [17]. With the approach of [17], each peer establishes a transport layer secure session with the guidance server when it joins P2P network. The peer sends its ID and password over the secure channel. Then, in return, the guidance server sends a shared secret key to the peer. The shared secret key is used for peer authentication. In data exchange, the guidance server acts as the trusted third party mediating the exchange of content among peers. When a peer A uploads to a peer B, it sends encrypted content to peer B. To decrypt, B must request the decryption key from the guidance server. The requests for keys serve as the proof that A has uploaded some content to B. Thus, when the guidance server receives a key request, it credits A for uploading content to B. This approach may allow the network operator to collect valid peer-level information with reasonable overhead.

The malicious peers also can report more number of neighboring peers than real one so that they can have more traffic bound. If a third party like the tracker of BitTorrent returns the neighboring peer list to the peers, the third party can encrypt each peer's address with its private key so that no one can add more neighboring peers on purpose. To avoid the case where malicious peers exchange the encrypted IP addresses with each other, peer's IP returned by the third party can be modified like (peer's IP, receiver) so that only the corresponding peer can use the information for the report. In case of P2P network where there is no third party who returns neighboring peers, the peer report can be utilized to estimate a number of neighboring peers as an alternative way. For example, the number of peers in the report can be a number of neighboring peers.

C. Multiple P2P Applications

When there exist multiple P2P applications, allocation of the traffic bound should be fair to P2P applications. Basically, this can be done by utilizing the neighboring peer information. If all P2P applications have equal priority to utilize the traffic bound, the traffic bound for *j*th P2P application can be calculated as follows:

$$\tilde{g}_i^{l_t,j} = \tilde{g}_i^{l_t} * \frac{v_i^{l_t,j}}{\sum_{j=1}^{|M|} v_i^{l_t,j}}, \tag{17}$$

where $v_i^{l_t,j}$ is $v_i^{l_t}$ of *j*th P2P application and M is a set of P2P applications utilizing the guidance. On the other hand, if one P2P application (i.e., j') has priority (e.g., γ times higher than others) to utilize the traffic bound due to its contract with BiCo provider, its traffic bound is calculated as follows:

$$\tilde{g}_i^{l_t,j'} = \tilde{g}_i^{l_t} * \frac{\gamma * v^{l_t,j'}}{\sum_{j=1}^{|M|} v_i^{l_t,j}}. \tag{18}$$

Then, by each P2P application, $\tilde{g}_i^{l_t,j}$ can be further allocated to communication between arbitrary NSes as introduced earlier.

Regarding the preference value, δ can be adjusted according to the priorities of P2P applications so that P2P application with high priority can use a link that may not be preferred by most other P2P applications.

V. Conclusion

We propose the bilateral cooperation between the network operator and the peers to issue better guidances while overcoming the limitations of existing work. We posit that the network operator can collect enough and accurate network information efficiently by utilizing information from both parties and that the traffic bound is effective to control P2P traffic. Our simulation shows that the traffic bound plays an important role and improves the network efficiency compared to the existing unilateral interaction in traffic control of inter-domain as well as intra-domain case. As a future work, we plan to extend current design to cover false report case by the malicious peers with low overhead. It would also be interesting to reflect the complex relationships between network operators in the guidance generation.

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