Flow Aggregated Traffic-Driven Label Mapping in Label Switching Network

Ken-ichi Nagami , Hiroshi Esaki , Yasuhiro Katsube , Osamu Nakamura

Abstract— **Label switching technology enables high performance and flexible layer-3 packet forwarding based on the fixed length label information mapped to the layer-3 packet stream. A Label Switching Router (LSR) forwards layer-3 packets based on their layer-3 address information or their label information mapped to the layer-3 address information.**

Two label mapping policies have been proposed. One is a traffic-driven mapping, where the label is mapped for a layer-3 packet stream of each host-pair according to the actual packet arrival. The other is a topology-driven mapping, where the label is mapped, in advance, for a layer-3 packet stream toward the same destination network, regardless of actual packet arrival to the LSR.

This paper evaluates the required number of labels under each of these two label mapping policies using the real backbone traffic traces. The evaluation shows that both label mapping policies require a large number of labels. In order to reduce the required number of labels, we propose a label mapping policy which is a combination of the two label mapping policies above. This is traffic-driven label mapping for the packet stream toward the same destination network. The evaluation shows that the proposed label mapping policy requires only about one tenth as many labels compared with the traffic-driven label mapping for the host-pair packet stream, and the topology-driven label mapping for the destination network packet stream.

Keywords— **Internet, Communication systems, Asynchronous transfer mode**

I. Introduction

The data networks using the TCP/IP technology, i.e., the Internet and intranet, are growing both in geographical and numerical scale, as well as in traffic volume. Also, recent and upcoming applications often require a specific quality of service (QoS) or a class of service (CoS) rather than the conventional best-effort service. Label switching technology will satisfy these requirements, i.e., high speed and large processing capability while providing QoS and CoS, with reasonable implementation cost. A Label Switching Router (LSR) forwards layer-3 packets using either their layer-3 address information or their label information mapped to the layer-3 address information.

Several architectures for LSR, including ARIS (Aggregate route-based IP switching) [7], [8], CSR (Cell Switch Router) [3], [4], IP Switch [1], [2] and TSR (Tag Switch Router) [5], [6], have been proposed with their own protocol designs. The protocol to establish the mappings between a packet stream and a corresponding label is generally called a LDP (Label Distribution Protocol) discussed in the IETF (Internet Engineering Task Force) MPLS (MultiProtocol Label Switching) Working Group.

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From the viewpoints of the scalability and the implementation feasibility of LSR, it is important to evaluate the required number of labels in label switching networks. The number of required labels depends on a label mapping trigger, which is an event to invoke the label mapping, on the granularity of a packet stream, and on the scale of the network.

Two kinds of label mapping triggers have been proposed. One is a traffic-driven mapping, where the label is mapped to a packet stream according to the actual packet arrival. The other is a topology-driven mapping, where the label is mapped, in advance, to a packet stream using the network topology information regardless of actual packet arrival to the LSR.

Several kinds of granularity for a packet stream can be defined. The typical definitions for the packet stream are a host-pair packet stream and destination network packet stream. The host-pair packet stream is defined as a set of packets having the same source and destination layer-3 addresses. The destination network packet stream is defined as a set of packets having the same destination network prefix. Other packet stream definitions will be discussed in section II.

Two typical label mapping policies have been proposed. One is specified in IFMP (Ipsilon Flow Management Protocol) [2] and FANP (Flow Attribute Notification Protocol) [4], where the LSR uses the host-pair packet stream as the granularity of the packet stream definition and applies traffic-driven label mapping. Lin and Mckeown [10] have evaluated the number of required labels using actual traffic traces on the Internet, and show that a large number of labels is required on the Internet backbone with this label mapping policy. The other label mapping policy is specified in TDP (Tag Distribution Protocol) [6], where LSR uses the destination network packet stream as the granularity of the packet stream definition and applies topology-driven label mapping. With this label mapping policy, the number of required labels becomes as large as the number of routing table entries maintained by the LSR.

This paper evaluates the required number of labels under each of the above two label mapping policies using the real traffic traces on a wide area Internet backbone. The required number of labels with the traffic-driven mapping for the host-pair packet stream is quite large, and the required number of labels with the topology-driven mapping for the destination network packet stream is also large.

In order to reduce the required number of labels, we propose a label mapping policy, which is an integration of the above label mapping policies. The label is mapped to the packet stream toward a specific destination network triggered by the arrival of its traffic. The required number of labels with the proposed label mapping policy is evaluated using the real wide area Internet backbone traffic.

Section II describes an overview of LSR, the label mapping triggers for LSP and the granularity of the packet stream. Section III describes the evaluation of the required number of labels with the conventional two label mapping policies; the traffic-driven mapping with host-pair packet stream and the topology-driven mapping with destination network packet stream. Section IV describes the evaluation of the proposed label mapping policy with various granularities of the packet stream. Section V gives a brief conclusion.

II. Overview of Label Switching Router

A. Architectural Overview

The label switching concept enables layer-3 packets to be forwarded either using the layer-2 label (e.g., VPI/VCI) or using the shim label [9] between the layer-2 header and layer-3 header. The label is used as information to forward the packets without analyzing the layer-3 address (e.g., IP address). This means that the label represents the destination address of the layer-3 packets. By using the label instead of the layer-3 address for packet forwarding, the LSR does not need to look up anything in the best match policy based routing table, whose search key is the layer-3 address.

The packet forwarding at the LSR is shown figure 1. The LSR has a layer-3 forwarding engine and label forwarding engine. It is connected with two LSR-edge routers (Edge1 and Edge2).

LSRs are connected with two types of VC. One is the Default VC, another is the Label Switched VC.

The Default VC is used for conventional packet forwarding. For example, when Edge1 sends a packet to Edge2 using conventional packet forwarding, Edge1 sends the packet through the default VC. LSR receives it and transmits it to the layer-3 forwarding engine through the label forwarding engine. The layer-3 forwarding engine of the LSR looks up the routing table according to the destination of the packet and sends it through the default VC. Then, Edge 2 receives it. LSR forwards the packets using the layer-3 engine.

The Label Switched VC is used for cut-through packet forwarding [3]. For example, when Edge1 sends a packet to Edge2 using the cut-through packet forwarding, Edge1 sends the packet through the label switched VC. LSR receives it and forwards it using only the layer-2 forwarding engine to send it through the Label Switched VC. LSR forwards these packets faster than with the conventional forwarding because LSR doesn't need to look up the layer-3 packet. The conjunction of the Label Switched VC is called the Label Switched Path (LSP).

LSR has to establish the relationship between the packet stream and the corresponding label for label switched packet forwarding. Label Distributed Protocol (LDP) establishes the mapping between the packet stream and the label.

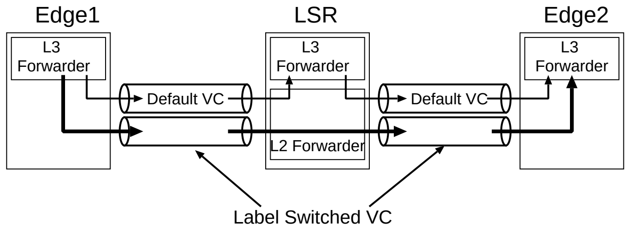

Fig. 1. LSR

One of major applications of LSR is ATM-LSR, that contains the cell switch module as a label forwarding engine. In ATM-LSR, the LSR system has to allocate a packet reassemble buffer space for every LSP. Since there is a hardware limitation regarding the available packet reassemble buffer space, an ATM-LSR system has the maximum number of labels (i.e., the maximum number of LSP) to be able to provide for label switching purpose. From the viewpoints of the scalability and the implementation feasibility of LSR system, it is important to evaluate the required number of labels in a label switching network. The required number of labels depends on the following three parameters.

- Label mapping triggers
- Granularity of packet stream
- Scale of the network

B. Label Mapping Triggers

There are two types of triggers to control the LSPs, which are traffic-driven label mapping and topology-driven label mapping.

With the traffic-driven mapping, the LSP is established on demand according to the appearance of data packets at a node. The LSP is maintained as long as packets are forwarded through the LSP. When the node recognizes that the LSP is not active any more, it is released.

With the topology-driven mapping, the LSP is established in advance according to the routing protocol information. For example, the LSP is established when a routing entry appears through the routing protocol information. The LSR maintains LSP as long as the corresponding routing entry exists. LSR tears down the LSP, when the corresponding routing entry is deleted.

The advantage of the traffic-driven would be that the required amount of label space is smaller than that for the topology-driven. This is because, in the topology-driven system, LSP is established and maintained, even though no data packet is forwarded through the LSP.

The advantage of the topology-driven is that all data packets can be forwarded through the LSP. In the traffic-driven system, some portion of data packets are forwarded without label switching, i.e., with conventional layer-3 packet forwarding.

C. Granularity of Packet Stream

The LSR system can define wide variety of packet stream granularity. In this paper, the following packet stream granularity is used for evaluation.

- set of the packets which have the same source and destination addresses, i.e., so-called micro-flow. It is denoted as (src, dst).
- set of the packets which have the same source address and destination network prefix. It is denoted as (src, dstnet).
- set of the packets which have the same source and destination network prefixes. It is denoted as (srcnet, dstnet).
- set of the packets which have the same destination address. It is denoted as (*, dst).
- set of the packets which have the same destination network prefix. It is denoted as (*, dstnet).

III. Evaluations of Conventional Label Mapping Policies

A. Evaluated Traffic Condition

This subsection briefly describes the traffic conditions used for the performance evaluations in this paper.

- Traffic monitoring point
  Figure 2 shows a traffic monitoring point. A traffic monitoring host is attached to the Ethernet segment which is located between the WIDE (Widely Integrated and Distributed Environment) project internet backbone network in Japan and the U.S. The host records the traffic using the tcpdump application on the host. The measurement was been performed around for two hours (7437 seconds), from 14:08 JST November 4 1997 to 16:11 JST November 4 1997. The traffic traces are recorded for each direction, separately.
- Packet forwarding rate
  Table I shows the average packet transmission speed, in megabits per second (Mbps) and in packets per second (pps), at the monitoring point for both directions. The average packet transfer rate was 1.225 Mbps and 329 pps, for the traffic incoming into the AS (WIDE project backbone network), while it was 0.926 Mbps and 564 pps for the traffic outgoing from the AS.

Direction	Transfer Rate [Mbps]	Transfer Rate [pps]
to the AS	1.225	329
from the AS	0.926	564

TABLE I
Average Transfer Rate

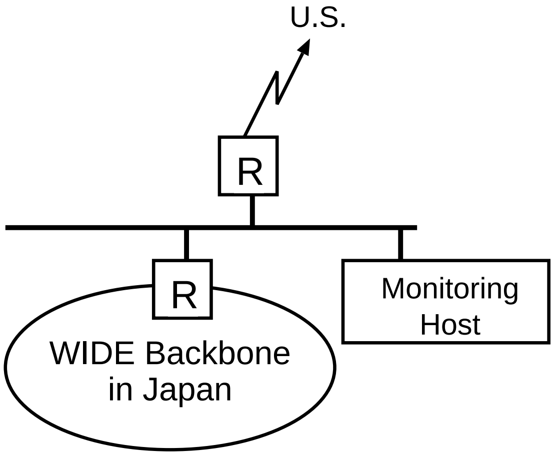

Fig. 2. Traffic Monitoring Point

B. Evaluation Results

B.1 Evaluations for Topology-Driven Mapping

In this subsection, we evaluate the number of labels for the conventional topology-driven label mapping, where each label is mapped to the destination network packet stream shown in the routing table entry.

The total number of the routing table entries at the traffic monitoring point was 2865. The number of routing entries for outside AS was only five and the routing entries for the inside AS was 2860. When the labels are established with the conventional topology-driven mapping, the required number of labels is the same as the number of routing entries. This means that 2860 labels are required for the conventional topology-driven mapping policy toward the inside AS.

Next, we evaluate the required number of labels, where we use the full-route routing table. In this case, it could be assumed that the analyzed LSR is located at the Internet backbone. Table II shows the number of entries in the full-route routing table. The total number of entries in the full-route routing table was 50903. Routing entries for inside AS was 2518, and the routing entries for the outside AS was 48385.

With full-route routing table, if the labels are established with the conventional topology-driven mapping policy, we need 2518 labels for the incoming traffic to the AS, and we need 48385 labels for the traffic leaving the AS. The result shows that, with the conventional topology-driven policy, the number of required labels has to be large enough in an Internet backbone area.

B.2 Evaluations for Conventional Traffic-Driven Mapping

In this subsection, we evaluate the number of required labels for the conventional traffic-driven mapping, where each label is mapped for each host-pair packet stream. The followings are the parameters applied in the LSR system.

- The label-established trigger is invoked whenever the HTTP/FTP/TELNET/NNTP packets are sent out from the LSR.

- The label-released trigger is invoked when no packet is sent during the Disconnect Timer Interval. The value of the Disconnect Timer Interval was 10,30,60,120,240,300 and 600 seconds.
- The LDP establishment is completed with 100 ms delay. [1] The packets are transmitted using the conventional layer-3 forwarding function for 100 ms, after the label-established trigger is invoked.

We evaluate the number of required labels and the cut-through ratio. Here, the cut-through ratio is defined as the number of packets transferred through the label switching divided by the number of all packets transferred both through label switching and through the conventional layer-3 forwarding function.

Figure 3 shows the number of the required labels and cut-through ratios for the outgoing traffic from the AS. Figure 4 shows those for the incoming traffic into the AS.

In both figure 3 and 4, the cut-through ratio is almost the same when the disconnect timer interval is more than 60 ms. This result indicates that the value of the disconnect timer interval should be 60 ms. Therefore, the number of required labels and the cut-through ratio, when the disconnect timer interval is 60 ms, are shown below.

The number of labels with the host-pair packet stream outgoing from the AS is 1131 and the cut-through ratio is 68 %. The required number of labels incoming into the AS is 365 and the cut-through ratio is 61 %.

When we implement an LSR system using an ATM technology, there is a limitation regarding the number of labels (VCs). This is because, in ATM-LSR, the LSR system has to allocate a packet reassemble buffer space for every LSP. The existing ATM hardware could provide few hundreds of labels for LSR system. The result shows that, in the Internet backbone area, a fairly large number of labels are required with the conventional traffic-driven mapping for the host-pair packet stream.

IV. Flow Aggregated Traffic-Driven Label Mapping Policy

A. Flow Aggregated Traffic-Driven Label Mapping Policy

In the section III, we show that the conventional label mapping policies require a fairly large number of labels. In order to reduce the required number of labels, we propose a new label mapping policy. The label is mapped to the packet stream toward a specific destination network triggered by the actual packet arrival. This policy is denoted as a traffic-driven label mapping with the flow aggregated packet stream, in this paper. In this section, the required number of labels with the proposed flow aggregated traffic-driven policy is evaluated using the real Internet backbone traffic traces.

[1]The label mapping establishment time depends on several parameters, e.g., LSR's software and hardware implementation or system configuration. 100 ms is an actually required label mapping establishment time in a CSR system, which is one of LSR implementations, using an SVC. Here, using a PVC, it is far less than that of SVC.

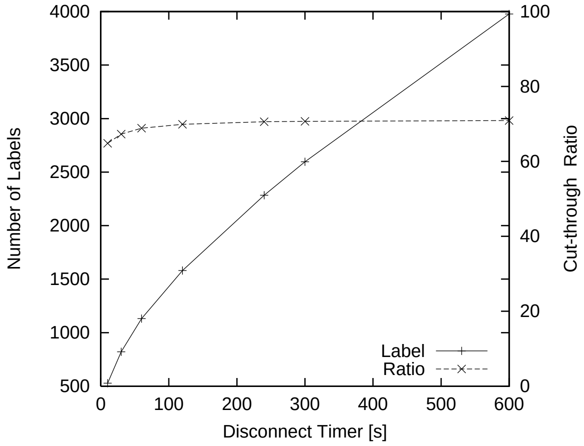

Fig. 3. Number of labels and cut-through ratio directed outside of AS

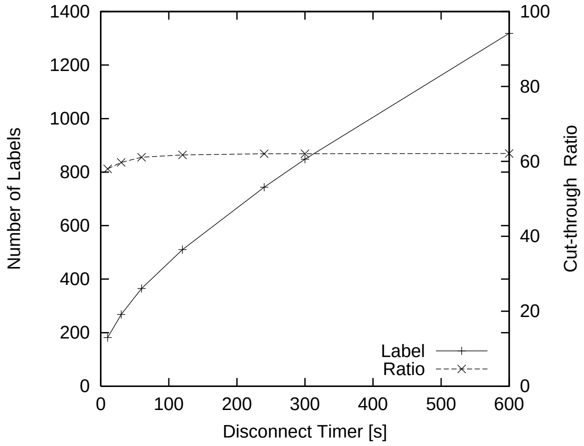

Fig. 4. Number of labels and cut-through ratio directed inside of AS

B. Evaluation of Flow Aggregated Traffic-Driven Policy

The flow aggregated traffic-driven label mapping policy is evaluated using the same Internet backbone traffic traces used in the section III. The performance of the proposed policy is evaluated with different granularities of the packet stream, including packet stream granularity with the conventional topology-driven.

B.1 Evaluation of Actually Referred Routing Entries

In this subsection, we evaluate the number of actually referred routing entries using the real Internet backbone traffic. We evaluated both regarding the incoming packet flow to the AS, and regarding the outgoing packet flow from the AS.

First, we evaluated the actually referred routing entries, where we use a default routing with small number of individual routing entries for outgoing packets from the AS. We analyzed which routing entries were actually referred to when the individual packets were transmitted from the LSR toward each AS. The results are shown in figures 5, 6 and table II.

Figure 5 and 6 show the referred frequency of each individual routing entry during the monitoring period. The horizontal axis shows the destination prefix of the packets. For example, when the LSR forwards the packet whose destination IP address is "192.69.251.56" and the LSR has a corresponding best-matched routing entry of "192.69.251.0/24" for the forwarded packet, this packet forwarding event is included for the referred routing entry at the position of "192.69.251.0" on the horizontal axis. Here, "0.0.0.0" on the horizontal axis corresponds where the packet are forwarded with the default routing.

Figure 5 shows that 96 % of packets directed outside of the AS are forwarded using the default route (at "0.0.0.0" on the horizontal axis). Table II shows the number of routing entries at the end of monitoring period, and the actually referred routing entries during the monitoring period. The LSR has five routing entries for outside AS, i.e., one is for the default routing and four entries are for individual destination network outside the AS. All external five routing entries are referred to during the monitoring period. Here, in the figure 5, more than five routing entries are referred to, even though there are only five routing entries for outside the AS. Some routing entries temporally disappeared from the routing entry, due to some routing instability. In this case, the packets toward the temporally disappearing network(s) inside the AS are forwarded to the outside AS using the default routing. In the figure, these kinds of packet forwarding are included as the sampled packet forwarding. Therefore, the number of referred routing entries during the monitoring period is more than five, that exists in the routing entries directed to the outside AS.

Regarding the incoming packet flow toward the own AS, 209 routing entries are referred to during the monitored period. In this evaluation, the network, corresponding to the most frequently referred routing entry, receives about 33 % of incoming packets through the LSR. When a label is established with the proposed mapping policy, it is sufficient to provide only 209 labels. The actual number of labels required during the analyzed period is less than 209. This is because 209 are not the maximum, but the accumulated number of routing entries referred to during the analyzed period. On the contrary, as evaluated in the section III, when we apply to the conventional topology-driven mapping, the number of required labels for traffic toward the own AS has to be 2860. As a result, the number of required labels with the proposed mapping policy is less than 7% of that with the conventional topology-driven mapping policy.

The second evaluation is where we use a full-route routing table for outgoing packets from the AS. The total number of the full-route routing table entries was 50903. As shown in table II, the number of routing entries for the own AS was 2518, and the number of routing entries for outside the AS was 48385. The results of the evaluation are shown in figure 7 and table II. Again, the horizontal axis shows the destination prefix of the packets, and "0.0.0.0" on the horizontal axis corresponds where the packet are forwarded with the default routing. The default routing in the figure 7 is the case where the packets are forwarded using the default route, since those packets do not belong to any routing entries in the LSR.

As shown in table II, 106 labels are required for the packets toward the own AS, and 7530 labels are required for the packets toward the outside AS. The number of required labels with the conventional topology-driven policy is 50903. On the contrary, the total number of required labels with the proposed policy is only 7636 (= 7530 + 106). The means that the number of required labels with the proposed mapping policy is only 15 % of that with the conventional topology-driven mapping policy.

	In the AS Route	Full Route
Total Entries	2865	50903
Entries directed outside of AS	5	48385
Entries directed inside of AS	2860	2518
Referred Entries directed outside of AS	5(100%)	7530(16%)
Referred Entries directed inside of AS	209(7%)	106(4%)

TABLE II
Number of routing entries

B.2 Evaluations with Granularity of Packet Stream

In this subsection, we evaluate the required number of labels and the cut-through ratio for the proposed label mapping policy with several packet stream granularities. The parameters of the traffic-driven mapping in the LSR are the same as in section III. Five granularities of packet stream, which are (src, dst), (src, dstnet), (srcnet, dstnet), (*, dst) and (*, dstnet), are evaluated.

Figures 8 and 9 show the number of the required labels and the cut-through ratio for the outgoing traffic from the AS. Figures 10 and 11 show the number of the required labels and the cut-through ratio for the incoming traffic to the AS. The horizontal axis shows the value of the Disconnect Timer Interval. In the evaluation, we use the default routing with several individual routing entries for packet forwarding toward outside the AS.

As shown in figure 9 and 11, the cut-through ratios for both incoming and outgoing packets are almost the same when the disconnect timer is more than 60 ms. Therefore, the disconnect timer value should be 60 ms. The number of labels and the cut-through ratio when the disconnect timer is 60 ms are shown in tables IV and III.

As shown in the table III, the number of required labels with the host-pair packet stream is 1131 for the outgoing packets from the AS. This corresponds to the case where the conventional topology-driven policy (evaluated in the section III) is applied. On the contrary, the number of required labels mapped to the same destination network (*, dstnet) granularity is only 99. It is more than 10 times less, compared with the case using the host-pair packet

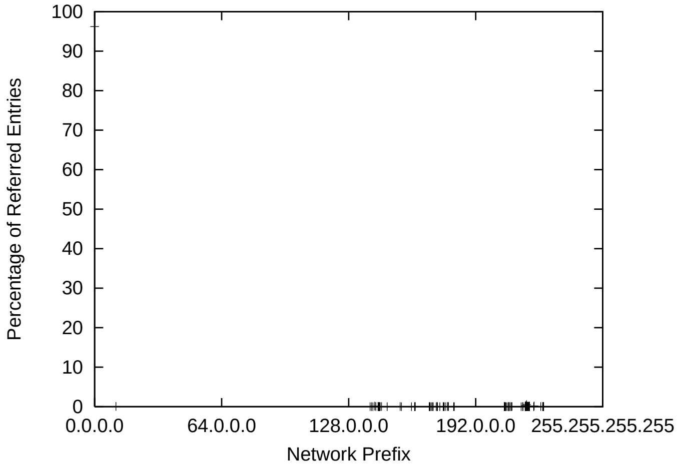

Fig. 5. Percentage of referred entries directed outside of the AS

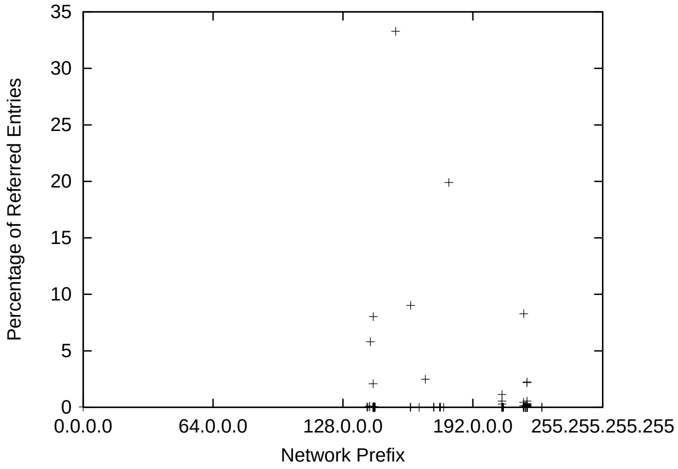

Fig. 6. Percentage of referred entries directed inside of the AS

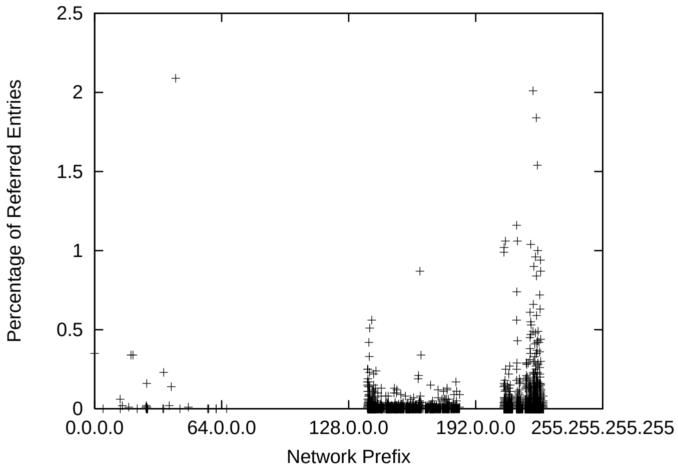

Fig. 7. Percentage of referred entries directed outside of the AS

stream granularity. Also, the cut-through ratio increases from 68 % to 99 %.

Table IV shows that the number of required labels with (*, dstnet) granularity, for the incoming packets to the AS, is 20 times less than that with (src, dst) granularity. Again, the cut-through ratio increases from 61%, to 95%.

Furthermore, we evaluated the number of the required labels using the full-route routing table for the packet forwarding toward the outside AS. Figures 12 and 13 show the number of the required labels and cut-through ratio for the traffic directed to the outside AS. Figures 14 and 15 show those for the traffic directed toward the own AS. As same as the previous evaluation, the disconnect timer value is selected as 60 ms. The number of the required labels is shown in tables VI and V.

Table VI shows the evaluation result for the incoming packets toward the own AS. The number of required labels with (src, dst) granularity, that corresponds to the conventional traffic-driven policy, is 1131. On the contrary, the number of required labels with (*, dstnet) granularity is 542. The number of required labels with (*, dstnet) granularity is about a half of that with (src, dst) granularity.

Table V shows the evaluation result for the outgoing packet flows from the AS. The number of labels for (src, dst) granularity, that corresponds to the conventional traffic-driven policy, is 365. On the contrary, the number of required labels with (*, dstnet) granularity is 16. The number of required labels with (*, dstnet) granularity is about 22 times less than that with (src, dst) granularity.

The results show that the traffic-driven mapping with the flow aggregation (e.g., aggregated packet flow with a destination network) significantly decreases the number of required labels, and also increases the cut-through ratio.

Granularity	Number of Labels	Cut-through Ratio
(src, dst)	1131	68
(*, dst)	859	73
(src, dstnet)	498	78
(srcnet, dstnet)	113	94
(*, dstnet)	99	99

TABLE III

Number of labels and cut-through ratio directed outside of the AS

V. Conclusions

This paper evaluates the number of required labels and the cut-through ratio in the LSR, using actual Internet backbone traffic traces. The number of required labels depends on the label mapping triggers, the scale of network, and on the granularity of packet stream. With the conventional label mapping policies, which are the topology-driven mapping with the destination network packet stream or the traffic-driven mapping with the host-

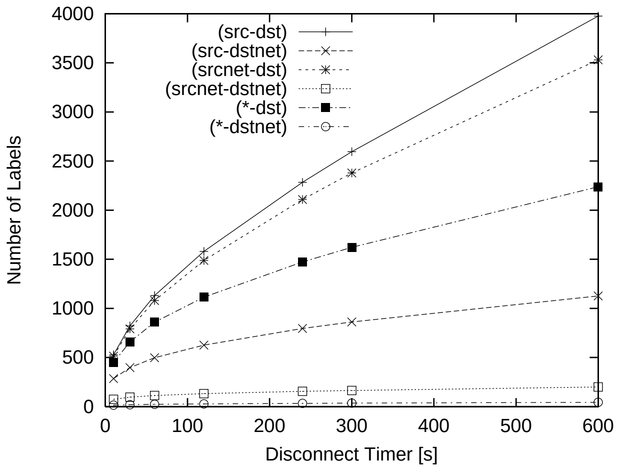

Fig. 8. Number of labels directed outside of the AS

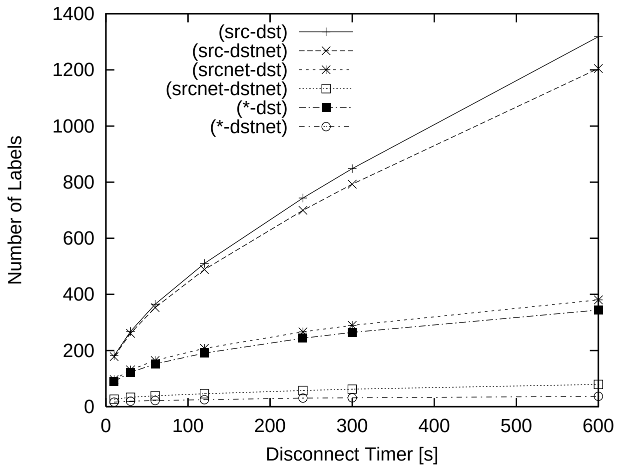

Fig. 10. Number of labels directed inside of the AS

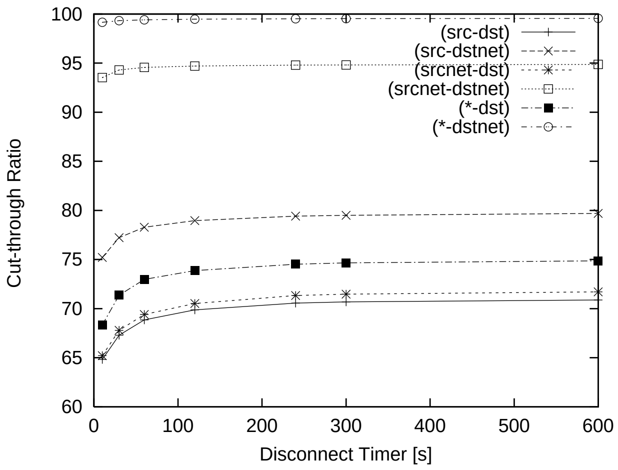

Fig. 9. Cut-through ratio directed outside of the AS

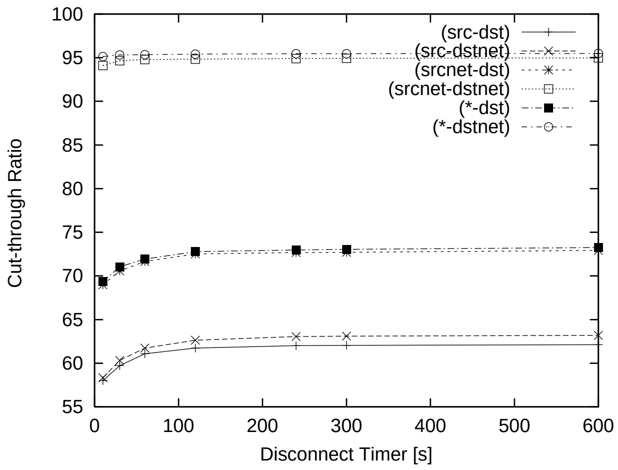

Fig. 11. Cut-through ratio directed inside of the AS

Granularity	Number of Labels	Cut-through Ratio
(src, dst)	365	61
(src, dstnet)	353	62
(*, dst)	152	72
(srcnet, dstnet)	38	95
(*, dstnet)	21	95

TABLE IV

Number of labels and cut-through ratio directed inside of the AS

Granularity	Number of Labels	Cut-through Ratio
(src, dst)	1131	68
(src, dstnet)	990	70
(*, dst)	859	73
(srcnet, dstnet)	883	74
(*, dstnet)	542	86

TABLE V

Number of labels and cut-through ratio directed outside of the AS with full-route

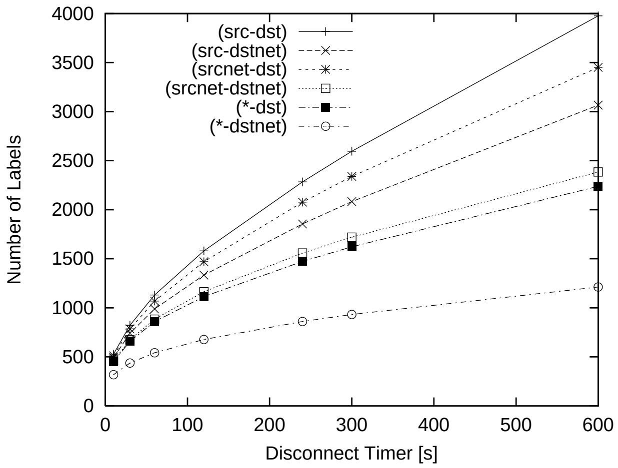

Fig. 12. Number of labels directed outside of the AS using full-route

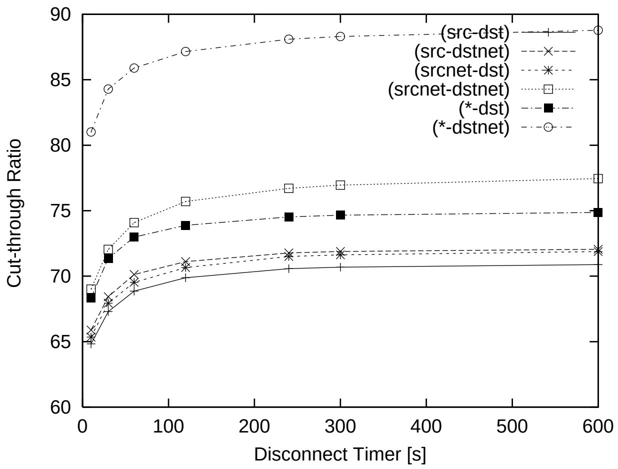

Fig. 13. Cut-through ratio directed outside of the AS using full-route

Granularity	Number of Labels	Cut-through Ratio
(src, dst)	365	61
(src, dstnet)	352	62
(srcnet, dstnet)	310	69
(*, dst)	152	72
(*, dstnet)	16	99

TABLE VI
Number of labels and cut-through ratio directed inside of the AS with full-route

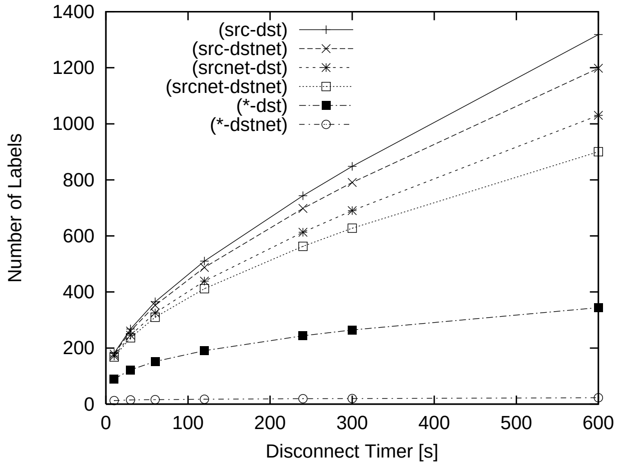

Fig. 14. Number of labels directed inside of the AS using full-route

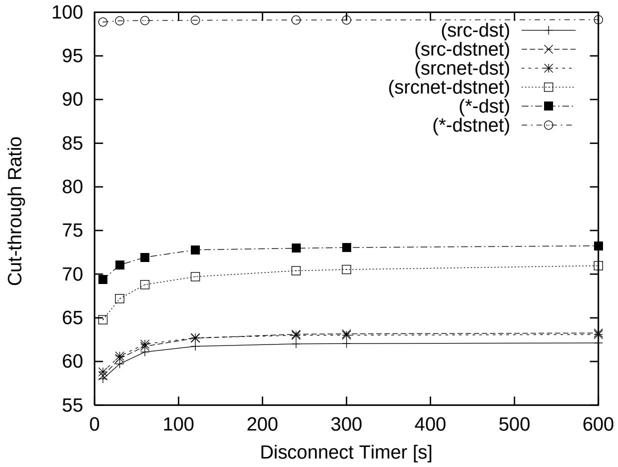

Fig. 15. Cut-through ratio directed inside of the AS using full-route

pair packet stream, the required number of labels becomes large.

Therefore, this paper proposes and evaluates a new label mapping policy (i.e., flow aggregated traffic-driven policy) to reduce the required number of labels and to increase the cut-through ratio. The proposed policy uses label mapping with the aggregated packet stream toward a specific destination network, triggered by the actual packet arrival belonging to the defined aggregated packet stream. By the evaluations using the actual Internet backbone traffic traces, it is shown that the proposed label mapping policy will work well. For example, the required number of labels with the proposed label mapping policy is reduced to only one tenth of that with conventional policy; that is, 1131 labels with conventional policy is reduced to only 99 labels with the proposed policy. Also, the proposed policy increases the cut-through ratio from 68 % to 99 %.

These evaluation results indicate that, for LSRs in the internet backbone area, the proposed flow aggregated traffic-driven label mapping policy will be practically useful. The future work should include the evaluation of the required number of labels using other traffic traces (e.g., at Internet NAP) and other flow aggregation policies because the results depend on traffic traces. We think the proposed policy is useful in some scale of the network. In other scale of the network, the simple topology-driven policy or the simple traffic-driven policy may be practical and appropriate. Also, in some scale of networks, as well as the proposed policy, a hybrid scheme, e.g., the traffic-driven operation across ASes over the topology-driven operation within the AS, would be appropriate. Which label mapping policy is appropriate for various scales of the networks should be for further study item.

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