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Gandhi

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(54) CAPACITY AND PERFORMANCE AWARE LOAD BALANCER SELECTION

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H04L 45/12	(2022.01)
H04L 45/745	(2022.01)

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CPC ***H04L 47/125*** (2013.01); ***H04L 43/0864*** (2013.01); ***H04L 45/123*** (2013.01); ***H04L 45/745*** (2013.01)

(58) **Field of Classification Search**
CPC H04L 47/125; H04L 12/4633; H04L 12/4641; H04L 45/04; H04L 45/586; H04L 45/64; H04L 45/66; H04L 45/74; H04L 45/745
See application file for complete search history.

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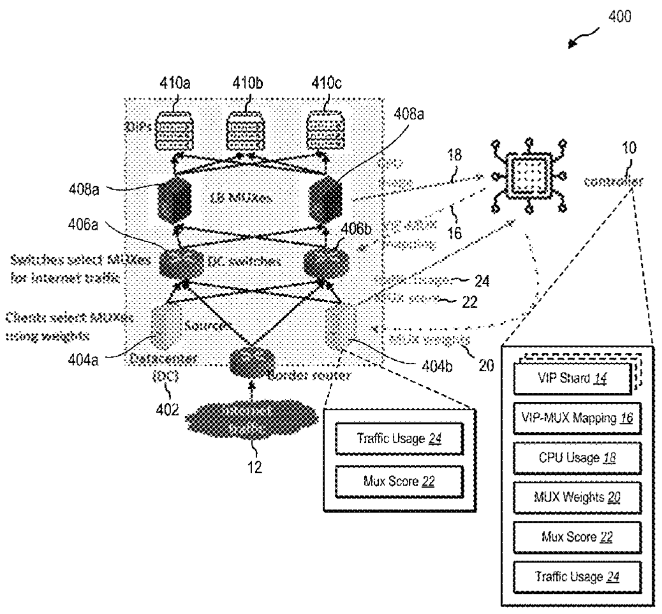
(57) ABSTRACT

The present disclosure relates to methods and systems for providing performance aware MUX selection for traffic in layer-4 load balancing. The methods and systems assign a subset of VIP ranges (VIP shards) to a subset of MUXes based on capacity of the MUXes. The methods and systems allow sources (end-hosts) in the same datacenter (DC) to select the MUXes for intra-DC traffic. The methods and systems allow the sources to use weights calculated by a controller for splitting the traffic across MUXes based on an end-to-end latency of the MUXes. The methods and systems allow the sources to know the MUXes handling the traffic by using packet modification and allow the MUXes to route the packets to reach specific MUXes.

19 Claims, 9 Drawing Sheets



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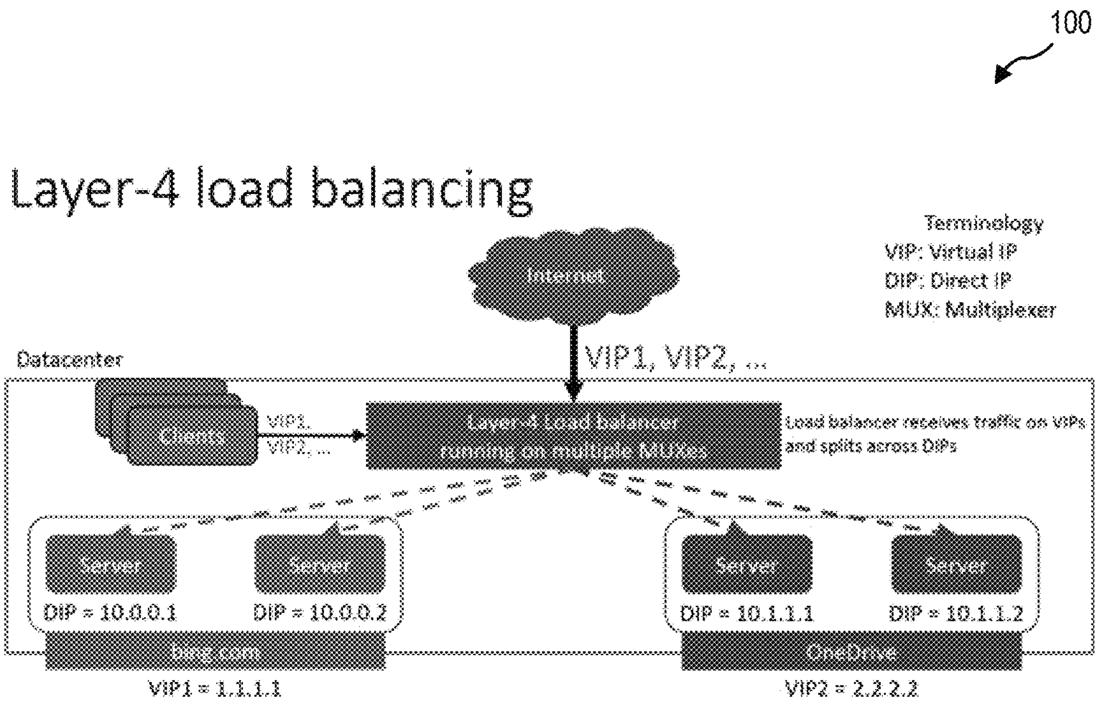

100
Layer-4 load balancing
Terminology
VIP: Virtual IP
DIP: Direct IP
MUX: Multiplexer
Internet
VIP1, VIP2, ...
Datacenter
Clients
VIP1, VIP2, ...
Layer-4 Load balancer running on multiple MUXes
Load balancer receives traffic on VIPs and splits across DIPs
Server
Server
Server
Server
DIP = 10.0.0.1
DIP = 10.0.0.2
DIP = 10.1.1.1
DIP = 10.1.1.2
bing.com
OneDrive
VIP1 = 1.1.1.1
VIP2 = 2.2.2.2

FIG. 1

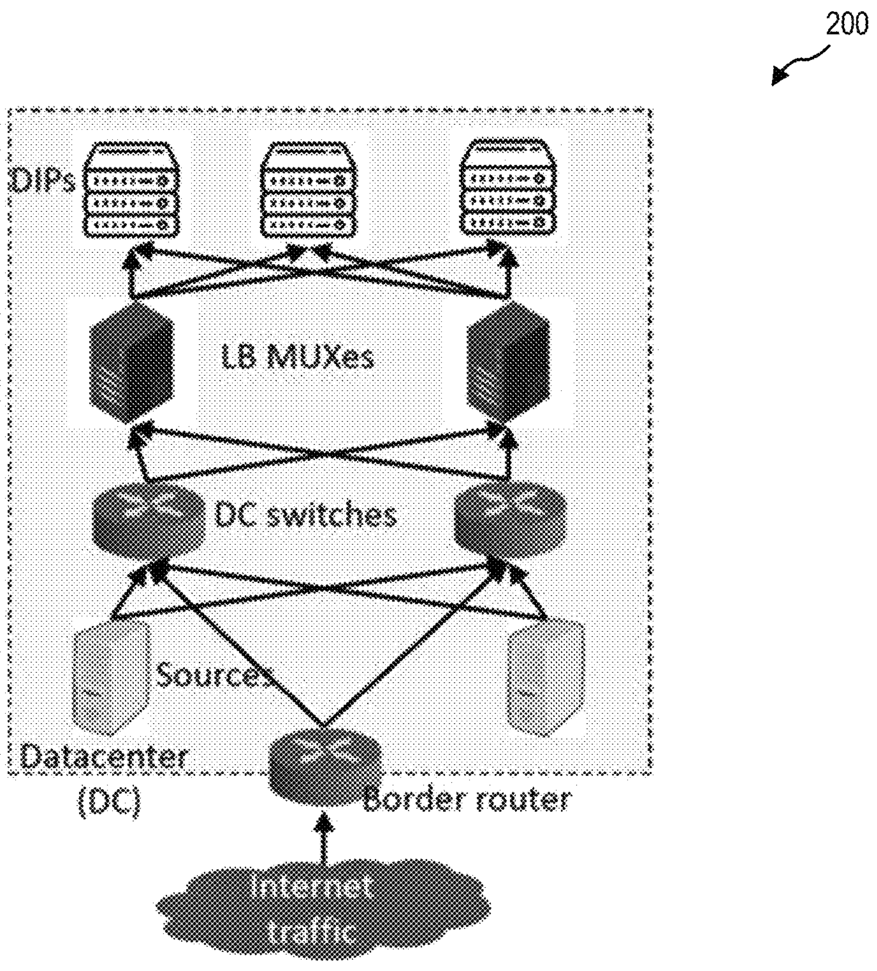
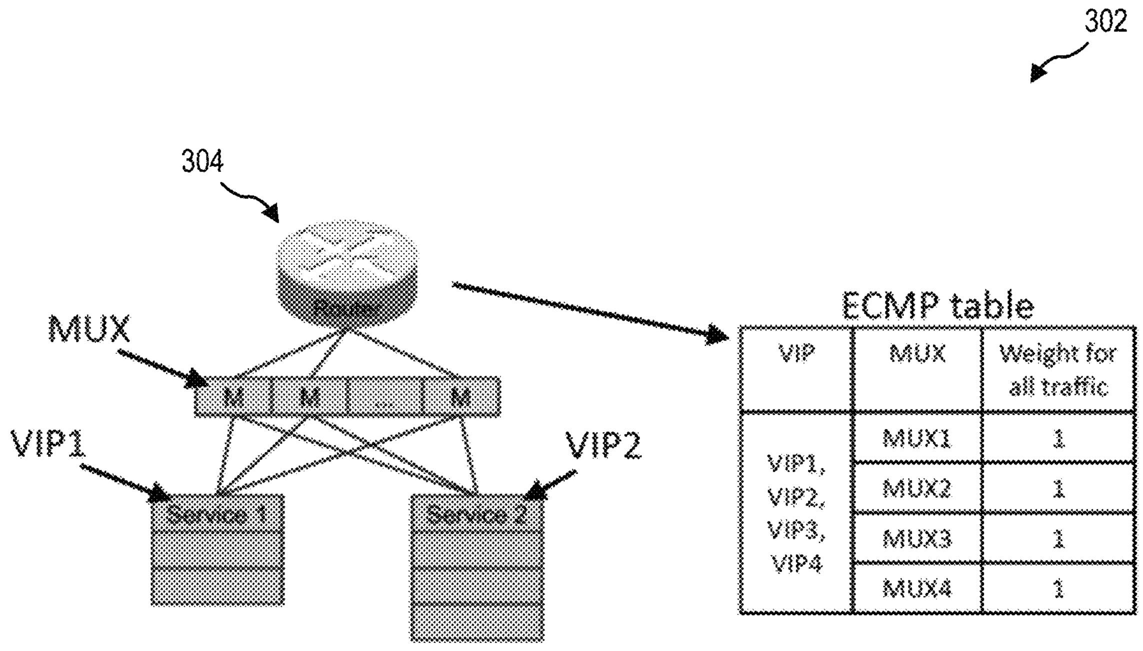

200
DIPs
LB MUXes
DC switches
Sources
Datacenter
(DC)
Border router
Internet
traffic

FIG. 2



VIP	MUX	Weight for all traffic
VIP1, VIP2, VIP3, VIP4	MUX1	1
	MUX2	1
	MUX3	1
	MUX4	1

FIG. 3

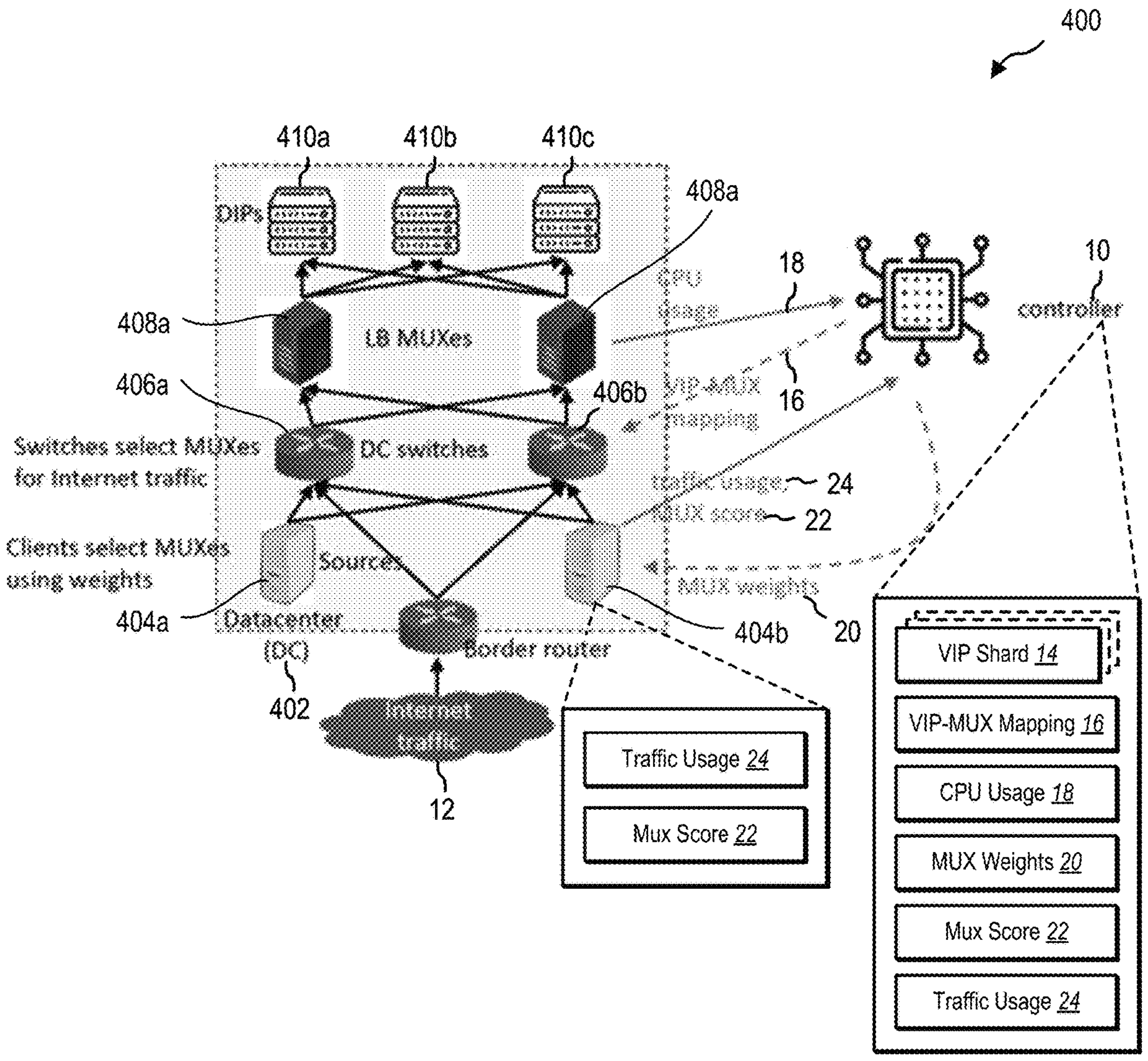

400
410a
410b
410c
DIPs
408a
408a
LB MUXes
18
CPU usage
10
controller
406a
406b
DC switches
VIP-MUX mapping
16
Switches select MUXes for Internet traffic
traffic usage
24
MUX score
22
Clients select MUXes using weights
Sources
MUX weights
20
404a
Datacenter (DC)
404b
Border router
402
Internet traffic
12
Traffic Usage 24
Mux Score 22
VIP Shard 14
VIP-MUX Mapping 16
CPU Usage 18
MUX Weights 20
Mux Score 22
Traffic Usage 24

FIG. 4

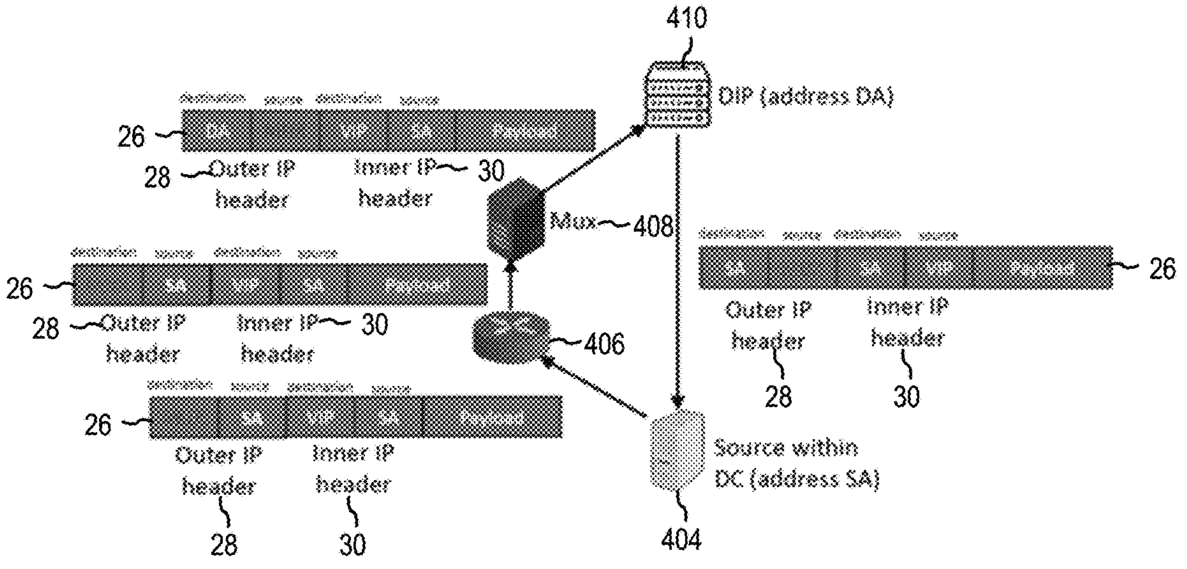
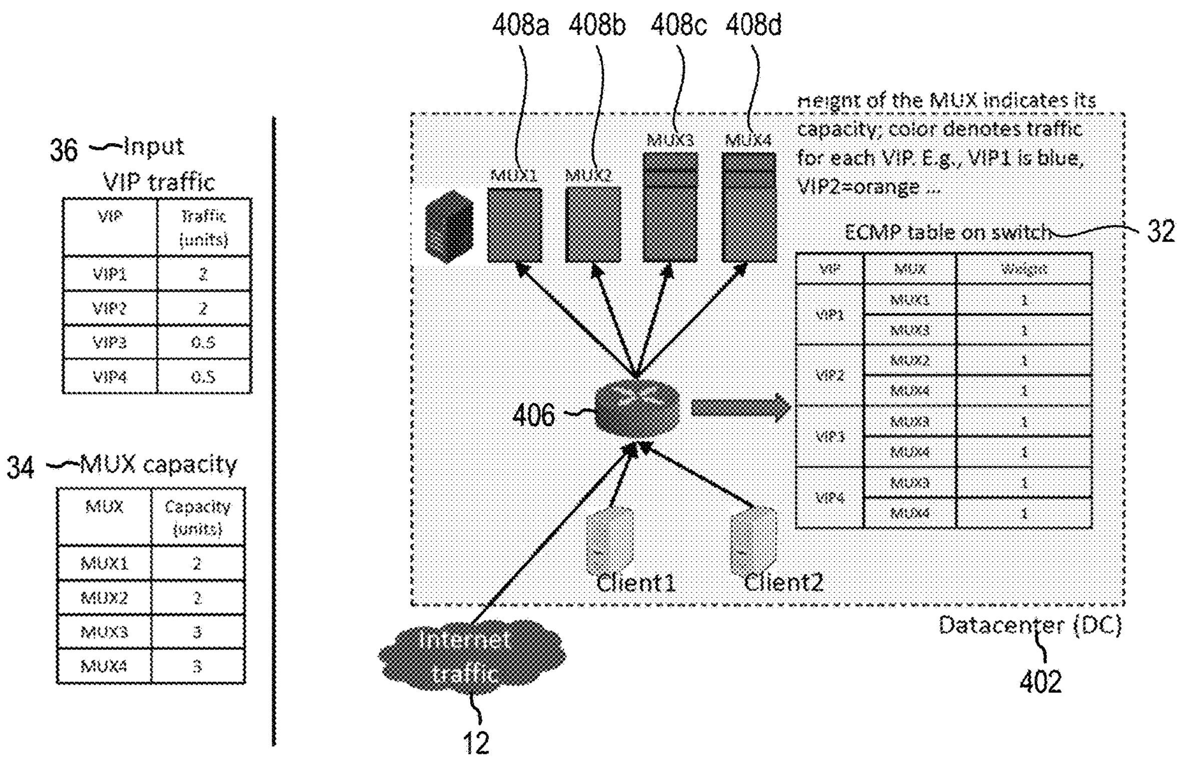

410
DIP (address DA)
destination
source
destination
source
26
DA
VIP
SA
Payload
28
Outer IP header
Inner IP header
30
Mux
408
26
SA
VIP
SA
Payload
28
Outer IP header
Inner IP header
30
406
26
SA
VIP
SA
Payload
Outer IP header
Inner IP header
28
30
SA
SA
VIP
Payload
26
Outer IP header
Inner IP header
28
30
Source within DC (address SA)
404

FIG. 5

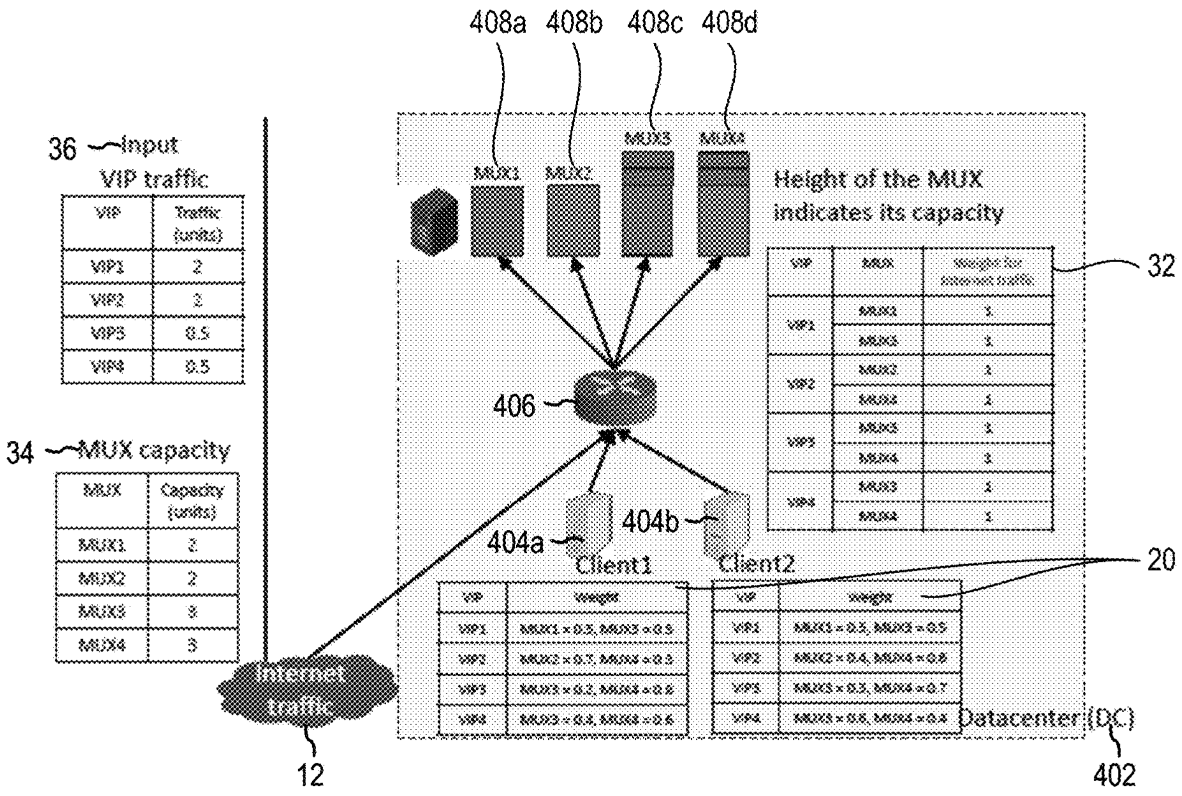


VIP	Traffic (units)
VIP1	2
VIP2	2
VIP3	0.5
VIP4	0.5

MUX	Capacity (units)
MUX1	2
MUX2	2
MUX3	3
MUX4	3

VIP	MUX	Weight
VIP1	MUX1	1
	MUX3	1
VIP2	MUX2	1
	MUX4	1
VIP3	MUX3	1
	MUX4	1
VIP4	MUX3	1
	MUX4	1

FIG. 6



VIP	Traffic (units)
VIP1	2
VIP2	2
VIP3	0.5
VIP4	0.5

MUX	Capacity (units)
MUX1	2
MUX2	2
MUX3	3
MUX4	3

VIP	MUX	Weight for internet traffic
VIP1	MUX1	1
	MUX3	1
VIP2	MUX2	1
	MUX4	1
VIP3	MUX3	1
	MUX4	1
VIP4	MUX3	1
	MUX4	1

VIP	Weight
VIP1	MUX1 × 0.5, MUX3 × 0.5
VIP2	MUX2 × 0.7, MUX4 × 0.3
VIP3	MUX3 × 0.2, MUX4 × 0.8
VIP4	MUX3 × 0.4, MUX4 × 0.6

VIP	Weight
VIP1	MUX1 × 0.5, MUX3 × 0.5
VIP2	MUX2 × 0.4, MUX4 × 0.6
VIP3	MUX3 × 0.3, MUX4 × 0.7
VIP4	MUX3 × 0.6, MUX4 × 0.4

FIG. 7

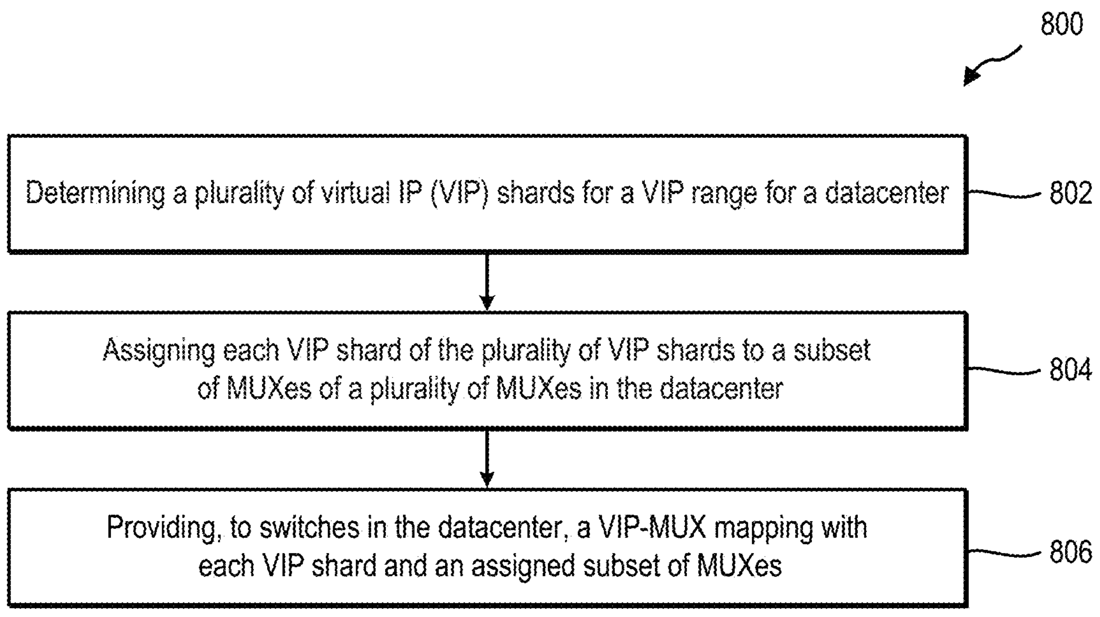

800
Determining a plurality of virtual IP (VIP) shards for a VIP range for a datacenter
802
Assigning each VIP shard of the plurality of VIP shards to a subset of MUXes of a plurality of MUXes in the datacenter
804
Providing, to switches in the datacenter, a VIP-MUX mapping with each VIP shard and an assigned subset of MUXes
806

FIG. 8

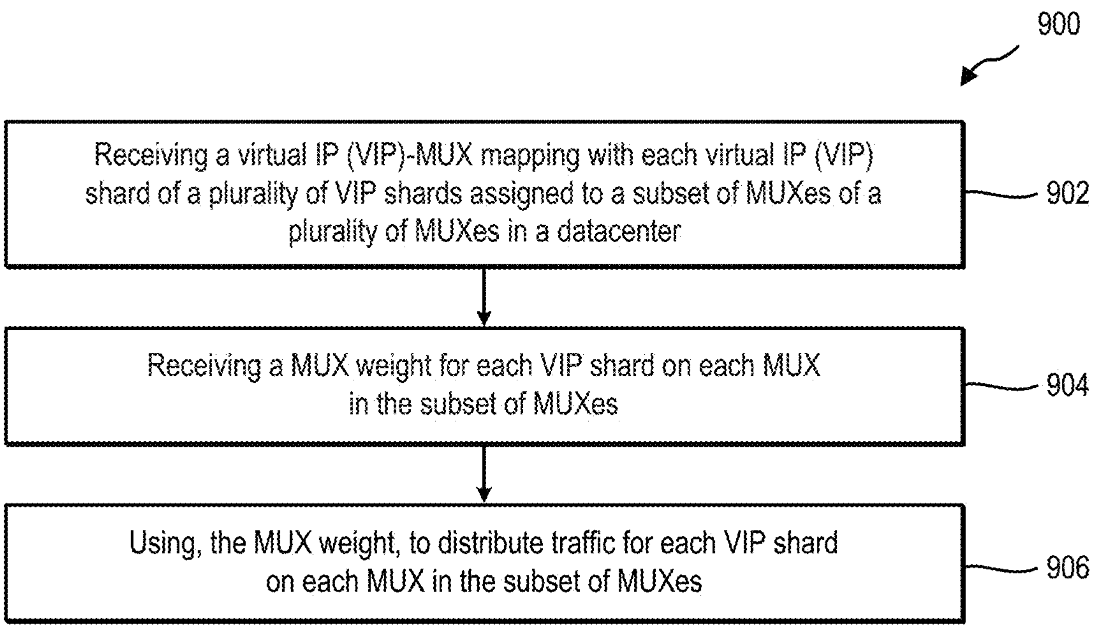

900
Receiving a virtual IP (VIP)-MUX mapping with each virtual IP (VIP) shard of a plurality of VIP shards assigned to a subset of MUXes of a plurality of MUXes in a datacenter
902
Receiving a MUX weight for each VIP shard on each MUX in the subset of MUXes
904
Using, the MUX weight, to distribute traffic for each VIP shard on each MUX in the subset of MUXes
906

FIG. 9

CAPACITY AND PERFORMANCE AWARE LOAD BALANCER SELECTION

BACKGROUND

A layer-4 load balancer (LB) is one of the foundational blocks for online services. Online services expose small number of virtual addresses (VIPs) to receive the traffic. Internally, the layer-4 LB runs on many virtual machines (VMs) with their own unique direct IPs (DIPs). The layer-4 LB receives the traffic on VIPs and splits it across DIPs.

BRIEF SUMMARY

This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

Some implementations relate to a method. The method includes determining a plurality of virtual IP (VIP) shards for a VIP range for a datacenter, wherein each VIP shard is a subset of the VIP range. The method includes assigning each VIP shard of the plurality of VIP shards to a subset of multiplexers (MUXes) of a plurality of MUXes in the datacenter. The method includes providing, to switches in the datacenter, a VIP-MUX mapping with each VIP shard and an assigned subset of MUXes.

Some implementations relate to a device. The device includes a processor; memory in electronic communication with the processor; and instructions stored in the memory, the instructions being executable by the processor to: determine a plurality of virtual IP (VIP) shards for a VIP range for a datacenter, wherein each VIP shard is a subset of the VIP range; assign each VIP shard of the plurality of VIP shards to a subset of multiplexers (MUXes) of a plurality of MUXes in the datacenter; and provide, to switches in the datacenter, a VIP-MUX mapping with each VIP shard and an assigned subset of MUXes.

Some implementations relate to a method. The method includes receiving, from a controller, a virtual IP (VIP)-MUX mapping with each virtual IP (VIP) shard of a plurality of VIP shards assigned to a subset of multiplexers (MUXes) of a plurality of MUXes in a datacenter, wherein each VIP shard is a subset of a VIP range for the datacenter. The method includes receiving, from the controller, a MUX weight for each VIP shard on each MUX in the subset of MUXes. The method includes using, the MUX weight, to distribute traffic for each VIP shard on each MUX in the subset of MUXes.

Some implementations relate to a device. The device includes a processor; memory in electronic communication with the processor; and instructions stored in the memory, the instructions being executable by the processor to: receive, from a controller, a virtual IP (VIP)-MUX mapping with each virtual IP (VIP) shard of a plurality of VIP shards assigned to a subset of multiplexers (MUXes) of a plurality of MUXes in a datacenter, wherein each VIP shard is a subset of a VIP range for the datacenter; receive, from the controller, a MUX weight for each VIP shard on each MUX in the subset of MUXes; and use, the MUX weight, to distribute traffic for each VIP shard on each MUX in the subset of MUXes.

Additional features and advantages will be set forth in the description which follows, and in part will be obvious from the description, or may be learned by the practice of the teachings herein. Features and advantages of the disclosure may be realized and obtained by means of the instruments and combinations particularly pointed out in the appended claims. Features of the present disclosure will become more fully apparent from the following description and appended claims or may be learned by the practice of the disclosure as set forth hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to describe the manner in which the above-recited and other features of the disclosure can be obtained, a more particular description will be rendered by reference to specific implementations thereof which are illustrated in the appended drawings. For better understanding, the like elements have been designated by like reference numbers throughout the various accompanying figures. While some of the drawings may be schematic or exaggerated representations of concepts, at least some of the drawings may be drawn to scale. Understanding that the drawings depict some example implementations, the implementations will be described and explained with additional specificity and detail through the use of the accompanying drawings in which:

FIG. **1** illustrates an example of an existing layer-4 load balancer system.

FIG. **2** illustrates an example of logical layers in an existing layer-4 load balancer.

FIG. **3** illustrates an example of MUX selection in an existing layer-4 load balancer.

FIG. **4** illustrates an example environment for MUX selection based on MUX capacity in accordance with implementations of the present disclosure.

FIG. **5** illustrates an example packet structure for sending packets to MUXes for intra-datacenter (DC) traffic in accordance with implementations of the present disclosure.

FIG. **6** illustrates an example of MUX selection for Internet traffic in a datacenter in accordance with implementations of the present disclosure.

FIG. **7** illustrates an example of MUX selection for Internet traffic and intra-DC traffic in a datacenter in accordance with implementations of the present disclosure.

FIG. **8** illustrates an example method for MUX selection in accordance with implementations of the present disclosure.

FIG. **9** illustrates an example method for performance aware MUX selection in accordance with implementations of the present disclosure.

DETAILED DESCRIPTION

A layer-4 load balancer (LB) is one of the foundational blocks for online services. Online services expose small number of virtual addresses (VIPs) to receive traffic. The traffic may come from outside services (e.g., Internet traffic) or from clients within a datacenter (DC). Internally, the layer-4 LB runs on many virtual machines (VMs) with their own unique direct IPs (DIPs). The layer-4 LB receives the traffic on VIPs and splits it across DIPs. An online service deploys multiple servers with DIPs, primarily to scale and to provide high availability. The DIPs run behind a load-balancer (LB) that exposes one or more virtual IPs (VIPs) to receive the traffic from outside the service or from clients within a datacenter.

FIG. **1** illustrates an example of an existing layer-4 LB system **100** in a datacenter (DC). The layer-4 LB receives the traffic from the Internet for the VIPs (e.g., VIP1 and

VIP2) and splits the Internet traffic across the DIPs. The layer-4 LB also receives the traffic from different clients within the datacenter and splits traffic from the clients across the DIPs. There is no single instance of the layer-4 LB. The layer-4 LB runs on multiple instances (called multiplexers (MUXes)). One example is the layer-4 LB runs on hundreds of MUXes in the datacenter. The VIP traffic is split across the MUXes. Each MUX then sends the traffic (the Internet traffic or the traffic from the clients) across DIPs. Existing LB designs assign all VIPs to all MUXes in a datacenter.

FIG. **2** illustrates an example of logical layers in an existing layer-4 LB system **200**. Clients (on the Internet or internally in the same datacenter) sends requests on a VIP. The VIP packet is first intercepted by switches. In existing layer-4 LB designs, network switches select the MUX for traffic in the same datacenter. There may be hundreds of MUXes in a datacenter. The switches select MUXes using ECMP (equal-cost-multi-path) and forward the packet to the selected MUX. The MUXes store a VIP-DIP mapping for all VIPs. The MUXes select DIPs and forward the packet to the DIPs. In existing, LB designs, traffic from each source is split equally among MUXes.

FIG. **3** illustrates an example of an existing MUX selection in an existing layer-4 LB system (e.g., the layer-4 LB system **100** (FIG. **1**) or the layer-4 LB system **200** (FIG. **2**)). Each router/switch **304** in a datacenter (DC) has an ECMP table **302** for the entire VIP range. The weight for each MUX is set to "1" and the traffic is uniformly split across all MUXes in the datacenter (DC). In existing LB designs, there is no support for sources to know the MUX handling traffic.

Recent advances in LBs have shown that there are many options for MUXes. For example, the MUXes can run on software instances, or hardware, or FPGAs. Thus, different instances of MUXes can have radically different capacities. The MUXes may be hosted on instances with other applications too raising a noisy-neighbor problem, where the capacity of the MUX can dynamically change. Thus, the MUXes can have different and dynamic capacities.

Existing solutions do not support MUXes of different capacities or cause the size of the ECMP table to increase substantially (e.g., increase by more than ten times the size). Datacenter applications are increasingly becoming latency-sensitive with few microsecond latencies. MUXes impose additional latency through congestion at the MUXes (e.g., MUXes running at high CPU add latency to packet processing), congestion on network paths (e.g., paths leading from source VMs to MUXes can observe congestion), and MUXes are far away (the selected MUXes may be far away from the sources adding to the latency). In existing solutions, the sources in datacenters have no control over MUX selection. As a result, the sources in the datacenters cannot do MUX selection based on the performance.

The present disclosure includes a number of practical applications that provide benefits and/or solve problems associated with layer-4 load balancing. Examples of these applications and benefits are discussed in further detail below.

The methods and systems automatically provide performance aware MUX selection for traffic in layer-4 load balancing. The methods and systems of the present disclosure assign a subset of the VIPs to individual MUXes based on the capacity and traffic of the MUXes. Instead of storing the full VIP range on each MUX, MUXes in the methods and systems of the present invention store a subset of VIP ranges (referred to herein as VIP shards) based on capacity of the MUXes. The VIP range is split across a plurality of VIP shards (e.g., VIP1 shard, VIP2 shard, VIP3 shard, etc.).

MUXes with more capacity receive more VIP shards relative to MUXes with less capacity. For example, if MUX2 has more capacity relative to MUX 1, MUX 1 is assigned VIP1 shard and MUX 2 is assigned VIP1 shard and the VIP2 shard).

The methods and systems contain the size of the ECMP table size (e.g., maintaining a current size of the ECMP table or reducing a size of the ECMP table). The methods and systems offload MUX selection to sources in the same datacenter, as opposed to network switches doing such selection (as done in current LB solutions). In the methods and systems of the present disclosure sources measure the latency from each MUX. In some implementations, packet modifications and routing occur to enable sources to measure the latencies from different MUXes. Using the measurements, sources select MUXes using weights. The weights are calculated so that the performance is maximized without exceeding MUX capacities.

The methods and systems of the present disclosure assigns a subset of VIPs to individual MUXes based on capacity and traffic, resulting in an advantage of providing capacity aware MUX selection without exploding the ECMP table size (e.g., without significantly increasing the ECMP table size).

The methods and systems of the present disclosure allow sources (end-hosts) in the same DC to select the MUXes for intra-DC traffic, resulting in an advantage of the sources can select the MUXes in response to the performance of the MUXes. The methods and systems of the present disclosure allow the sources to select the MUXes by monitoring end-to-end latency. The methods and systems of the present disclosure allow the sources to use weights calculated by a controller for splitting the traffic across MUXes, aiding the sources in selecting MUXes with good performance. The methods and systems of the present disclosure allow the sources to know the MUXes handling the traffic by using packet modification and routing changes that comply with today's datacenter networks. The methods and systems allow the sources to route the packets to reach the specific MUXes.

One technical advantage of the methods and systems of the present disclosure include supporting capacity aware MUX selection. Another technical advantage of the methods and systems of the present disclosure is performance aware MUX selection for sources in datacenters. Another technical advantage of the methods and systems of the present disclosure is reducing a size of the ECMP table. Another technical advantage of the methods and systems of the present disclosure is improved performance and operability. Another technical advantage of the methods and systems of the present disclosure is low overhead in terms of cost, deployability, and operability.

Referring now to FIG. **4**, illustrated is an example environment **400** for selecting MUXes based on MUX capacity in a datacenter **402**. The environment **400** includes a controller **10** in communication with the sources **404** (e.g., sources **404***a*, **404***b* up to r, where r is a positive integer), the switches **406** (e.g., switches **406***a*, **406***b* up to s, where s is a positive integer), and the MUXes **408** (e.g., MUXes **408***a*, **408***b* up to m, where m is a positive integer). For example, the datacenter **402** has hundreds of MUXes **408**. In some implementations, the controller **10** is a virtual machine or server in the datacenter **402**. The switches **406** select the MUXes **408** for the Internet traffic **12** received at the datacenter **402**.

The controller **10** breaks the VIP range into multiple VIP shards **14**. The VIP range is a fixed block of IP addresses for the datacenter **402**. The VIP range is split it across "N" VIP shards **14** (where Nis a positive integer). The VIP shards **14** are a subset of the VIPs. In some implementations, N is a power of 2 (e.g., 2, 4, 8, etc.). For example, if the VIP range is 10.0.0.0/14, the VIP range is split into VIP shards **14** of (VIP1 shard) 10.0.0.0/16, (VIP2 shard) 10.1.0.0/16, (VIP3 shard) 10.2.0.0/16, etc. The controller **10** receives the CPU usage **18** of the MUXes **408** and uses the CPU usage **18** to determine a capacity of each MUX **408** (e.g., a capacity of MUX **408***a*, a capacity of MUX **408***b*).

The controller **10** uses a VIP-MUX mapping **16** to assign a subset of the VIP shards **14** to the MUXes based on a MUX capacity and the VIP shard **14** traffic. Each VIP shard **14** is assigned to "K" MUXes **408** (where K is a positive integer). For example, a first VIP Shard **14**$_1$ is assigned to MUX **408***a* and a second VIP shard **14**$_2$ is assigned to MUX **408***b*. In some implementations, the total ECMP table size is equal to N*K. For example, if the datacenter **402** includes 100 MUXes **408**, the number (N) of VIP shards **14** is equal to 8 and number (K) of MUXes **408** assigned to each VIP shard **14** is equal 12, the total size of the ECMP table (N*K) is equal to 96, which is less than the total number of MUXes **408** (100) in the datacenter. If N and K are selected so that N*K is less than M, the size of the ECMP table is reduced while still building capacity aware MUX selection.

In some implementations, the controller **10** uses an integer linear program (ILP) for assigning the VIP shards **14** to individual MUXes **408** based on capacity. An objective of the integer linear program is to minimize a maximum CPU usage **18** (CPU load) on each of the MUXes **408** (e.g., minimize y). Constraints of the integer linear program that the controller **10** uses for assigning VIP shards **14** to MUXes **408** are illustrated below in the equations (1), (2), and (3). The constraints include that each VIP shard **14** is assigned to K MUXes **408** (equation (1)), traffic on each MUX **408** is under a capacity of the MUX **408** (equation (2)), and y (the maximum CPU load on each MUX **408**) is greater than the CPU load on each MUX **408** (equation (3)).

$$\forall\ v \epsilon V,\ \sum\nolimits_{m \epsilon M} X_v^m = K \tag{1}$$

$$\forall\ m \epsilon M,\ \sum\nolimits_{v \in V} X_v^m * t_v / K * C_v \leq \text{Capacity}_m \tag{2}$$

$$\forall\ m \epsilon M,\ y \geq \sum\nolimits_{v \in V} X_v^m * t_v * C_v \tag{3}$$

where $X^m{}_v$ is a binary variable that is set if the v-th VIP shard **14** is assigned to the m-th MUX **408**; K is the number of MUXes **408** to be assigned to each VIP shard **14**; M is the set of MUXes **408**; V is the set of VIP shards **14**; t_v is the total traffic on the v-th VIP shard **14**; C_v is CPU utilization for unit traffic of the VIP shard **14**; Capacity$_m$ is the capacity of the m-th MUX, and y is the maximum CPU load on each MUX **408**.

The controller **10** provides the VIP-MUX mapping **16** to the switches **406**. The switches **406** use the VIP-MUX mapping **16** to send the VIP shards **14** to the subset of MUXes **408** associated with the VIP shards **14**. VIPs are not assigned to all MUXes **408** in the datacenter **402**, instead, the MUXes **408** receive VIP shards **14** depending on MUX capacity and VIP traffic. The MUXes **408** receive the VIP shards **14** and sends the traffic of the VIP shards **14** to the DIPs **410** (e.g., **410***a*, **410***b*, **410***c*). The weight for each VIP shard **14** on each MUX **408** is equal to "1" in the ECMP table at the switches **406**. The traffic for each VIP shard **14**

is split equally among the MUXes **408** assigned to each VIP shard **14**, helping to reduce a size of the ECMP table.

By splitting the VIP range into VIP shards **14** and mapping the VIP shards **14** to MUXes **408** using the capacity of the MUXes **408**, the controller **10** automatically provides capacity aware MUX selection for the Internet traffic **12** received at the datacenter **402**.

In some implementations, the sources **404** within the datacenter **402** select the MUX **408** for each VIP shard **14** for intra-datacenter (DC) traffic depending on a performance of the MUX **408**. Intra-DC traffic is traffic originating from virtual machines (VMs) within the datacenter **402** and reaching virtual machines (VMs) within the datacenter **402**. Each source **404** collects the traffic usage **24** (e.g., the end-to-end latency) for each MUX **408** for each VIP shard **14** on a MUX **408**. The latency for each MUX **408** is determined by measuring the time between sending a synchronize (SYN) and receiving a SYN-acknowledgment (ACK).

Each source **404** identifies the MUX **408** handling the VIP shard **14** for the intra-DC traffic using IP-to-IP encapsulation of the packet for the VIP shard **14**. Each source **404** attaches to an outer header of the packet for the VIP shard **14** a destination address (the IP address of the MUX **408**) and a source address of the packet (IP address of the source **404**). The switches **406** forward the packet to the MUX **408** specified in the packet header as the destination address and the MUX **408** decapsulates the outer header of the packet for the VIP shard **14**.

In some implementations, each source **404** maintains a round-trip-time (RTT) for each connection to obtain the latency for each MUX **408**. Each source **404** starts a timer when sending the SYN packet of the connection. The SYN packet goes to the DIP **410** through the MUXes **408**. The TCP mechanism allows the SYNs to respond immediately. As a result, the DIPs **410** send back the SYN-ACK to the sources **404**. The source **404** measures the time between sending the SYN and receiving the SYN-ACK for determining the latency.

Each source **404** uses the traffic usage **24** to calculate a MUX score **22** for each VIP shard **14** on each MUX **408**. One example of an algorithm that the sources **404** use to calculate a MUX score **22** is illustrate below in Algorithm **1**.

Algorithm 1

```
1) Each source (s):
  For each VIP-shard (v):
    For each MUX (m):
      measures average latency across all DIPs (latency_{s,v,m})
2) Calculates the minimum latency across all MUXes (minL_{s,v})
3) Score calculated as: Score_{s,v,m} =  minL_{s,v} / latency_{s,v,m}
```

Each source **404** measures the average latency across all DIPs **410***a*, **410***b*, **410***c* and calculates the minimum latency across all MUXes **408***a*, **408***b*. The MUX score **22** is calculated by dividing the minimum latency across all MUXes **408***a*, **408** by the average latency across all DIPs **410***a*, **410***b*, **410***c*. Each source **404** calculates the MUX score **22** for each VIP shard **14** on each MUX **408**. For example, source **404***a* calculates a MUX score **22** of 100 for a VIP1 shard on MUX **408***a* and a MUX score **22** of 90 for a VIP1 shard on MUX **408***b*. The MUX score **22** is calculated based on the relative latency of the MUXes **408**. Different sources **404** may have different MUX scores **22** for a MUX **408**.

Each source **404** provides the traffic usage **24** observed for each MUX **408** and the MUX score **22** calculated for each MUX **408** to the controller **10**. The controller **10** calculates MUX weights **20** for each MUX **408** using the traffic usage **24** and the MUX score **22**. The MUX weights **20** are calculated by the controller **10** based on a latency of the MUX **408**. For intra-DC traffic, latency matters for application performance. The application performance depends on the end-to-end latency from the source **404** to the MUX **408** to the DIP **410** back to the source **404**.

In some implementations, the controller **10** uses an integer linear program (ILP) for calculating the MUX weights **20**. An objective of an example integer linear program that the controller **10** uses to calculate the MUX weights **20** is illustrated below in the equation (4). The objective of the integer linear program is to maximize a total score of the MUX **408**. Constraints for the integer linear program that the controller **10** uses for calculating the MUX weights **20** are illustrated below in equations (5) and (6). The constraints include that the total weight from each source **404** across all MUXes **408** is 1 (equation (5)), and that the total traffic to each MUX **408** for the VIP shards **14** on each MUX **408** is under a capacity of the MUX **408** (equation (6)).

$$\sum_{s\epsilon S}\sum_{v\epsilon V}\sum_{m\in M} W^{v}_{s,m} * t^{v}_{s,m} * \text{Score}^{v}_{s,m} \tag{4}$$

$$\forall\ s\epsilon S,\ \forall\ v\epsilon V \sum_{m\epsilon M} w^{v}_{s,m} = 1 \tag{5}$$

$$\forall\ m\epsilon M,\ \forall\ v\epsilon V \sum_{s\in S} w^{v}_{s,m} * t^{v}_{s,m} \leq T^{v}_{m} \tag{6}$$

where $w_{s,m}{}^{v}$ is a variable between "0" and "1" that specifies a weight for the m-th MUX **408** at the s-th source **404** for the v-th VIP shard **14**; M is the set of MUXes **408**, V is the set of VIP shards **14**, S is the set of sources **404**, $t_{s,m}{}^{v}$ is the traffic from the s-th source **404** to the v-th VIP shard **14** via the m-th MUX **408**, $\text{Scores}_{s,m}{}^{v}$ is the score (out of 100) for the m-th MUX **408** at the s-th source **404** for the v-th VIP shard **14**, and $T^{v}{}_{m}$ is the traffic capacity at the m-th MUX **408** for the v-th VIP shard **14**.

The controller **10** sends the MUX weights **20** to the sources **404**. Each source **404** uses the MUX weights **20** for selecting a MUX **408** for each VIP shard **14** to maximize a total score while load balancing the intra-DC traffic without exceeding a capacity of the MUX **408**.

The environment **400** supports capacity away MUX **408** selection while preventing the ECMP table from increasing significantly (e.g., exploding a size of the ECMP table). The environment **400** reduces a size of the ECMP table compared to existing solutions for layer-4 LB. The environment **400** provides performance aware MUX **408** selection for sources **404** in a datacenter **402**.

In some implementations, each of the components of the environment **400** is in communication with each other using any suitable communication technologies. In addition, while the components of the environment **400** are shown to be separate, any of the components or subcomponents may be combined into fewer components, such as into a single component, or divided into more components as may serve a particular implementation. In some implementations, the components of the environment **400** include hardware, software, or both. For example, the components of the environment **400** may include one or more instructions stored on a computer-readable storage medium and executable by processors of one or more computing devices. The processors may be a general-purpose single or multi-chip microprocessor (e.g., an Advanced RISC (Reduced Instruction Set Computer) Machine (ARM)), a special purpose microprocessor (e.g., a digital signal processor (DSP)), a microcontroller, a programmable gate array, etc. Memory is in electronic communication with the processors. The memory may be any electronic component capable of storing electronic information. For example, the memory may be embodied as random access memory (RAM), read-only memory (ROM), magnetic disk storage mediums, optical storage mediums, flash memory devices in RAM, on-board memory included with the processor, erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM) memory, registers, and so forth, including combinations thereof. When executed by the one or more processors, the computer-executable instructions of one or more computing devices can perform one or more methods described herein. In some implementations, the components of the environment **400** include hardware, such as a special purpose processing device to perform a certain function or group of functions. In some implementations, the components of the environment **400** include a combination of computer-executable instructions and hardware.

FIG. **5** illustrates an example packet structure for sending packets to MUXes **408** for intra-datacenter (DC) traffic in a datacenter **402** (FIG. **4**). FIG. **5** is discussed in reference to the architecture of FIG. **4**.

The source **404** sends a packet **26** for a VIP shard **14** traffic to the switch **406** for the intra-DC traffic. The source **404** adds an outer IP header **28** and an inner IP header **30** to the packet **26**. The outer IP header **28** includes a destination of the MUX **408** (MUX IP address) and an IP address of the source **404**. The switch **406** forwards the packet **26** to the MUX **408** identified with the MUX IP address in the outer IP header **28**.

The MUX **408** encodes the MUX IP address as the source in the outer IP header **28** and the IP address of the DIP **410** as the destination in the outer IP header **28** and sends the packet **26** to the DIP **410**.

The DIP **410** encapsulates the packets **26** using IP-in-IP encapsulation. The DIP **410** writes the MUX IP address as the source in the outer IP header **28** of the packet **26** and the IP address of the source **404** as the destination address. The packets **26** include two headers (the outer IP header **28** and the inner IP header **30**) from the DIPs **410**. Existing layer-4 LBs do not include two headers in the packets **26** from the DIPs **410**. By using two headers (the outer IP header **28** and the inner IP header **30**) from the DIPs **410**, the sources **404** can identify the MUX **408** that handled the traffic for the packet **26**.

The sources **404** receives the packet **26** from the DIPs **410** and the sources **404** uses the MUX IP address in the outer IP header **28** to identify the MUX **408** that handled the traffic for the packet **26**. The sources **404** use the identity of the MUX **408** that handled the traffic for the packet **26** to determine an end-to-end performance of the MUX **408** and a latency of the MUX **408**.

FIG. **6** illustrates an example of MUX selection for Internet traffic **12** in datacenter **402**. FIG. **6** is discussed below in reference to the architecture of FIG. **4**. The height of the MUXes **408***a*, **408***b*, **408***c*, **408***d* indicates a MUX capacity **34**. For example, the MUX1 (MUX **408***a*) capacity is two units, the MUX2 (MUX **408***b*) capacity is two units, the MUX3 (MUX **408***c*) capacity is three units, and the MUX4 (MUX **408***d*) capacity is three units. In some implementations, the units are packets per second. For example, MUX1 (MUX **408***a*) can process 200K packets/second (200 thousand packets per second) and MUX3 (MUX **408***c*) can process 300K packets/second (300 thousand packets per second).

The input VIP traffic **36** (in this illustrated example, the Internet traffic **12**) is divided into four VIP shards **14** (VIP1 shard, VIP2 shard, VIP3 shard, VIP4 shard). For example, the traffic for VIP1 is two units, the traffic for VIP2 is two units, the traffic for VIP3 is half a unit, and the traffic for VIP4 is half a unit. In some implementations, the units are packets per second of the VIP shard **14** traffic. The input VIP traffic **36** for each VIP is monitored at all MUXes **408** and the amount of traffic for each VIP is determined in response to the input VIP traffic **36** monitoring. For example, the traffic for VIP1 is 100K packets/second (100 thousand packets per second) and the traffic for VIP2 is 200K packets/second (200 thousand packets per second).

The controller **10** assigns the VIP shards **14** to the different MUXes **408***a*, **408***b*, **408***c*, **408***d* based on the MUX capacity **34** and the traffic for the VIP shards **14**. In some implementations, the controller **10** uses an ILP with the constraints of the ILP illustrated in equations (1), (2), and (3) to determine the VIP shard **14** assignments to the different MUXes **408***a*, **408***b*, **408***c*, **408***d*.

For example, the controller **10** assigns the VIP1 shard to MUX1 (MUX **408***a*) and MUX3 (**408***c*). The controller assigns the VIP2 shard to MUX2 (MUX **408***b*) and MUX4 (MUX **408***d*). The controller assigns the VIP3 shard to MUX3 (MUX **408***c*) and MUX4 (MUX **408***d*). The controller assigns the VIP4 shard to MUX3 (MUX **408***c*) and MUX4 (MUX **408***d*). Different shadings of the MUXes **408***a*, **408***b*, **408***c*, **408***d* correspond to different VIP shards **14** assigned to the MUXes **408***a*, **408***b*, **408***c*, **408***d*.

The ECMP table **32** on the switch **406** includes the VIP shards **14** and the corresponding MUX **408** assignments for the VIP shards **14**. The switches **406** use the ECMP table **32** to determine where to send the VIP shard **14** traffic. For example, the switch **406** sends the traffic for VIP1 shard to MUX1 (MUX **408***a*) and MUX3 (**408***c*), sends the traffic for VIP2 shard to MUX2 (MUX **408***b*) and MUX4 (MUX **408***d*), sends the traffic for VIP3 shard to MUX3 (MUX **408***c*) and MUX4 (MUX **408***d*), and sends the traffic for VIP4 shard to MUX3 (MUX **408***c*) and MUX4 (MUX **408***d*).

The ECMP table **32** also includes a weight for each of the MUXes **408***a*, **408***b*, **408***c*, **408***d*. The weight for each VIP shard **14** on each MUX **408** is equal to "1." The traffic for each VIP shard **14** is split equally by the switches **406** among the MUXes **408** in the subset assigned to each VIP shard **14**, helping to reduce a size of the ECMP table **32**. The size of the illustrated ECMP table **32** is eight. The VIP shard **14** traffic is assigned to the MUXes **408***a*, **408***b*, **408***c*, **408***d* based on the VIP shard **14** traffic and the MUX capacity **34**.

Referring now to FIG. **7**, illustrated is an example of MUX selection for the Internet traffic **12** and intra-DC traffic in a datacenter **402**. FIG. **7** is discussed below in reference to the architectures of FIGS. **4-6**. The height of the MUXes **408***a*, **408***b*, **408***c*, **408***d* indicates a MUX capacity **34**. For example, the MUX1 (MUX **408***a*) capacity is two units, the MUX2 (MUX **408***b*) capacity is two units, the MUX3 (MUX **408***c*) capacity is three units, and the MUX4 (MUX **408***d*) capacity is three units.

The input VIP traffic **36** in this illustrated example includes the Internet traffic **12** and intra-DC traffic. The input VIP traffic **36** is divided into four VIP shards **14** (VIP1 shard, VIP2 shard, VIP3 shard, VIP4 shard). For example, the

traffic for VIP1 is two units, the traffic for VIP2 is two units, the traffic for VIP3 is half a unit, and the traffic for VIP4 is half a unit.

For the Internet traffic **12** received at the datacenter **402**, the Internet traffic **12** is received directly by the switches **406**, and the switches **406** use the VIP-MUX mapping **16** from the controller **10** in the ECMP table **32** to handle the Internet traffic **12**, as discussed in FIG. **6**. For intra-DC traffic, the controller **10** sends the MUX weights **20** to clients (sources **404***a*, **404***b*) and the clients (sources **404***a*, **404***b*) select the MUXes **408***a*, **408***b*, **408***c*, **408***d* using the MUX weights **20** to maximize performance of the intra-DC traffic.

In some implementations, the controller determines the MUX weights **20** using the ILP (discussed in reference to equations (4), (5), and (6)) and sends the MUX weights **20** to the clients (sources **404***a*, **404***b*). The MUX weights **20** are calculated by the controller **10** without violating the MUX capacity **34**. The clients (sources **404***a*, **404***b*) use the MUX weights **20** to select which MUX **408***a*, **408***b*, **408***c*, **408***d* to assign to the VIP shard intra-DC traffic. The MUX weights **20** are also used by the clients (sources **404***a*, **404***b*) to determine an amount of the VIP shard **14** traffic to send to the MUXes **408***a*, **408***b*, **408***c*, **408***d*.

In the illustrated example, the client1 (source **404***a*) splits the intra-DC traffic for the VIP1 shard equally between the MUX1 (MUX **408***a*) and the MUX3 (**408***c*). For example, the MUX weight **20** for MUX1 is equal to 0.5 and 50% of the VIP1 shard intra-DC traffic from client1 (source **404***a*) is sent to MUX1 and the MUX weight **20** for MUX2 is equal to 0.5 and 50% of the VIP1 shard intra-DC traffic is sent to MUX2. The client1 (source **404***a*) sends more of the traffic for the VIP2 shard to MUX2 (MUX **408***b*) as compared to the traffic for the VIP2 shard sent to MUX4 (MUX **408***d*). For example, the MUX weight **20** for MUX2 for the VIP2 shard traffic is equal to 0.7 and 70% of the VIP2 shard intra-DC traffic is sent to MUX2 and the MUX weight **20** for MUX4 for the VIP2 shard traffic is equal to 0.3 and 30% of the VIP2 shard intra-DC traffic is sent to MUX4. The client1 (source **404***a*) sends more of the traffic for the VIP3 shard to MUX4 (MUX **408***d*) as compared to MUX3 (MUX **408***c*). For example, the MUX weight **20** for MUX4 for the VIP3 shard traffic is equal to 0.8 and 80% of the VIP3 shard intra-DC traffic is sent to MUX4 and the MUX weight **20** for MUX3 for the VIP3 shard traffic is equal to 0.2 and 20% of the VIP3 shard intra-DC traffic is sent to MUX3. The client1 (source **404***a*) sends more of the traffic for the VIP4 shard to MUX4 (MUX **408***d*) as compared to MUX3 (MUX **408***c*). For example, the MUX weight **20** for MUX4 for the VIP4 shard traffic is equal to 0.6 and 60% of the VIP4 shard intra-DC traffic is sent to MUX4 and the MUX weight **20** for MUX3 for the VIP4 shard traffic is equal to 0.4 and 40% of the VIP3 shard intra-DC traffic is sent to MUX3.

In the illustrated example, the client2 (source **404***b*) splits the intra-DC traffic for the VIP1 shard equally between the MUX1 (MUX **408***a*) and the MUX3 (**408***c*). For example, the MUX weight **20** for MUX1 is equal to 0.5 and 50% of the VIP1 shard intra-DC traffic is sent to MUX1 and the MUX weight **20** for MUX2 is equal to 0.5 and 50% of the VIP1 shard intra-DC traffic is sent to MUX2. The client2 (source **404***b*) sends more of the traffic for the VIP2 shard to MUX4 (MUX **408***d*) as compared to the traffic for the VIP2 shard sent to MUX2 (MUX **408***b*). For example, the MUX weight **20** for MUX4 for the VIP2 shard traffic is equal to 0.6 and 60% of the VIP2 shard intra-DC traffic is sent to MUX4 and the MUX weight **20** for MUX2 for the VIP2 shard traffic is equal to 0.4 and 40% of the VIP2 shard intra-DC traffic is sent to MUX2. The client2 (source **404***b*) sends more of the traffic for the VIP3 shard to MUX4 (MUX **408***d*) as compared to MUX3 (MUX **408***c*). For example, the MUX weight **20** for MUX4 for the VIP3 shard traffic is equal to 0.7 and 70% of the VIP3 shard intra-DC traffic is sent to MUX4 and the MUX weight **20** for MUX3 for the VIP3 shard traffic is equal to 0.3 and 30% of the VIP3 shard intra-DC traffic is sent to MUX3. The client2 (source **404***b*) sends more of the traffic for the VIP4 shard to MUX3 (MUX **408***c*) as compared to MUX4 (MUX **408***d*). For example, the MUX weight **20** for MUX3 for the VIP4 shard traffic is equal to 0.6 and 60% of the VIP4 shard intra-DC traffic is sent to MUX3 and the MUX weight **20** for MUX4 for the VIP4 shard traffic is equal to 0.4 and 40% of the VIP3 shard intra-DC traffic is sent to MUX4.

Each client (sources **404***a*, **404***b*) may have different MUX weights **20** for the VIP shards **14**. In addition, each client (sources **404***a*, **404***b*) may have different weights for each MUX **408***a*, **408***b*, **408***c*, **408***d* for different VIP shards **14**.

The clients (sources **404***a*, **404***b*) use the MUX weights **20** to assign the selected MUX **408***a*, **408***b*, **408***c*, **408***d* as the destination IP address in the packet **26** outer IP header **28**. For example, client1 (source **404***a*) assigns 70% of the packets **26** for the VIP2 shard traffic with the IP address for MUX2 (MUX **408***b*) in the destination address in the outer IP header **28** and assigns 30% of the packets **26** for the VIP2 shard traffic with the IP address for MUX4 (MUX **408***d*) in the destination address in the outer IP header **28**.

The packets **26** from the clients (sources **404***a*, **404***b*) within the datacenter **402** are forwarded by the switches **406** to the MUXes **408***a*, **408***b*, **408***c*, **408***d* identified in the destination addresses in the outer IP header **28** of the packets **26** by the clients (sources **404***a*, **404***b*).

The clients (sources **404***a*, **404***b*) use the MUX weights **20** to send the packets **26** to specific MUXes **408***a*, **408***b*, **408***c*, **408***d* based on performance (end-to-end) latency of the MUXes **408***a*, **408***b*, **408***c*, **408***d*.

FIG. **8** illustrates an example method **800** for MUX selection. The actions of the method **800** are discussed below with reference to FIGS. **1**-**7**.

At **802**, the method **800** includes determining a plurality of virtual IP (VIP) shards for a VIP range for a datacenter. The controller **10** determines a plurality of VIP shards **14** for a VIP range for the datacenter **402**. Each VIP shard **14** is a subset of the VIP range for the datacenter **402**.

At **804**, the method **800** includes assigning each VIP shard of the plurality of VIP shards to a subset of MUXes of a plurality of MUXes in the datacenter. The controller **10** assigns each VIP shard **14** to a subset of MUXes **408** in the datacenter **402**.

In some implementations, the controller **10** determines a MUX capacity **34** of each MUX **408** and assigns each VIP shard **14** to the subset of MUXes **408** based on the MUX capacity **34** and traffic for each VIP shard **14**. In some implementations, the MUX capacity **34** is determined based on receiving a CPU usage **18** from each MUX **408** and using the CPU usage **18** to determine an available amount of the MUX capacity **34**. The traffic for each VIP shard **14** assigned to a MUX **408** is under the MUX capacity **34** of the MUX **408** (e.g., within the available amount of the MUX capacity **34**). In some implementations, the controller **10** uses an ILP (e.g., the ILP discussed with the constraints illustrated in equations (1), (2), and (3)) to assign each VIP shard **14** to the subset of MUXes **408** based on the MUX capacity **34**. The ILP minimizes a maximum CPU usage on each MUX **408**.

In some implementations, the controller **10** receives a MUX score **22** for each MUX **408** of the plurality of MUXes in a datacenter **402**. The controller **10** uses an ILP (e.g., as discussed in equation 2) to calculate a MUX weight **20** for each VIP shard **14** on each MUX **408** based on the MUX score **22**. The controller **10** sends the MUX weight **20** for each VIP shard **14** on each MUX **408** to the sources **404** in the datacenter **402**. In some implementations, the MUX score **22** is calculated for each VIP shard **14** on each MUX **408** based on a latency of each MUX **408**. The sources **404** use the MUX weights **20** to distribute intra-datacenter traffic for each VIP shard **14** on each MUX **408** based on a performance of the MUXes **408**.

At **806**, the method **800** includes providing, to switches in the datacenter, a VIP-MUX mapping with each VIP shard and an assigned subset of MUXes. The controller **10** provides a VIP-MUX mapping **16** with each VIP shard **14** and the assigned subset of MUXes **408** to the switches **406** in the datacenter **402**. In some implementations, the VIP-MUX mapping **16** is stored, at the switches, in an equal-cost-multi-path (ECMP) table **32**. The size of the ECMP table **32** is equal to a number of VIP shards **14** multiplied by a number of MUXes in the subset of MUXes **408**. The switches **406** use the VIP-MUX mapping **16** to send the traffic for a VIP shard **14** to a corresponding MUX to handle the traffic for the VIP shard **14**.

The method **800** provides capacity aware MUX selection in a datacenter for handling traffic for the datacenter. The method **800** also provides performance aware MUX selection for intra-datacenter traffic.

FIG. **9** illustrates an example method **900** for performance aware MUX selection. The actions of the method **900** are discussed below with reference to FIGS. **1**-**7**.

At **902**, the method **900** includes receiving, from a controller, a virtual IP (VIP)-MUX mapping with each virtual IP (VIP) shard of a plurality of VIP shards assigned to a subset of MUXes of a plurality of MUXes in a datacenter. Each source **404** in the datacenter **402** receives from the controller **10** a VIP-MUX mapping **16** with each VIP shard **14** assigned to a subset of MUXes **408** in the datacenter **402**. Each VIP shard **14** is a subset of the VIP range for the datacenter **402**.

At **904**, the method **900** includes receiving, from the controller, a MUX weight for each VIP shard on each MUX in the subset of MUXes. Each source **404** receives from the controller **10** the MUX weights **20** for each VIP shard **14** and each MUX **408**. In some implementations, each source **404** determines a MUX score **22** for each VIP shard **14** on each MUX **408** based on a latency of each MUX **408**. The latency of each MUX **408** is determined by each source **404** observing a round-trip-time of connections on each MUX **408** by using a start time for sending a packet **26** to the MUX **408** for traffic of a VIP shard **14** and an end time for receiving the packet **26** from the MUX **408**. In some implementations, the round-trip-time is determined by the sources **404** identifying a source IP address of a MUX **408** that transmitted the packet **26** in an outer internet protocol (IP) header **28** in the packet **26**.

Each source **404** sends the MUX score **22** for each VIP shard **14** on each MUX **408** to the controller **10**. In some implementations, different MUXes **408** have different MUX scores **22** for a same VIP shard **14**. The controller **10** uses the MUX score **22** to determine the MUX weight **20**.

Each source **404** receives from the controller **10** a MUX weight **20** for each VIP shard **14** on each MUX **408**. In some implementations, different sources **404** in the datacenter **402** have different MUX weights **20** for each VIP shard **14** on each MUX **408**.

At **906**, the method **900** includes using, the MUX weight, to distribute traffic for each VIP shard on each MUX in the subset of MUXes. The traffic is intra-datacenter traffic. Each source **404** uses the MUX weight **20** to determine a portion of traffic for each VIP shard **14** to distribute to each MUX **408** in the subset of MUXes assigned to a VIP shard **14**. Each source **404** uses an outer IP header **28** of packets **26** for the traffic of the VIP shard **14** to assign a source IP address of the MUX **408** to receive the packets **26**. Each source **404** sends the packets **26** to a switch **406** in the datacenter **402** and the switch **406** sends the packets **26** to the IP address of the MUX **408** identified in the outer IP header **28** of the packets **26**.

The method **900** provides performance aware MUX selection for intra-datacenter traffic. The method **900** also allows sources **404** in the datacenter to select which MUXes **408** receive the intra-DC traffic.

As illustrated in the foregoing discussion, the present disclosure utilizes a variety of terms to describe features and advantages of the methods and systems. Additional detail is now provided regarding the meaning of such terms. For example, as used herein, a "machine learning model" refers to a computer algorithm or model (e.g., a classification model, a clustering model, a regression model, a language model, an object detection model) that can be tuned (e.g., trained) based on training input to approximate unknown functions. For example, a machine learning model may refer to a neural network (e.g., a convolutional neural network (CNN), deep neural network (DNN), recurrent neural network (RNN)), or other machine learning algorithm or architecture that learns and approximates complex functions and generates outputs based on a plurality of inputs provided to the machine learning model. As used herein, a "machine learning system" may refer to one or multiple machine learning models that cooperatively generate one or more outputs based on corresponding inputs. For example, a machine learning system may refer to any system architecture having multiple discrete machine learning components that consider different kinds of information or inputs.

The techniques described herein may be implemented in hardware, software, firmware, or any combination thereof, unless specifically described as being implemented in a specific manner. Any features described as modules, components, or the like may also be implemented together in an integrated logic device or separately as discrete but interoperable logic devices. If implemented in software, the techniques may be realized at least in part by a non-transitory processor-readable storage medium comprising instructions that, when executed by at least one processor, perform one or more of the methods described herein. The instructions may be organized into routines, programs, objects, components, data structures, etc., which may perform particular tasks and/or implement particular data types, and which may be combined or distributed as desired in various implementations.

Computer-readable mediums may be any available media that can be accessed by a general purpose or special purpose computer system. Computer-readable mediums that store computer-executable instructions are non-transitory computer-readable storage media (devices). Computer-readable mediums that carry computer-executable instructions are transmission media. Thus, by way of example, and not limitation, implementations of the disclosure can comprise at least two distinctly different kinds of computer-readable mediums: non-transitory computer-readable storage media (devices) and transmission media.

As used herein, non-transitory computer-readable storage mediums (devices) may include RAM, ROM, EEPROM, CD-ROM, solid state drives ("SSDs") (e.g., based on

RAM), Flash memory, phase-change memory ("PCM"), other types of memory, other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to store desired program code means in the form of computer-executable instructions or data structures and which can be accessed by a general purpose or special purpose computer.

The steps and/or actions of the methods described herein may be interchanged with one another without departing from the scope of the claims. In other words, unless a specific order of steps or actions is required for proper operation of the method that is being described, the order and/or use of specific steps and/or actions may be modified without departing from the scope of the claims.

The term "determining" encompasses a wide variety of actions and, therefore, "determining" can include calculating, computing, processing, deriving, investigating, looking up (e.g., looking up in a table, a database, a datastore, or another data structure), ascertaining and the like. Also, "determining" can include receiving (e.g., receiving information), accessing (e.g., accessing data in a memory) and the like. Also, "determining" can include resolving, selecting, choosing, establishing, predicting, inferring, and the like.

The articles "a," "an," and "the" are intended to mean that there are one or more of the elements in the preceding descriptions. The terms "comprising," "including," and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements. Additionally, it should be understood that references to "one implementation" or "an implementation" of the present disclosure are not intended to be interpreted as excluding the existence of additional implementations that also incorporate the recited features. For example, any element described in relation to an implementation herein may be combinable with any element of any other implementation described herein. Numbers, percentages, ratios, or other values stated herein are intended to include that value, and also other values that are "about" or "approximately" the stated value, as would be appreciated by one of ordinary skill in the art encompassed by implementations of the present disclosure. A stated value should therefore be interpreted broadly enough to encompass values that are at least close enough to the stated value to perform a desired function or achieve a desired result. The stated values include at least the variation to be expected in a suitable manufacturing or production process, and may include values that are within 5%, within 1%, within 0.1%, or within 0.01% of a stated value.

A person having ordinary skill in the art should realize in view of the present disclosure that equivalent constructions do not depart from the spirit and scope of the present disclosure, and that various changes, substitutions, and alterations may be made to implementations disclosed herein without departing from the spirit and scope of the present disclosure. Equivalent constructions, including functional "means-plus-function" clauses are intended to cover the structures described herein as performing the recited function, including both structural equivalents that operate in the same manner, and equivalent structures that provide the same function. It is the express intention of the applicant not to invoke means-plus-function or other functional claiming for any claim except for those in which the words 'means for' appear together with an associated function. Each addition, deletion, and modification to the implementations that falls within the meaning and scope of the claims is to be embraced by the claims.

The present disclosure may be embodied in other specific forms without departing from its spirit or characteristics. The described implementations are to be considered as illustrative and not restrictive. The scope of the disclosure is, therefore, indicated by the appended claims rather than by the foregoing description. Changes that come within the meaning and range of equivalency of the claims are to be embraced within their scope.

What is claimed is:

1. A method, comprising:

determining a plurality of virtual IP (VIP) shards for a VIP range for a datacenter, wherein each VIP shard is a subset of the VIP range;

assigning each VIP shard of the plurality of VIP shards to a subset of multiplexers (MUXes) of a plurality of MUXes in the datacenter;

providing, to switches in the datacenter, a VIP-MUX mapping with each VIP shard and an assigned subset of MUXes;

receiving a MUX score for each MUX of the plurality of MUXes;

using an integer linear program (ILP) to calculate a MUX weight for each VIP shard on each MUX based on the MUX score; and

sending, to sources in the datacenter, the MUX weight for each VIP shard on each MUX.

2. The method of claim **1**, further comprising:

determining a MUX capacity of each MUX of the plurality of MUXes in the datacenter; and

assigning each VIP shard to the subset of MUXes based on the MUX capacity and traffic for each VIP shard.

3. The method of claim **2**, wherein the traffic for each VIP shard assigned to a MUX is under the MUX capacity for the MUX.

4. The method of claim **2**, wherein determining the MUX capacity further includes receiving a central processing unit (CPU) usage from each MUX and using the CPU usage to determine an available amount of the MUX capacity.

5. The method of claim **2**, further comprising:

using an integer linear program (ILP) to assign each VIP shard to the subset of MUXes based on the MUX capacity, wherein the integer linear program minimizes a maximum central processing unit (CPU) usage on each MUX of the plurality of MUXes.

6. The method of claim **2**, wherein the traffic is Internet traffic, and the method further comprises:

using, by the switches, the VIP-MUX mapping to send the traffic for a VIP shard to a corresponding MUX to handle the traffic for the VIP shard.

7. The method of claim **6**, wherein the VIP-MUX mapping is stored, at the switches, in an equal-cost-multi-path (ECMP) table.

8. The method of claim **7**, wherein a size of the ECMP table is equal to a number of VIP shards multiplied by a number of MUXes in the subset of MUXes.

9. The method of claim **1**, wherein the MUX score is calculated for each VIP shard on each MUX based on a latency of each MUX.

10. The method of claim **1**, further comprising:

using, by the sources, the MUX weights to distribute traffic for each VIP shard on each MUX, wherein the traffic is intra-datacenter traffic.

11. A method, comprising:

receiving, from a controller, a virtual IP (VIP)-MUX mapping with each virtual IP (VIP) shard of a plurality of VIP shards assigned to a subset of multiplexers (MUXes) of a plurality of MUXes in a datacenter, wherein each VIP shard is a subset of a VIP range for the datacenter;

receiving, from the controller, a MUX weight for each VIP shard on each MUX in the subset of MUXes; and

using, the MUX weight, to distribute traffic for each VIP shard on each MUX in the subset of MUXes.

12. The method of claim **11**, further comprising:

determining a MUX score for each VIP shard on each MUX in the subset of MUXes based on a latency of each MUX; and

sending, to the controller, the MUX score for each VIP shard on each MUX, wherein the controller uses the MUX score to determine the MUX weight.

13. The method of claim **12**, wherein the latency of each MUX is determined by observing a round-trip-time of connections on each MUX by using a start time for sending a packet to a MUX for traffic of a VIP shard and an end time for receiving the packet from the MUX.

14. The method of claim **13**, wherein the round-trip-time is determined by identifying a source IP address of a MUX that transmitted the packet in an outer internet protocol (IP) header in the packet.

15. The method of claim **11**, further comprising:

determining, using the MUX weight, a portion of traffic for each VIP shard to distribute to each MUX in the subset of MUXes assigned to each VIP shard.

16. The method of claim **15**, further comprising:

using an outer internet protocol (IP) header of packets for the traffic to assign a source IP address of a MUX to receive the packets; and

sending the packets to a switch in the datacenter and the switch sends the packets to the IP address of the MUX identified in the outer IP header of the packets.

17. The method of claim **11**, wherein different MUXes have different MUX scores for a VIP shard.

18. The method of claim **11**, wherein different sources in the datacenter have different MUX weights for each VIP shard on each MUX.

19. The method of claim **11**, wherein the traffic is intra-datacenter traffic.

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