



US009270601B2

(12) **United States Patent**  
**Lin et al.**

(10) **Patent No.:** **US 9,270,601 B2**  
(45) **Date of Patent:** **Feb. 23, 2016**

(54) **PATH RESOLUTION FOR HIERARCHICAL LOAD DISTRIBUTION**

(58) **Field of Classification Search**  
CPC ..... H04L 47/17  
See application file for complete search history.

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(56) **References Cited**

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U.S. PATENT DOCUMENTS

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5,437,029	A	7/1995	Sinha	
8,787,154	B1 *	7/2014	Medved et al.	370/225
8,824,274	B1 *	9/2014	Medved et al.	370/217
2004/0202135	A1 *	10/2004	Han et al.	370/332
2006/0036719	A1 *	2/2006	Bodin et al.	709/223
2009/0296579	A1 *	12/2009	Dharwadkar et al.	370/235
2012/0039161	A1 *	2/2012	Allan et al.	370/216
2013/0051394	A1	2/2013	Gavrilov	
2014/0160925	A1 *	6/2014	Xu et al.	370/235
2014/0244966	A1 *	8/2014	Bosshart et al.	711/206
2014/0293786	A1 *	10/2014	Lin et al.	370/235

(\* ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 181 days.

(21) Appl. No.: **14/025,114**

FOREIGN PATENT DOCUMENTS

(22) Filed: **Sep. 12, 2013**

EP 2 613 502 10/2013

(65) **Prior Publication Data**

\* cited by examiner

US 2014/0293786 A1 Oct. 2, 2014

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**Related U.S. Application Data**

(57) **ABSTRACT**

(60) Provisional application No. 61/807,181, filed on Apr. 1, 2013, provisional application No. 61/812,052, filed on Apr. 15, 2013.

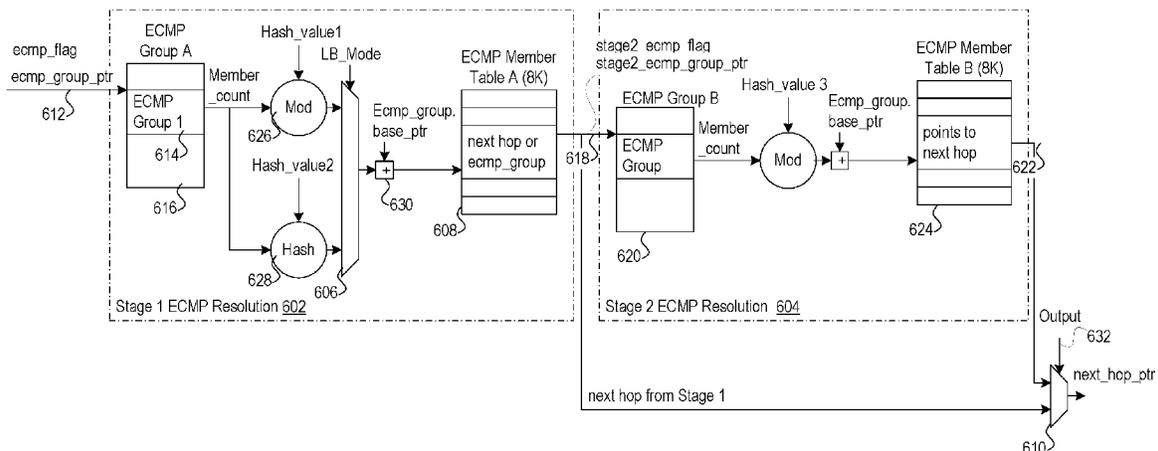
Network devices perform multiple stage path resolution. The path resolution may be ECMP resolution. Any particular stage of the multiple stage path resolution may be skipped under certain conditions. Further, the network device facilitate redistribution of traffic when a next hop goes down in a fast, efficient manner, and without reassigning traffic that was going to other unaffected next hops, using multiple stage ECMP resolution.

(51) **Int. Cl.**  
**G01R 31/08** (2006.01)  
**H04L 12/801** (2013.01)

(52) **U.S. Cl.**  
CPC ..... **H04L 47/17** (2013.01)

**20 Claims, 13 Drawing Sheets**

600



100

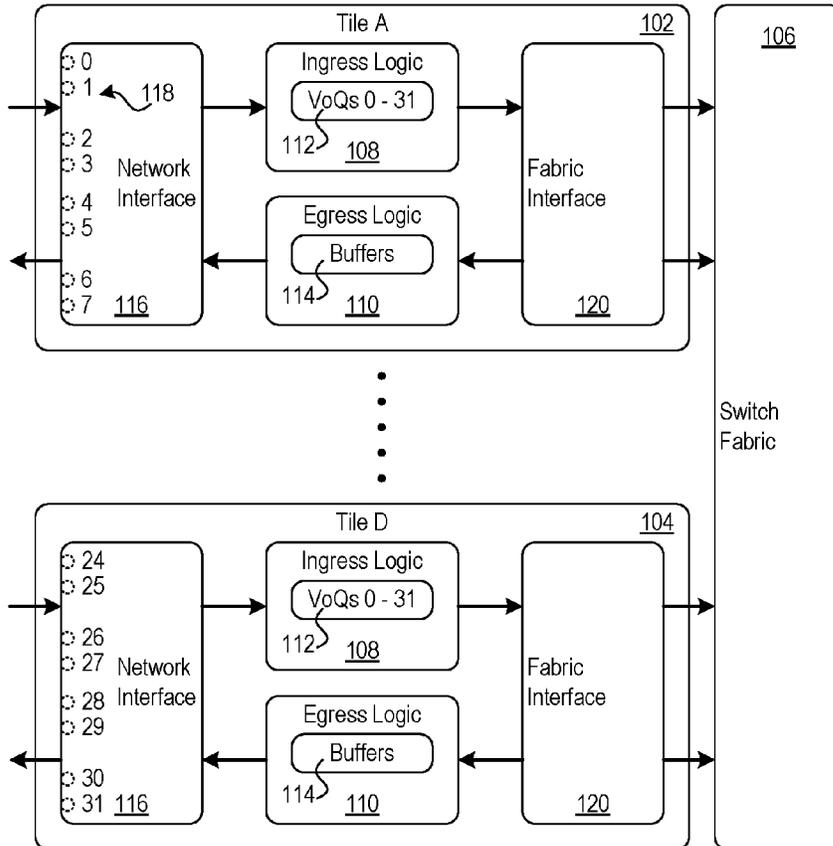


Figure 1

200  
↙

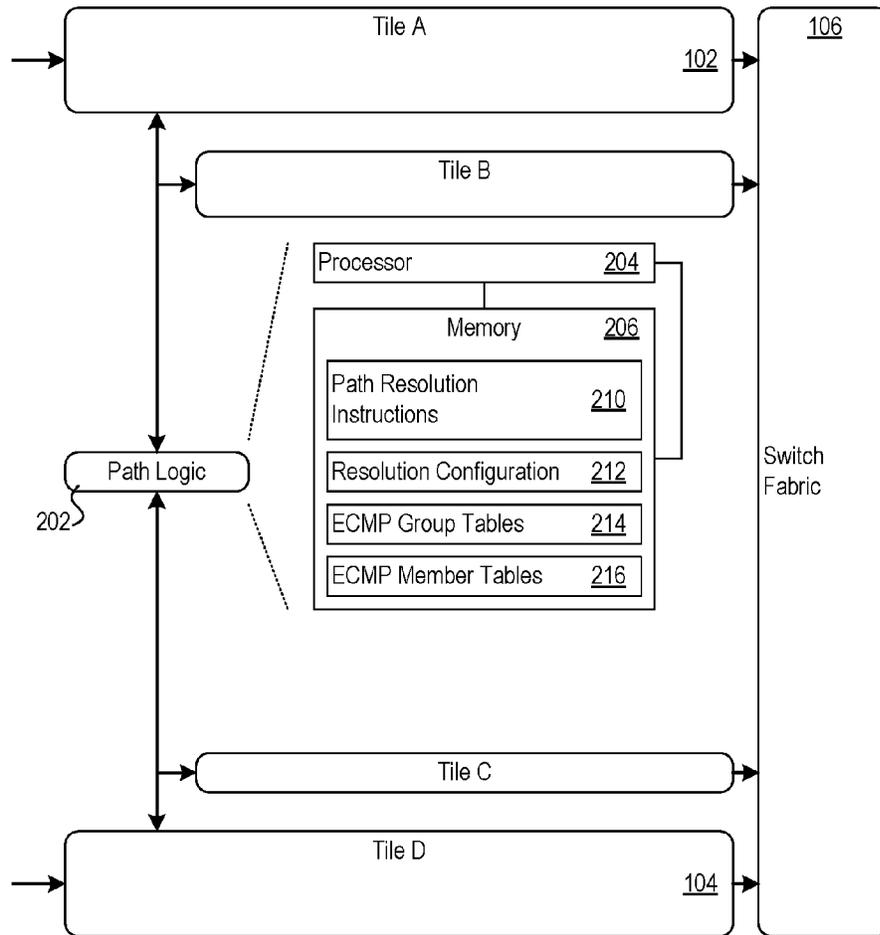
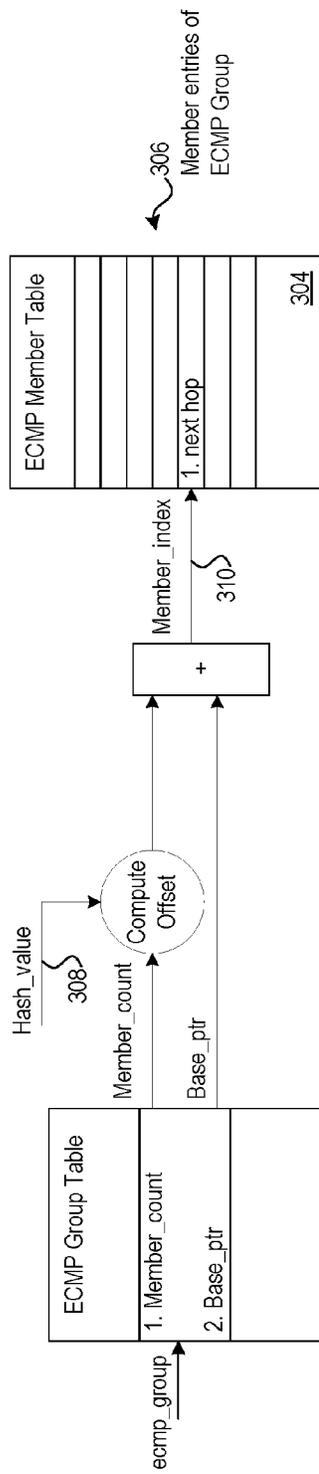


Figure 2

300 ↗



Prior Art

Figure 3

400 ↗

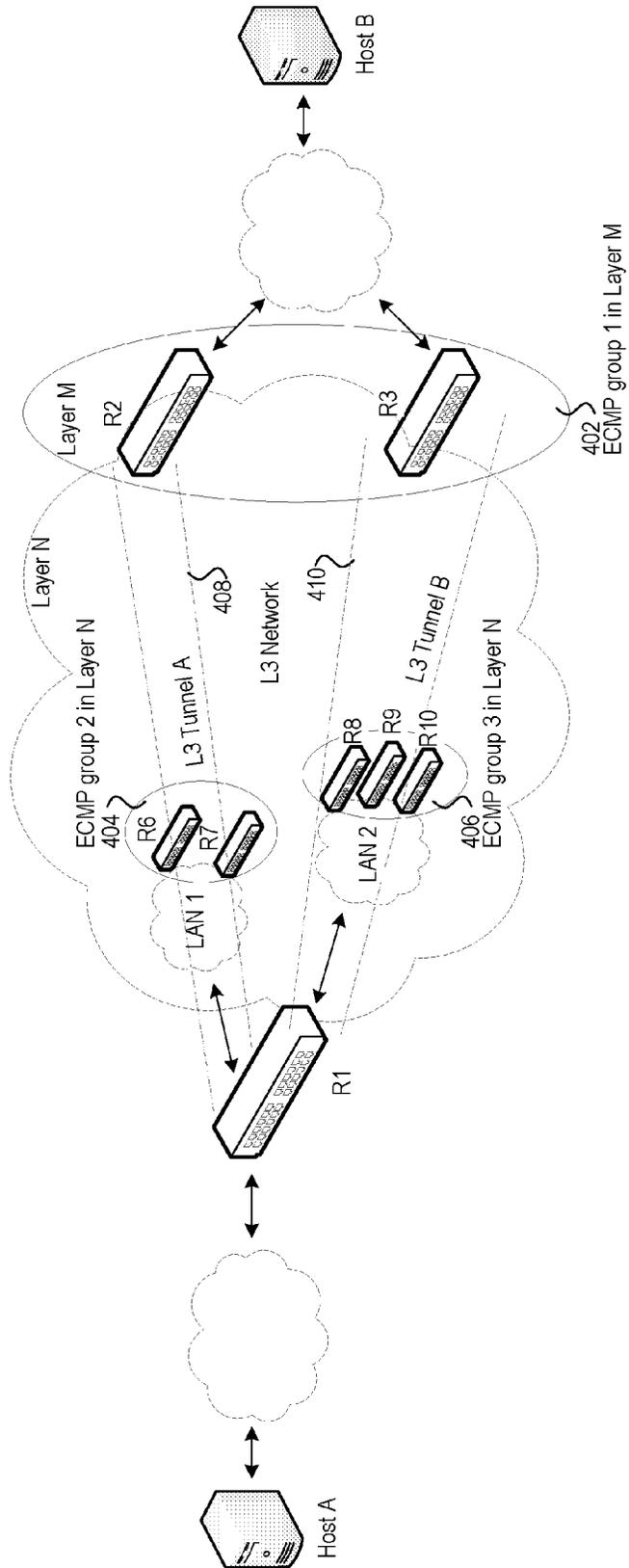


Figure 4

500  
↘

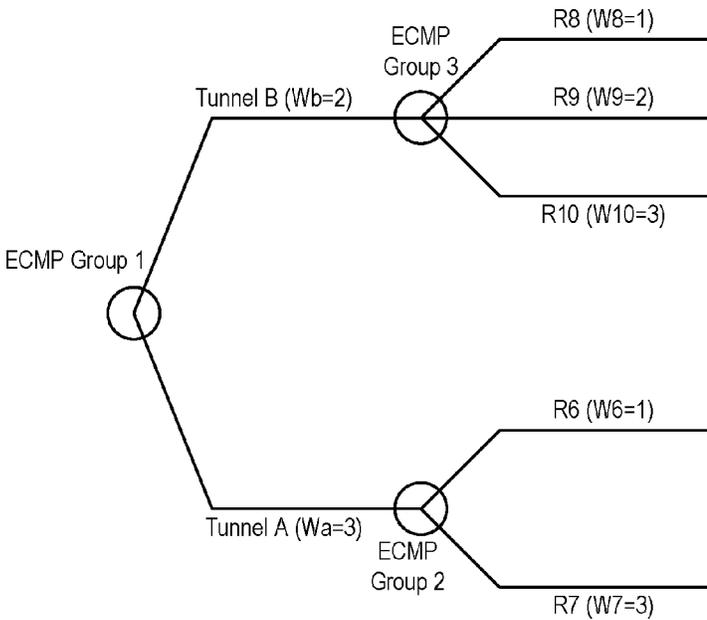


Figure 5

600 ↗

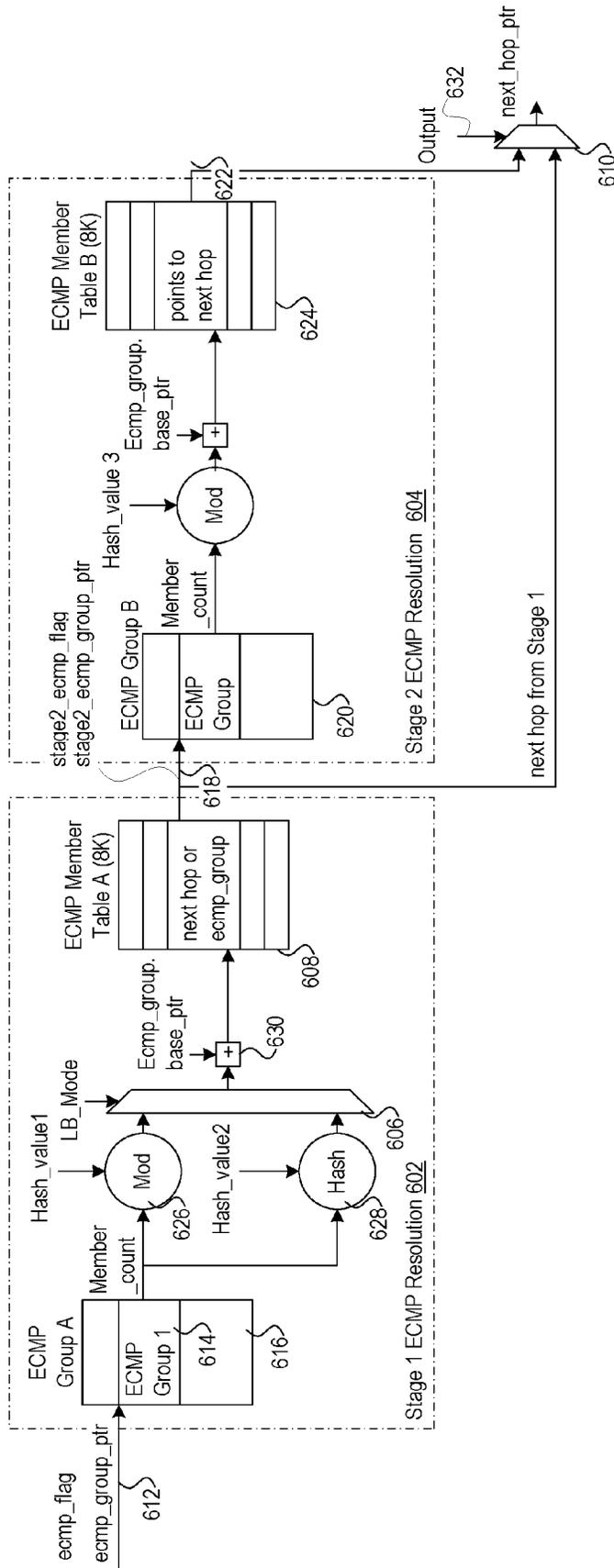
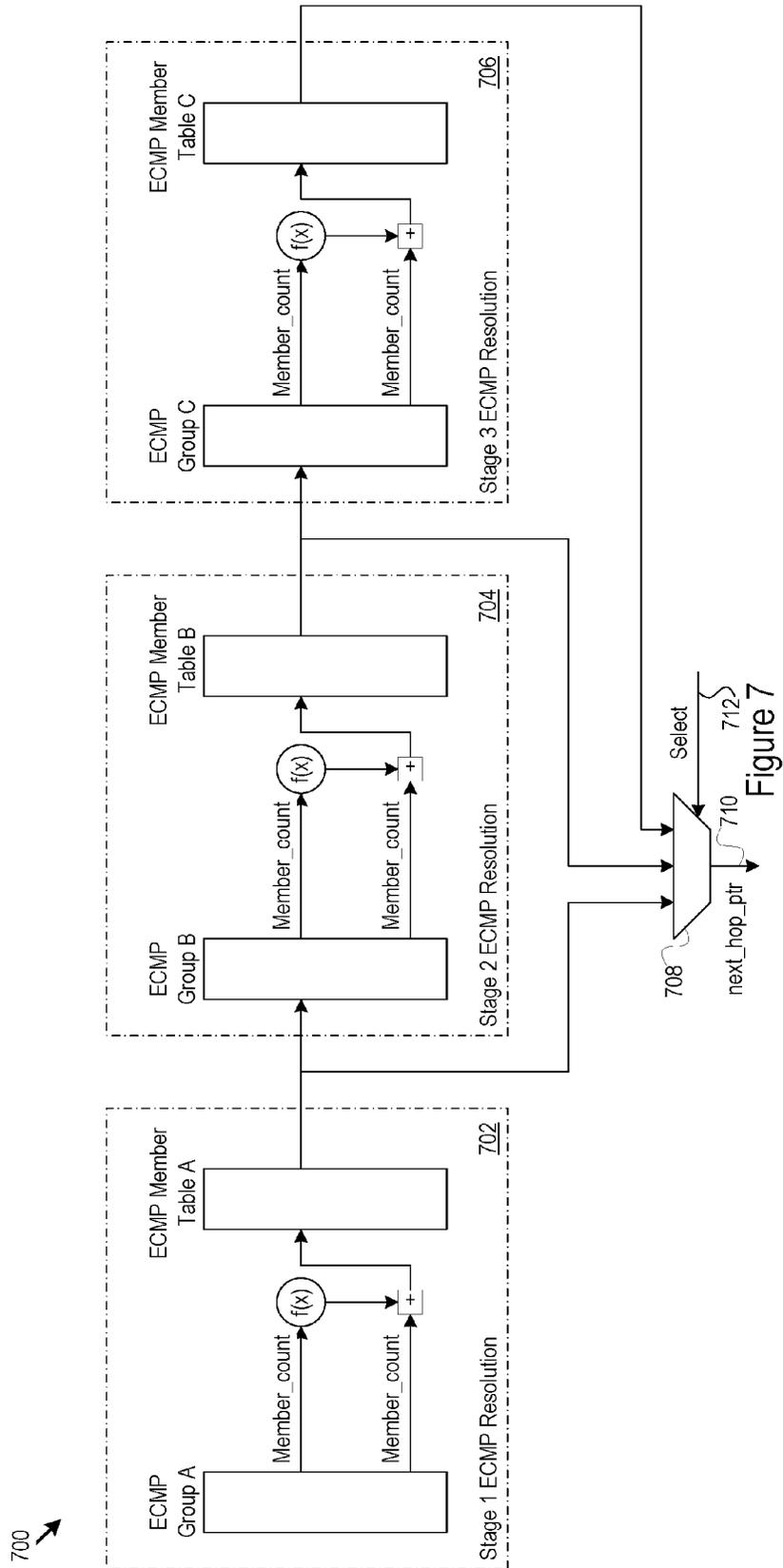


Figure 6



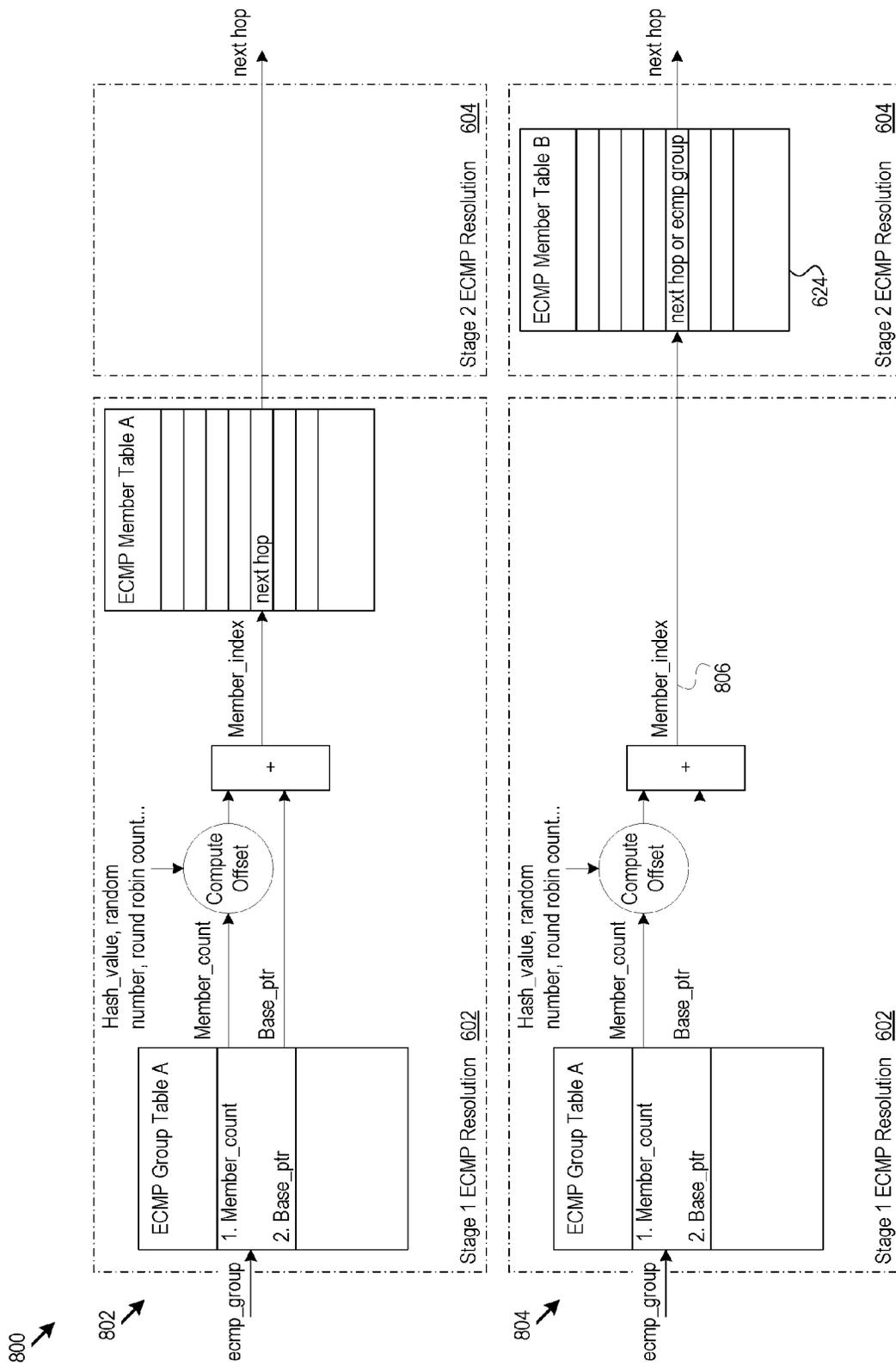


Figure 8

900 ↗

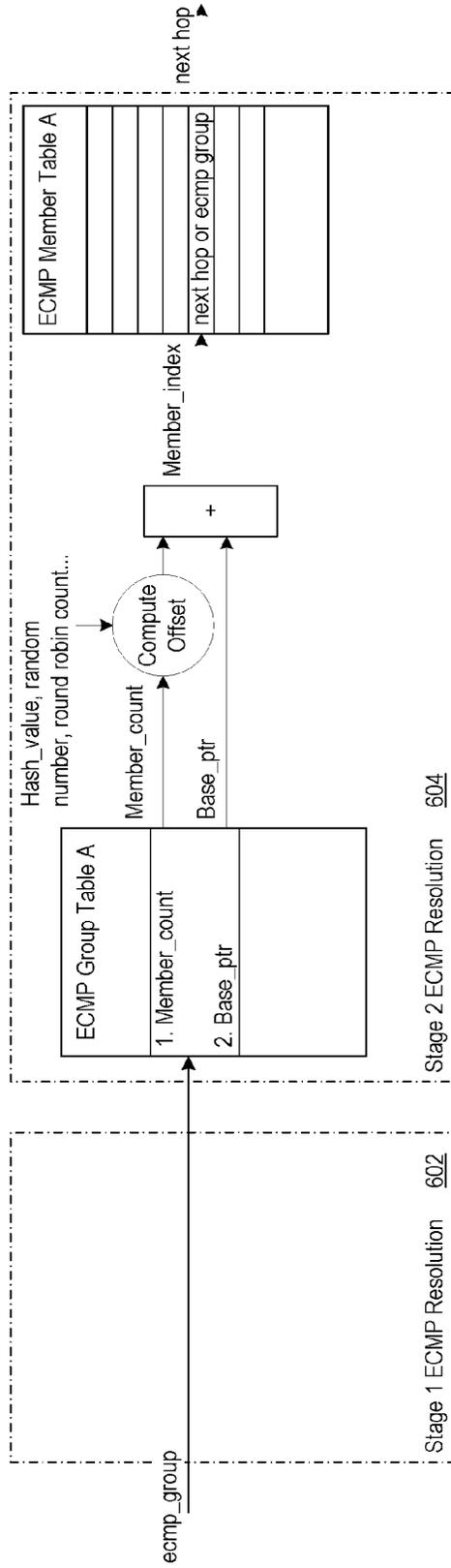


Figure 9

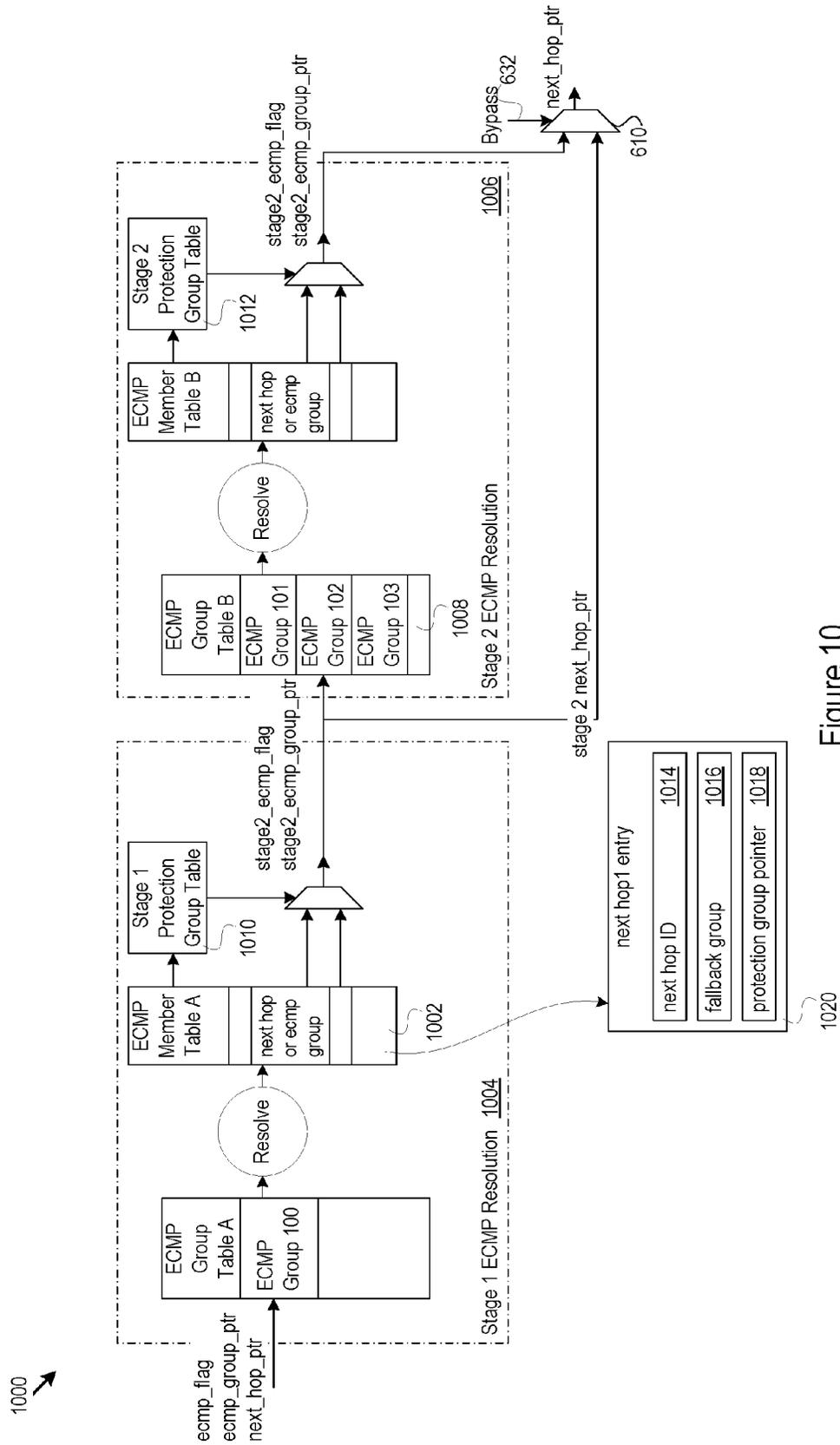


Figure 10

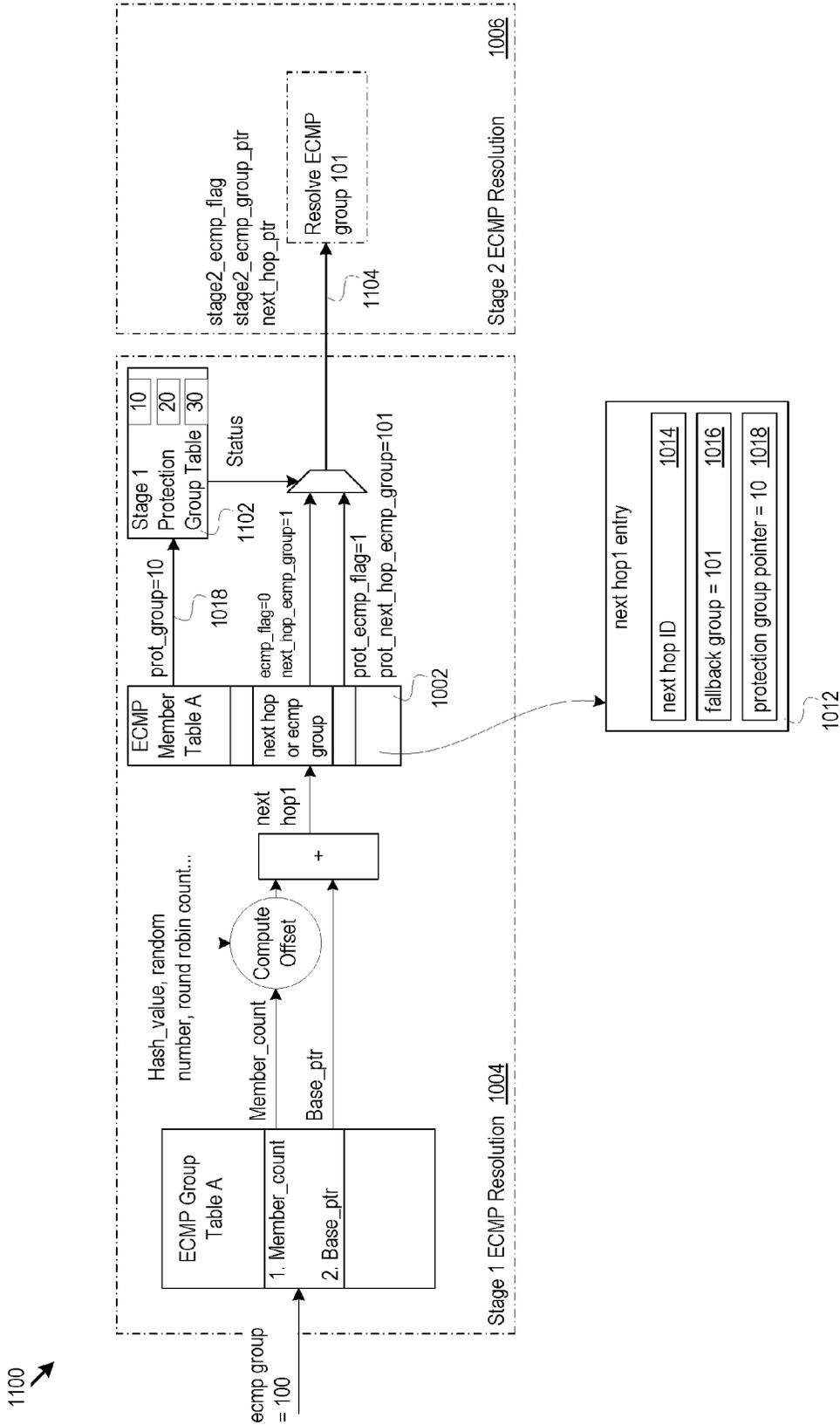


Figure 11

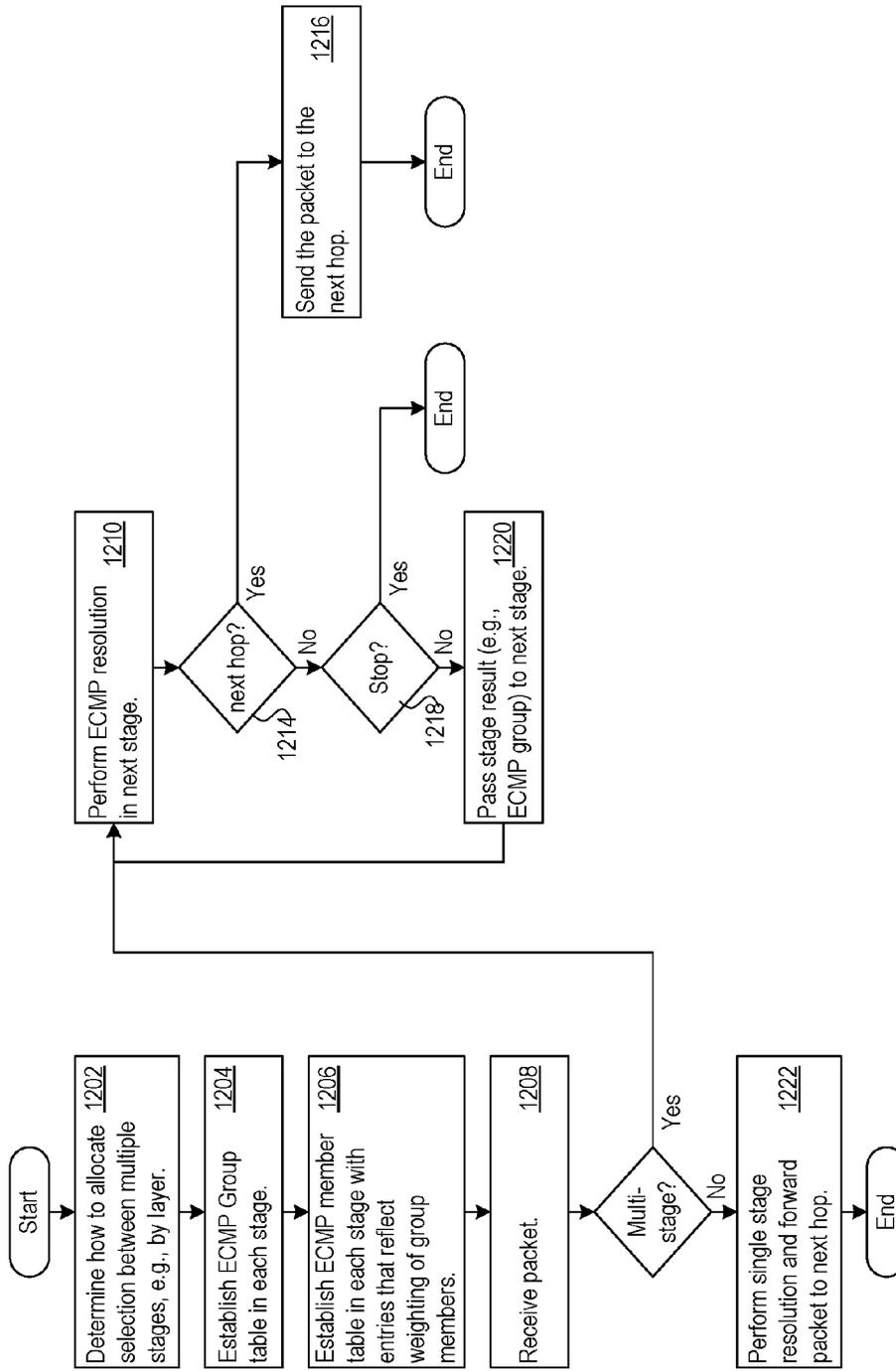


Figure 12

1200 →

1300 ↗

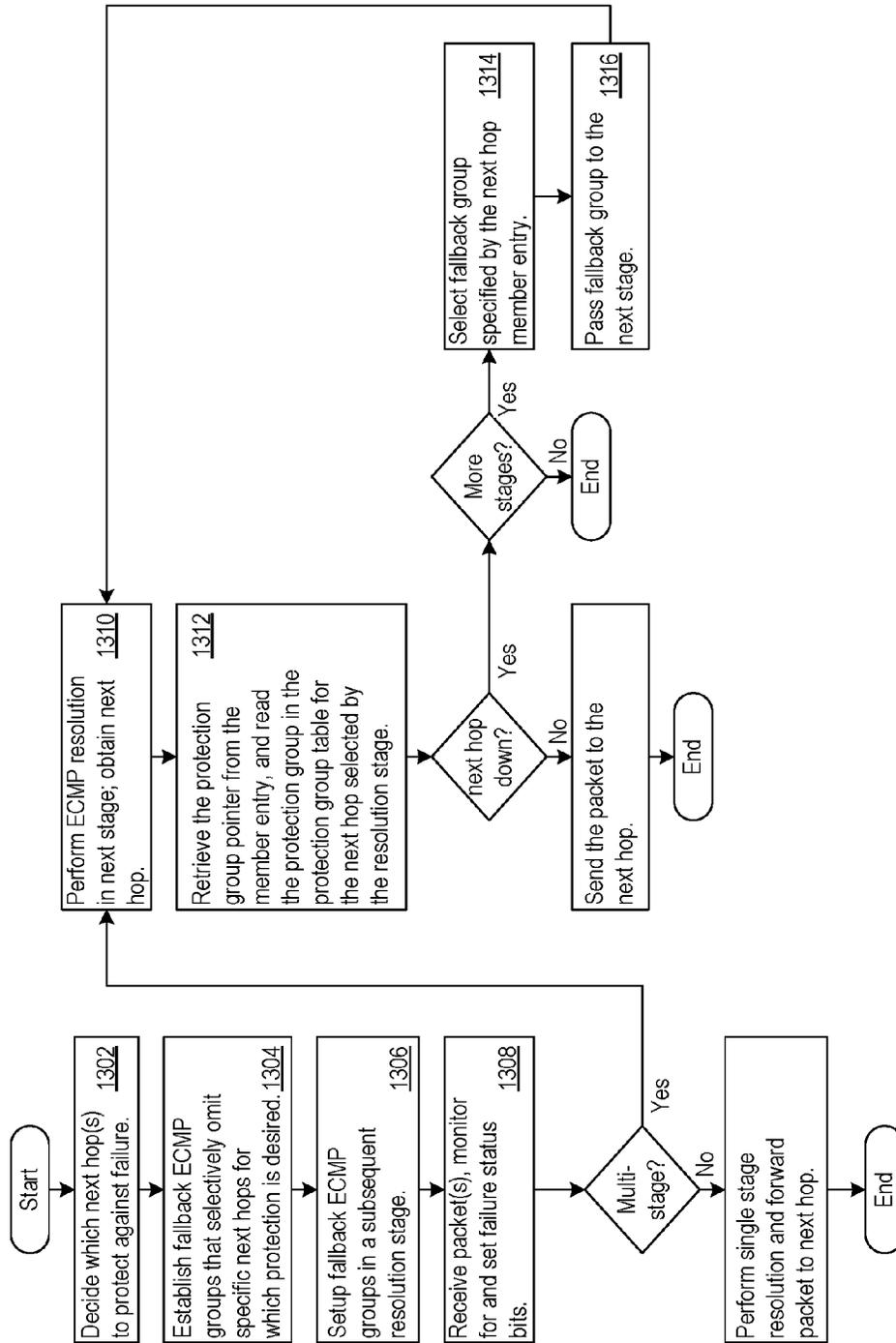


Figure 13

## PATH RESOLUTION FOR HIERARCHICAL LOAD DISTRIBUTION

### 1. PRIORITY CLAIM

This application claims priority to, and incorporates by reference, U.S. Provisional Patent Application Ser. No. 61/807,181, filed 1-Apr.-2013, and U.S. Provisional Patent Application Ser. No. 61/812,052, filed 15-Apr.-2013.

### 2. TECHNICAL FIELD

This disclosure relates to networking. This disclosure also relates to path resolution in network devices such as switches and routers.

### 3. BACKGROUND

High speed data networks form part of the backbone of what has become indispensable worldwide data connectivity. Within the data networks, network devices such as switching devices direct data packets from source ports to destination ports, helping to eventually guide the data packets from a source to a destination. Improvements in packet handling, including improvements in path resolution, will further enhance performance of data networks.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The innovation may be better understood with reference to the following drawings and description.

FIG. 1 shows an example of a switch architecture that may include packet marking functionality.

FIG. 2 is an example switch architecture extended to include packet marking functionality.

FIG. 3 shows an example of Equal Cost Multi-Path (ECMP) resolution.

FIG. 4 shows an example of an overlay network.

FIG. 5 shows an example of path weighting.

FIGS. 6-9 show examples of multiple stage ECMP resolution.

FIGS. 10-11 show example of traffic redistribution.

FIGS. 12-13 shows logic for multiple stage ECMP resolution and traffic redistribution.

#### DETAILED DESCRIPTION

##### Example Architecture

FIG. 1 shows an example of a switch architecture **100** that may include path resolution functionality. The description below provides a backdrop and a context for the explanation of path resolution, which follows this example architecture description. Path resolution may be performed in many different network devices in many different ways. Accordingly, the example switch architecture **100** is presented as just one of many possible network device architectures that may include path resolution functionality, and the example provided in FIG. 1 is one of many different possible alternatives. The techniques described further below are not limited to any specific device architecture.

The switch architecture **100** includes several tiles, such as the tiles specifically labeled as tile A **102** and the tile D **104**. In this example, each tile has processing logic for handling packet ingress and processing logic for handling packet egress. A switch fabric **106** connects the tiles. Packets, sent for example by source network devices such as application servers, arrive at the network interfaces **116**. The network

interfaces **116** may include any number of physical ports **118**. The ingress logic **108** buffers the packets in memory buffers. Under control of the switch architecture **100**, the packets flow from an ingress tile, through the fabric interface **120** through the switching fabric **106**, to an egress tile, and into egress buffers in the receiving tile. The egress logic sends the packets out of specific ports toward their ultimate destination network device, such as a destination application server.

Each ingress tile and egress tile may be implemented as a unit (e.g., on a single die or system on a chip), as opposed to physically separate units. Each tile may handle multiple ports, any of which may be configured to be input only, output only, or bi-directional. Thus, each tile may be locally responsible for the reception, queueing, processing, and transmission of packets received and sent over the ports associated with that tile.

As an example, in FIG. 1 the tile A **102** includes 8 ports labeled 0 through 7, and the tile D **104** includes 8 ports labeled 24 through 31. Each port may provide a physical interface to other networks or network devices, such as through a physical network cable (e.g., an Ethernet cable). Furthermore, each port may have its own line rate (i.e., the rate at which packets are received and/or sent on the physical interface). For example, the line rates may be 10 Mbps, 100 Mbps, 1 Gbps, or any other line rate.

The techniques described below are not limited to any particular configuration of line rate, number of ports, or number of tiles, nor to any particular network device architecture. Instead, the techniques described below are applicable to any network device that incorporates the path resolution analysis logic described below. The network devices may be switches, routers, bridges, blades, hubs, or any other network device that handles routing packets from sources to destinations through a network. The network devices are part of one or more networks that connect, for example, application servers together across the networks. The network devices may be present in one or more data centers that are responsible for routing packets from a source to a destination.

The tiles include packet processing logic, which may include ingress logic **108**, egress logic **110**, analysis logic, and any other logic in support of the functions of the network device. The ingress logic **108** processes incoming packets, including buffering the incoming packets by storing the packets in memory. The ingress logic **108** may define, for example, virtual output queues **112** (VoQs), by which the ingress logic **108** maintains one or more queues linking packets in memory for the egress ports. The ingress logic **108** maps incoming packets from input ports to output ports, and determines the VoQ to be used for linking the incoming packet in memory. The mapping may include, as examples, analyzing addressee information in the packet headers, and performing a lookup in a mapping table that matches addressee information to output port(s).

The egress logic **110** may maintain one or more output buffers **114** for one or more of the ports in its tile. The egress logic **110** in any tile may monitor the output buffers **114** for congestion. When the egress logic **110** senses congestion (e.g., when any particular output buffer for any particular port is within a threshold of reaching capacity), the egress logic **110** may throttle back its rate of granting bandwidth credit to the ingress logic **108** in any tile for bandwidth of the congested output port. The ingress logic **108** responds by reducing the rate at which packets are sent to the egress logic **110**, and therefore to the output ports associated with the congested output buffers.

The ingress logic **108** receives packets arriving at the tiles through the network interface **116**. In the ingress logic **108**, a

packet processor may perform link-layer processing, tunnel termination, forwarding, filtering, and other packet processing functions on the received packets. The packets may then flow to an ingress traffic manager (ITM). The ITM writes the packet data to a buffer, from which the ITM may decide whether to accept or reject the packet. The ITM associates accepted packets to a specific VoQ, e.g., for a particular output port. The ingress logic **108** may manage one or more VoQs that are linked to or associated with any particular output port. Each VoQ may hold packets of any particular characteristic, such as output port, class of service (COS), priority, packet type, or other characteristic.

The ITM, upon linking the packet to a VoQ, generates an enqueue report. The ITM may also send the enqueue report to an ingress packet scheduler. The enqueue report may include the VoQ number, queue size, and other information. The ITM may further determine whether a received packet should be placed on a cut-through path or on a store and forward path. If the receive packet should be on a cut-through path, then the ITM may send the packet directly to an output port with as low latency as possible as unscheduled traffic, and without waiting for or checking for any available bandwidth credit for the output port. The ITM may also perform packet dequeuing functions, such as retrieving packets from memory, forwarding the packets to the destination egress tiles, and issuing dequeue reports. The ITM may also perform buffer management, such as admission control, maintaining queue and device statistics, triggering flow control, and other management functions.

In the egress logic **110**, packets arrive via the fabric interface **120**. A packet processor may write the received packets into an output buffer **114** (e.g., a queue for an output port through which the packet will exit) in the egress traffic manager (ETM). Packets are scheduled for transmission and pass through an egress transmit packet processor (ETPP) and ultimately out of the output ports.

The ETM may perform, as examples: egress packet reassembly, through which incoming cells that arrive interleaved from multiple source tiles are reassembled according to source tile contexts that are maintained for reassembly purposes; egress multicast replication, through which the egress tile supports packet replication to physical and logical ports at the egress tile; and buffer management, through which, prior to enqueueing the packet, admission control tests are performed based on resource utilization (i.e., buffer and packet descriptors). The ETM may also perform packet enqueue/dequeue, by processing enqueue requests coming from the ERPP to store incoming frames into per egress port class of service (CoS) queues prior to transmission (there may be any number of such CoS queues, such as 2, 4, or 8) per output port.

The ETM may also include an egress packet scheduler to determine packet dequeue events, resulting in packets flowing from the ETM to the ETPP. The ETM may also perform egress packet scheduling by arbitrating across the outgoing ports and COS queues handled by the tile, to select packets for transmission; flow control of egress credit scheduler (ECS), by which, based on total egress tile, per egress port, and per egress port and queue buffer utilization, flow control is sent to the ECS to adjust the rate of transmission of credit grants (e.g., by implementing an ON/OFF type of control over credit grants); flow control of tile fabric data receive, through which, based on total ETM buffer utilization, link level flow control is sent to the fabric interface **120** to cease sending any traffic to the ETM.

FIG. 2 shows an example architecture **200** which is extended to include the path logic **202**. The path logic **202** may be implemented in any combination of hardware, firm-

ware, and software. The path logic **202** may be implemented at any one or more points in the switch architecture **100**, or in other architectures in any network device. As examples, the path logic **202** may be a separate controller or processor/memory subsystem. Alternatively, the path logic **202** may be incorporated into, and share the processing resources of the ingress logic **108**, egress logic **110**, fabric interfaces **120**, network interfaces **116**, or switch fabric **106**.

In the example of FIG. 2, the path logic **202** includes a processor **204** and a memory **206**. The memory **206** stores path resolution instructions **210**, and resolution configuration information **212**. The path resolution instructions **210** may execute multiple stage Equal Cost Multi-Path (ECMP) routing as described below, for example. In that regard, the memory may also store ECMP group tables **214** and ECMP member tables **216**, the purpose of which is described in detail below.

The resolution configuration information **212** may guide the operation of the path resolution instructions **210**. For example, the resolution configuration information **212** may specify the number of size of ECMP groups, ECMP member tables, may specify hash functions, the number of stages in the path resolution, or other parameters employed by the multiple stage resolution techniques described below.

#### Path Resolution

In a network of interconnected nodes, there may be multiple paths from a source A to reach a destination B. The nodes may be routers or switches, as examples, or may be other types of network devices. Each node may make an independent decision of which path to take to reach the destination B and each node may determine a next hop node, e.g., the next node along a particular path (the “next hop”) to which to forward the packet. For each packet a node may perform ECMP resolution and may determine the next hop node on one of the equal cost paths to the destination B. One goal of ECMP resolution is to increase bandwidth available between A and B by distributing traffic among the equal cost paths.

In weighted ECMP, the paths between A and B forming an ECMP group may be weighted differently. The Weighted (W) ECMP (W-ECMP) resolution may then select a path from an ECMP group based on the weights of each path, typically given by the weights on the next hop nodes. FIG. 3 shows an example of W-ECMP resolution **300**.

In FIG. 3, the parameter `Ecmp_group` indexes an ECMP group table **302**. The ECMP group table stores ECMP group entries for different ECMP groups. In particular, an entry may include a member count (“member\_count”), which indicates the number of entries in the ECMP member table **304** for a particular group, and a base pointer (“base\_ptr”), which addresses the first entry in the ECMP member table **304** for the group.

In order to select among potentially multiple next hops **306** in the ECMP member table **304** for the ECMP group, the system may determine a hash value **308**. The hash value **308** may be a function of the data in selected packet fields. Given the hash value **308**, the next hop may be selected from the ECMP member table **304**. In particular, the system may determine the member index **310** into the ECMP member table **304**, at which the identifier of the next hop is stored, according to:

$$\text{member\_index} = (\text{hash\_value} \% (\text{member\_count} + 1)) + \text{base\_ptr}$$

Where the “%” operator is the modulo operator: remainder after division.

To accommodate next hops within a group has with different weights, the next hop may appear multiple times in the

5

ECMP member table **304** for the group, in proportion to its weighting. The multiple appearances in the ECMP member table **304** implements the weighting for the next hop by providing additional or fewer entries for the next hop, leading to additional or fewer selections of the next hop.

FIG. 4 shows an example of an overlay network **400**. An overlay network may include networks running on top of other networks. For example, a datacenter may run an L2 or L3 network over an existing underlying Internet Protocol (IP) network.

In this example, the overlay network **400** includes a layer N and a layer M. Within layer M is a first ECMP group **402**. Within layer N is a second ECMP group **404** and a third ECMP group **406**. FIG. 4 shows tunnel A **408** between nodes R1 and R2, and tunnel B **410** between nodes R1 and R3. The nodes may be routers, switches, or any other type of network device. In the overlay network **400**, assume for example that M is the overlay network running over network N, and that network N is an existing IP network. In FIG. 4, node R1 receives packets originating from Host A and forwards the packets toward Host B, e.g., at layer M and N. In this example, the node R1 may select between the following paths for reaching host B:

- {R2, R6}, {R2, R7}, {R3, R8}, {R3, R9}, {R3, R10}

The nodes R6, R7 and R8, R9, R10 are assumed, in this example, to forward only in Layer N. Any node, including the nodes R6-R10, may also perform ECMP resolution to select the next hops in Layer N to reach node R2, or R3 respectively. The example below is given from the perspective of the node R1 making a decision on which node is the next hop for a particular packet it has received.

Note that nodes, e.g., R1, in an overlay network may need to resolve ECMP paths in multiple layers. The ECMP paths in one or more layers may be weighted. FIG. 5 shows an example weighting **500** for the paths in FIG. 4 at R1 to reach host B. As shown in FIG. 5, tunnel A **408** has weight 3 and tunnel B **410** has weight 2. Thus, there is a relative weighting for the higher level network, layer M. FIG. 5 shows the weightings for the nodes in the lower level network also, Layer N. Thus, there is also a relative weighting for packet flow within the lower level network.

Table 1, below, summarizes the weights shown in FIG. 5.

TABLE 1

Entity	Weight	Comment
Tunnel A	W <sub>a</sub> = 3	The tunnel A will carry 1.5 times the traffic as tunnel B (e.g., 3 packets for every 2 packets that Tunnel B carries).
Tunnel B	W <sub>b</sub> = 2	Two of five packets will travel through Tunnel B.
R6	W <sub>6</sub> = 1	R6 will handle one third as much traffic as R7, and ¼ of the traffic for tunnel A
R7	W <sub>7</sub> = 3	R7 will handle 3 times the traffic as R6, and ¾th of the traffic for tunnel A
R8	W <sub>8</sub> = 1	R8 handles one sixth of the traffic for tunnel B
R9	W <sub>9</sub> = 2	R9 handles one third of the traffic for tunnel B
R10	W <sub>10</sub> = 3	R10 handles half of the traffic for tunnel B

To implement the weighting, the number of entries in the ECMP member table may grow as a multiplicative function of the weights. For this example:

$[(W_8 * W_b) + (W_9 * W_b) + (W_{10} * W_b)] * 2 + [(W_6 * W_a) + (W_7 * W_a)] * 3 = 24 + 36 = 60$  entries. In other words, there will be 24 entries of next hops from tunnel B and 36 entries of next hops from tunnel A, so that 1.5 times the traffic is routed through tunnel A as is routed through tunnel B. Within the 24 entries for tunnel B, there will be 4 node R8 entries, 8 node R9

6

entries, and 12 node R10 entries. Within the 36 entries for tunnel A, there will be 9 node R6 entries and 27 node R7 entries.

In other words, the number of entries per node in the ECMP member table reflects the desired percentage of traffic sent through that node. In the example above,

R6 handles  $(3/5) * (1/4)$  of all traffic =  $(3/20) = 15\%$  percent of all traffic

R7 handles  $(3/5) * (3/4) = (9/20) = 45\%$

R8 handles  $(2/5) * (1/6) = (2/30) = 6.66\%$

R9 handles  $(2/5) * (2/6) = (4/30) = 13.33\%$

R10 handles  $(2/5) * (3/6) = (6/30) = 20\%$

Sixty (60) is the least number, n, for which n\* percentage of traffic is an integer, for all path probabilities, because 60 includes 20 and 30 as a factor:

$60 * 15\% = 9$  entries for R6

$60 * 45\% = 27$  entries for R7

$60 * 6.66\% = 4$  entries for R8

$60 * 13.33\% = 8$  entries for R9

$60 * 20\% = 12$  entries for R10

When the relative probabilities change, the minimum number of entries will also change, and the minimum number of entries is very often a multiplicative function of the weights. This causes the ECMP member table **304** to grow quickly, consuming valuable resources in the system.

However, with the path resolution techniques described below, the number of ECMP member table entries may be reduced. For the example above, using the techniques described below, the number of ECMP member table entries may be reduced to:

$W_a + W_b + W_8 + W_9 + W_{10} + W_6 + W_7 = 15$  entries.

In other words, the path resolution techniques described below avoid growth in the number of entries as a function of the multiplication of the weights in the multiple layers. The reduction in the number of entries may translate into, as examples, a lower memory requirement for routing, freeing existing memory for other uses, or permitting less memory to be installed in the node, or other benefits.

A network device (e.g., as implemented by the architectures **100** and **200**, or by other architectures) may perform ECMP resolution in multiple stages. The multiple stage resolution may occur in hardware, or for example by executing the path resolution instructions **210** with the processor **204**, or in a combination of hardware and software. Examples of multiple stage ECMP resolution are shown in FIGS. 6-8. In FIG. 6, for example, a system **600** includes a first stage **602** (stage 1) of resolution and a second stage **604** (stage 2) of resolution. As just one example, the stages may resolve in order of higher to lower level layers, with a stage for each layer, and there may be any number of layers.

Continuing the example of FIG. 4, the first stage **602** resolves ECMP in Layer M (e.g., the higher level layer first). For example, an ECMP pointer **612** points to an ECMP group **614** in the ECMP group table **616**. The ECMP group **614** specifies the ECMP group **1412** (e.g., R2 and R3). The stage 1 ECMP member table **608** (e.g., 8K entries in size) implements the relative weighting of R2 and R3 using multiple entries for R2 (e.g., 3 entries as noted in Table 1) and R3 (e.g.,

2 entries as noted in Table 1). The output **618** of the first stage **602** may be considered an intermediate path resolution output. In this example, the output **618** of the first stage **602** is an identifier of either ECMP Group **2** (to reach R2) or ECMP Group **3** (to reach R3). Note that both ECMP Group **2** and ECMP Group **3** may point to different places in the ECMP group table **620** where the group **2** and group **3** entries are stored. The second stage **604** performs path resolution for Layer N, in sequence after the first stage **602** has resolved Layer M.

The second stage **604** resolves in Layer N (e.g., proceeding to the next lower network layer). The output **622** of the second stage **604** is next hop R6 or R7 to reach R2 (when stage **1** determined that R2 was the next hop), or next hop R8 or R9 or R10 to reach R3 (when stage **1** determined that R2 was the next hop). The stage **2** ECMP member table **624** (e.g., 8K entries in size) implements the relative weighting of R6, R7, R8, R9, and R10 (e.g., 3 entries for R7 and 1 entry for R6 as noted in Table 1).

FIG. **6** also shows optional mode selection logic **606**. The mode selection logic **606** may be responsive to an operational mode, such as load balancing mode (LB\_Mode). The load balancing mode selection may select among multiple options for generating an offset into the ECMP member table **608**. The LB\_Mode may determine whether load balancing between group members (e.g., R2 and R3) occurs based on packet hash values, random values, a counter, or other factors. In the example of FIG. **6**, the mode selection logic **606** chooses between a modulo function **626** (e.g., member count modulo a hash value obtained from packet fields) of the member count obtained from the ECMP group table **616** and a hash **628** of the member count. The adder **630** adds the offset output from the mode selection logic **606** to the base address obtained from the ECMP group **614** to obtain an index into the ECMP member table **608** that actually selects the ECMP group for R2 or R3.

Note that the ECMP member table **608** may specify a next hop when, e.g., a single level of resolution is performed, when the current stage resolves down to an actual next hop, or may specify a next ECMP group, e.g., that identifies a group in the next network layer down. A type entry (e.g., a bit field) in the ECMP member table **608** may specify which type of result (e.g., a next hop or a group) is found in any entry in the table. Further, different types of packets may be subject to different numbers of levels of resolution. If in this example, the network device is only forwarding in layer N for a particular packet, then there may be only one ECMP group to check.

Further, the output selection logic **610** may be responsive to the output selection signal **632**. The output selection signal **632** may determine whether the path resolution is finished at a particular stage (e.g., finished at stage **1 602**). In other words, the output selection signal **632** may force the resolution to end at any given stage, and, as a specific example, to be a single level resolution. The output selection signal **632** may be provided for backwards compatibility and for low latency operation by avoiding multiple sequential table lookups. In that case, the first stage **602** may be configured to operate as previously described, to resolve one or more stages of path selection using many more entries in the ECMP member table **608**, for example. In other words, the output selection signal **632** may facilitate operation in a reduced number of levels mode (e.g., a single level mode), in which there may be, in the final stage, a relatively larger ECMP member table as described above that holds a number of entries that may be a multiplicative function of the weights to implementing path weighting.

As a specific example, FIG. **7** shows a three stage example **700**. The example **700** includes a first stage **702**, a second stage **74**, and a third stage **706**. Output selection logic **708** selects the output of one of the stages as the next hop output **710**. An output selection signal **712** provides the control input to the output selection logic **708** to cause the output selection logic **708** to choose the output of one of the three stages for the next hop. With multiple (e.g., 2) stages of resolution, the path resolution may be considered to address multiple (e.g., 2) sequential tables for path resolution, instead of one very large table for path resolution.

In FIG. **8**, the example **802** shows that the output of the first stage **602** can also be a next hop, rather than a pointer into the group table for a subsequent stage. The direct output of a next hop in the first stage **602** may happen, for example, when the network device is forwarding only in a layer that is resolved by the first stage (in this example layer M) for all packets or for selected packets. In other words, the network device may bypass subsequent stages, such as the second stage **604** that ordinarily resolves layer N. In this example, the first stage **602** has resolved the path for layer M, and no further resolution is desired, e.g., because the specific packet does not need further path resolution. In general (and as shown in FIG. **7**), when any stage determines an actual next hop, then subsequent stages may be skipped because the actual next hop has been determined. Note also that each output of the multiple stages may be analyzed (e.g., using a multiplexer and the type bits) to select an actual next hop that was found in any stage, as the overall next hop output of the multiple stages.

FIG. **8** also shows an example **804** in which the resolved member index **806** from the first stage **602** points to the ECMP member table **624** in the second stage **604**. The member index may be the base pointer for the member table, plus the offset determined, e.g., by the member count. As examples, a modulo function, random number, round robin selection, or other function may determine the offset among the member count number of entries. In other words, the network device may interpret a member index as a pointer to a member table in a different stage. As a result, the ECMP group in any particular stage (e.g., the first stage **602**) may have access to entries in an ECMP member table in another stage (e.g., the second stage **604**), as well as to entries in the ECMP member table within that particular stage.

FIG. **9** shows that the first stage **602** may be bypassed if there is no ECMP resolution in Layer M. This may happen, for example, when the network device is forwarding a packet directly to tunnel B in, e.g., an overlay network such as that shown in FIG. **4**. In this example, the second stage **604** may resolve ECMP for the layer N tunnel B to select between R6 and R7. Thus, packets may be selectively subject to path resolution in any one or more of the stages in the multiple stage resolution architecture.

#### Traffic Redistribution

Described below are techniques to redistribute traffic to a downed next hop quickly and without reassigning traffic that was going to other unaffected next hops, using multi-stage ECMP resolution. For the purposes of illustration, assume that node A may forward packets to node B via 3 next hop routers R1, R2, R3, forming an ECMP Group. Assume also that ECMP Group member count is programmed to 3 and ECMP member table has 3 entries, R1, R2, R3. When R3 goes down, the network device updates member count to 2. The update, however, may cause traffic that was not flowing to R3 to be potentially reassigned to a different next hop, and this may result in temporary re-ordering of packets within a flow received at node B.

It may be desirable that only traffic that was previously assigned to R3 should be affected by R3 going down, and that only the R3 traffic should be redirected to either R1 or R2. In other words, traffic previously assigned to R1 should not change assignment to R2 and traffic previously assigned to R2 should not change to R1. It may also take a certain amount of time for the network device to reprogram the ECMP group table and each ECMP member table entry that included an R3 next hop entry (e.g., to remove the entry).

FIG. 10 shows an example traffic redistribution architecture 1000. In the architecture 1000, entries in the ECMP member table A 1002 may include redistribution protection entries. An example member table entry 1020 is shown for next hop 1. The member table entry 1020 includes: next hop ID 1014, which identifies a selected next hop, and the following redistribution protection entries: fallback group 1016, which identifies the ECMP group to use if a protection status is set; and protection group pointer 1018, which points to a protection group table from which to obtain status information. The status information may be, e.g., a bit that indicates whether the next hop is down. FIG. 10 shows examples of protection group tables 1010 and 1012, which are discussed further below.

Continuing the example with respect to FIG. 10, assume that the first stage 1004 ECMP Resolution has ECMP Group 100 containing next hop 1, next hop 2, next hop 3 as members, and that the second stage 1006 ECMP resolution has an ECMP group table 1008 specifying ECMP group 101, 102, and 103. Assume also that ECMP group 101 contains next hop 2 and next hop 3 as members; that ECMP Group 102 contains next hop 1 and next hop 3 as members; and that ECMP Group 103 contains next hop 1 and next hop 2 as members. In this example, the first stage 1004 ECMP member table is configured so that the next hop 1 entry points to protection group 10; the next hop 2 entry points to protection group 20; and the next hop 3 entry points to protection group 30.

Explained more generally, the architecture 1000 may establish fallback ECMP groups that selectively omit specific next hops for which protection is desired. For example, to protect against next hop 1 failure, an ECMP group is defined to include next hop 2 and next hop 3. Similarly, to protect against next hop 2 failure, an ECMP group is defined to include next hop 1 and next hop 3. And, to protect against next hop 3 failure, an ECMP group is defined to include next hop 2 and next hop 1. Accordingly regardless of which next hop fails, there is another ECMP group that omits the failed next hop and that can resolve the next hop in the path by specifying the allowable routing options other than the failed next hop. Note that a processing stage subsequent to the stage that detects the failure may resolve the fallback group.

As shown in FIG. 11, the first stage 1004 may resolve ECMP Group 100 to next hop 1, next hop 2 or next hop 3. Since the result of the first stage 1004 is a next hop, the network device need not execute the second stage 1006. When next hop 1 goes down, the network device software may set the status information in the protection group table 1102 accordingly (e.g., by setting a status bit to 1), for protection group 10 defined within the protection group table 1102.

Recall that ECMP member table A 1002 may include member table entries (e.g., the member table entry 1020) that include: next hop ID 1014, which identifies a selected next hop, and the following redistribution protection entries: fallback group 1016 (set to 101 in this example), which identifies the ECMP group to use if a protection status is set; and

protection group pointer 1018 (set to 10 in this example), which points to a protection group table from which to obtain status information.

When ECMP Group 100 resolves to next hop 1, the network device retrieves the protection group pointer 1018 from the member table entry 1020, and reads the protection group 10 in the protection group table 1102. The status information for protection group 10 indicates that next hop 1 is down. As a result, the network device selects the fallback ECMP group specified by fallback group 1016: ECMP group 101. Recall that ECMP group 101 includes next hop 2 and next hop 3 as members, and thus will not route any packets through next hop 1.

The network device passes the ECMP group selection (101) to the resolution stage 2 1006. The network device may also set the stage 2 ECMP flag 1104 to indicate that the second stage 1006 should act on the output of the first stage 1004. The second stage 1006 thus resolves ECMP group 101, and obtains either next hop 2 or next hop 3 as a next hop. The second stage 1006 may also check whether the selected next hop is down, using the protection group table, and member table entries described above. Thus, referring back to FIG. 10, the second stage 1006 may also include a protection group table 1012, and provide protection against next hop 2 or next hop 3 going down. Note also that the resolution architecture may provide bypass selection as described with respect to FIG. 6, using the output selection logic 610 and output selection signal 632.

In the approach described in FIGS. 10 and 11, the network device sets, e.g., a bit in the protection group table entry to protect against next hop failures. This may significantly decrease the failover time. In other words, the network device does not need to update all of the entries in the various ECMP member tables that point to next hop 1. Note that the approach described above facilitates fast redirection of traffic to the failed next hop to other members in the ECMP group. Further, the approach does not affect traffic that was not assigned to the failed next hop.

FIG. 12 shows logic 1200 that a network device may implement in hardware, software, or both to perform multiple stage ECMP path resolution. The logic 1200 determines how to allocate selection between multiple stages (1202). The allocation may be by network layer, for example, such that each stage performs ECMP path resolution for a particular network layer (e.g., layer M or N). However, other allocations of path resolution may be made, and some individual stages may be configured to resolve multiple layers, for example.

In each stage, the ECMP group table is established to include a group entry for each group that the stage will handle (1204). In each stage also, an ECMP member table is established to include group member entries for each group that reflect the weighting of the group members in each group (1206).

When the network device receives a packet (1208), the network device may perform multi-stage ECMP resolution. The network device need not use multi-stage ECMP resolution for every packet, however. Instead the network device may decide for which packets to perform ECMP resolution based on packet characteristics and packet criteria that may be present, for example, in the resolution configuration information 212.

When the network device will perform multi-stage ECMP resolution, the network device starts the next stage of resolution (1212). The result of the stage may be a next hop, for example (1214). In that case, the network device may send the packet to the next hop determined by the resolution stage (1216). Note that the network device may stop resolution at

any stage (1218). If resolution will continue, then the network device may pass the current resolution stage result on to the next stage (1220). The current resolution stage result may be an identifier of a next group (e.g., for routing in the next network layer), for example. Resolution may continue through as many stages as desired, until a next hop is identified, or until the network device decides to stop the resolution. When multi-stage resolution is not performed, then the logic 1200 may perform single stage resolution and forward the packet to the next hop (1222).

FIG. 13 shows logic 1300 that a network device may implement in hardware, software, or both to perform controlled traffic redistribution, e.g., in a multiple stage ECMP path resolution architecture. The logic 1300 determines how many and which next hop(s) to protect against failure (1302). For example, in an ECMP group of next hop 1, next hop 2, and next hop 3, the logic 1300 may decide to protect against a failure by any of the three next hops. Accordingly, the logic 1300 may establish fallback ECMP groups that selectively omit specific next hops for which protection is desired (1304). For example, to protect against next hop 1 failure, the logic 1300 defines an ECMP group that includes: {next hop 2, next hop 3}. Similarly, to protect against next hop 2 failure, the logic 1300 defines an ECMP group that includes {next hop 1, next hop 3}, and to protect against next hop 3 failure, the logic 1300 defines an ECMP group that includes: {next hop 2, next hop 1}. Accordingly regardless of which next hops fails, there is another ECMP group that omits the failed next hop and that can resolve the next hop in the path by specifying the allowable routing options that remain. The logic 1300 sets up the fallback ECMP groups in a processing stage subsequent to the stage that is able to detect a failure of an next hop (1306).

During operation, the network device, receives a packet (1308), and also monitors for next hop failure, and sets status bits accordingly, e.g., in the appropriate protection group tables. When the packet is subject to multi-stage path resolution, the logic 1300 submits the packet to the next stage of path resolution (1310). In that respect, the logic 1300 may, for example, retrieve the protection group pointer from the member entry, and read the protection group in the protection group table for the next hop selected by the resolution stage (1312). The protection group table, as noted above, includes status information that indicates whether the next hop is down, and the member group entry for a next hop includes identifies a fallback group to use in the next stage when the next hop is down.

When the next hop determined by the current stage is down, then the logic 1300 may select the fallback ECMP group specified by fallback group identifier in the next hop member entry (1314). The logic 1300 provides the fallback group identifier to the next resolution stage (1316). For example, the logic 1300 may provide a pointer into the ECMP group table in the next stage that points to the fallback group. ECMP resolution may then continue in the subsequent stage, e.g., to select from among the next hops in the fallback group as the next hop for the packet.

The methods, devices, techniques, and logic described above may be implemented in many different ways in many different combinations of hardware, software or both hardware and software. For example, all or parts of the system may include circuitry in a controller, a microprocessor, or an application specific integrated circuit (ASIC), or may be implemented with discrete logic or components, or a combination of other types of analog or digital circuitry, combined on a single integrated circuit or distributed among multiple integrated circuits. All or part of the logic described above may be implemented as instructions for execution by a pro-

cessor, controller, or other processing device and may be stored in a tangible or non-transitory machine-readable or computer-readable medium such as flash memory, random access memory (RAM) or read only memory (ROM), erasable programmable read only memory (EPROM) or other machine-readable medium such as a compact disc read only memory (CDROM), or magnetic or optical disk. Thus, a product, such as a computer program product, may include a storage medium and computer readable instructions stored on the medium, which when executed in an endpoint, computer system, or other device, cause the device to perform operations according to any of the description above.

The processing capability described above may be distributed among multiple system components, such as among multiple processors and memories, optionally including multiple distributed processing systems. Parameters, databases, and other data structures may be separately stored and managed, may be incorporated into a single memory or database, may be logically and physically organized in many different ways, and may implemented in many ways, including data structures such as linked lists, hash tables, or implicit storage mechanisms. Programs may be parts (e.g., subroutines) of a single program, separate programs, distributed across several memories and processors, or implemented in many different ways, such as in a library, such as a shared library (e.g., a dynamic link library (DLL)). The DLL, for example, may store code that performs any of the system processing described above. While various embodiments of the invention have been described, it will be apparent to those of ordinary skill in the art that many more embodiments and implementations are possible within the scope of the invention. Accordingly, the invention is not to be restricted except in light of the attached claims and their equivalents.

What is claimed is:

1. A method comprising:
  - providing, for a first layer of an overlay network, a first stage of path resolution for forwarding a packet toward a destination; and
  - providing a second stage of path resolution following the first stage; and
  - receiving in the second stage an intermediate path resolution output from the first stage, the first stage and second stage configured to sequentially determine a next hop for the packet.
2. The method of claim 1, where:
  - providing the first stage comprises providing a first stage of equal cost multi-path resolution.
3. The method of claim 2, where:
  - providing the second stage comprises providing a second stage of equal cost multi-path resolution.
4. The method of claim 1, where the second stage executes path resolution for a second layer of the overlay network.
5. The method of claim 1, where providing a first stage comprises:
  - providing an equal cost multi-path (ECMP) group table and an ECMP member table configured to generate the output.
6. The method of claim 5, where receiving comprises:
  - receiving an ECMP group pointer in the output.
7. The method of claim 6, further comprising:
  - executing path resolution in the second stage by choosing among members of an ECMP group referenced by the ECMP group pointer.
8. The method of claim 5, further comprising:
  - providing a load balancing mode selection signal operable to select among multiple options for generating an offset into the ECMP member table.

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- 9. A network device comprising:  
a processor; and  
a memory in communication with the processor, the memory comprising path resolution instructions that, when executed by the processor, cause the processor to:  
determine to execute a multiple stage next hop resolution for a received packet;  
initiate the multiple stage next hop resolution by determining, in a first stage, a first group of members;  
output a selected member from among the first group of members to a second stage, where the selected member comprises a reference to a second group of members in the second stage; and  
determine a routing output from among the second group of members.
- 10. The network device of claim 9, where: the routing output comprises an identifier of a next hop.
- 11. The network device of claim 9, where: the routing output comprises a reference to a third group of members in a third stage subsequent to second stage.
- 12. The network device of claim 9, where: the first group of members corresponds to a first network layer.
- 13. The network device of claim 12, where: the second group of members corresponds to a second network layer running underneath the first network layer.
- 14. The network device of claim 9, where the instructions, when executed, further cause the processor to:  
determine the selected member from a member table entry in a member table.
- 15. The network device of claim 14, where the member table entry comprises:  
a protection group pointer to information that specifies whether the selected member is down.
- 16. The network device of claim 14, where the member table entry comprises:

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- a fallback group identifier of a fallback group from which to continue next hop resolution in the second stage.
- 17. The network device of claim 14, where the second group of members comprises multiple entries for a specific next hop according to a relative weighting of the specific next hop.
- 18. A network device comprising:  
first path resolution stage circuitry comprising:  
a first stage equal cost multiple path (ECMP) group table identifying a first ECMP group; and  
a first stage ECMP member table comprising:  
a first member entry comprising a pointer to a different ECMP group table other than the first stage ECMP group table;  
second path resolution stage circuitry configured to receive a path resolution output from the first path resolution stage, the second path resolution stage circuitry comprising:  
a second stage equal cost multiple path (ECMP) group table identifying a second ECMP group; and  
a second stage ECMP member table comprising:  
multiple entries for a first next hop in the second ECMP group that implement a first weighting for the first next hop; and  
multiple entries for a second next hop in the second ECMP group that implement a second weighting for the second next hop.
- 19. The network device of claim 18, further comprising:  
load balancing circuitry configured to determine how an offset into the second member table is determined from among multiple options; and  
output selection signal circuitry configured to determine whether path resolution ends at the first stage or at the second stage.
- 20. The network device of claim 12, where the first layer comprises a layer of an overlay network.

\* \* \* \* \*

UNITED STATES PATENT AND TRADEMARK OFFICE  
**CERTIFICATE OF CORRECTION**

PATENT NO. : 9,270,601 B2  
APPLICATION NO. : 14/025114  
DATED : February 23, 2016  
INVENTOR(S) : Lin et al.

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Claims

Column 12, claim 1, line 36, after “for a first layer of an” replace “overly” with --overlay--.

Signed and Sealed this  
Sixteenth Day of August, 2016



Michelle K. Lee  
*Director of the United States Patent and Trademark Office*