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(54) REDUCTION OF MESSAGE AND COMPUTATIONAL OVERHEAD IN NETWORKS

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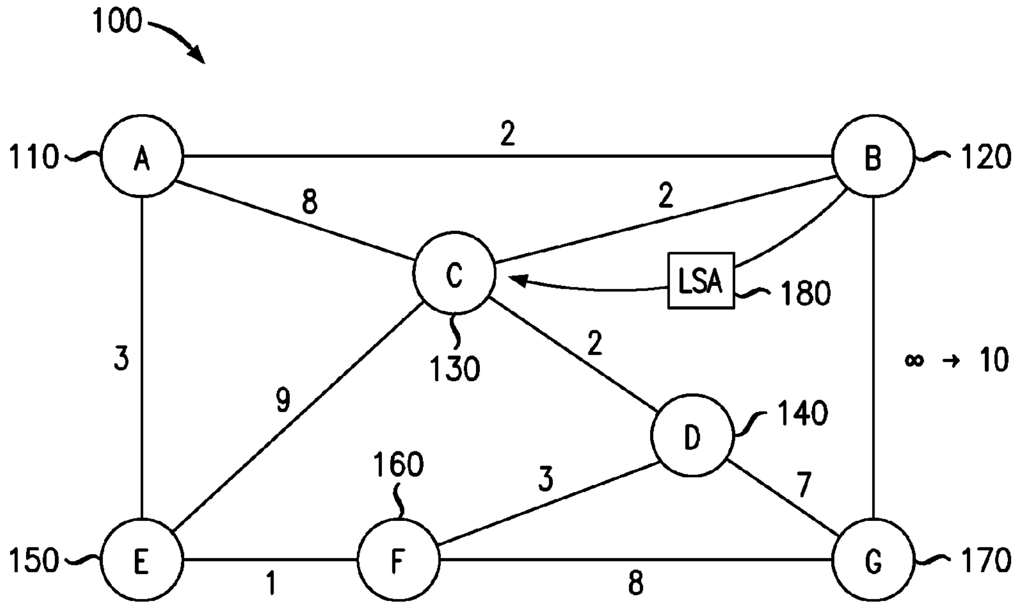
(57) **ABSTRACT**

Various exemplary embodiments relate to a method and related network node including one or more of the following: receiving, at the node, a network update message; determining whether the network update message should be propagated to other nodes; if the network update message should be propagated to other nodes, forwarding the network update message to at least one other node; and if the network update message should not be propagated to other nodes, refraining from forwarding the network update message to any other node. Various further embodiments relate to a method and related network node including one or more of the following: determining a first time period for the network update message; setting the first time period as a delay time; waiting for the delay time; and after the delay time has elapsed, computing new routing information based on the network update message.



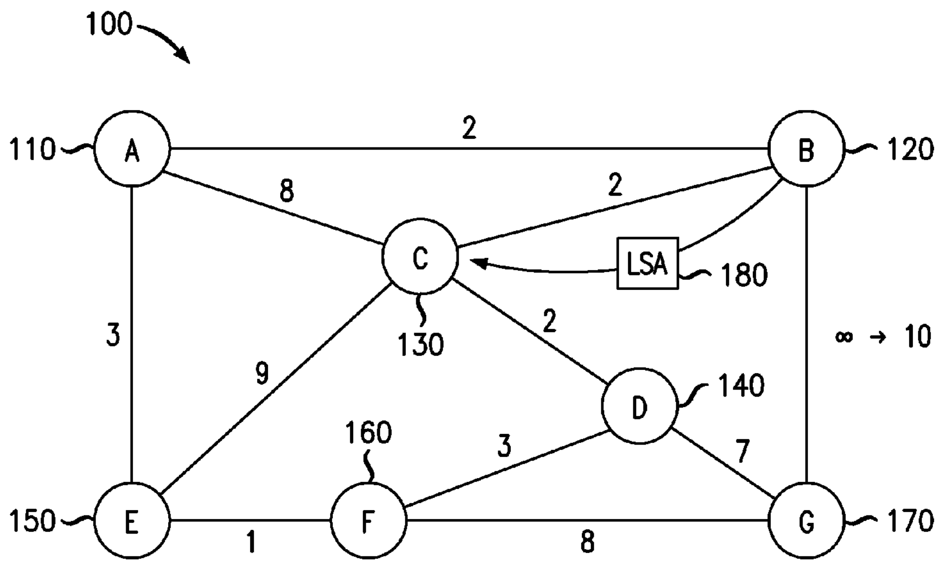


FIG. 1

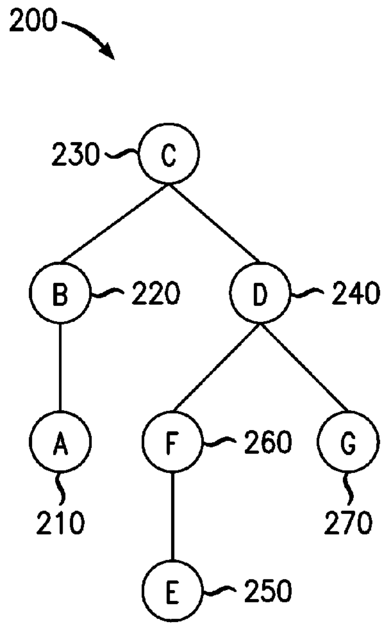
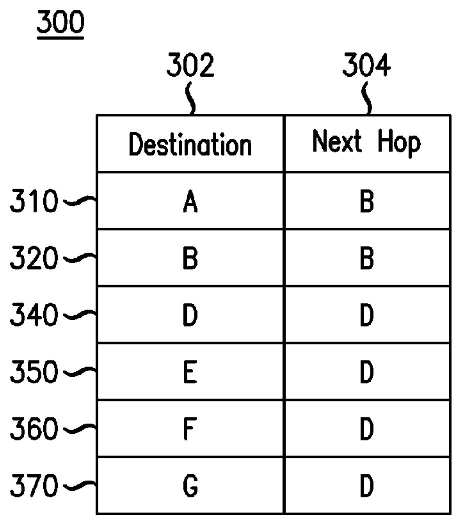


FIG. 2


300
302
304
310
320
340
350
360
370

Destination	Next Hop
A	B
B	B
D	D
E	D
F	D
G	D

FIG. 3

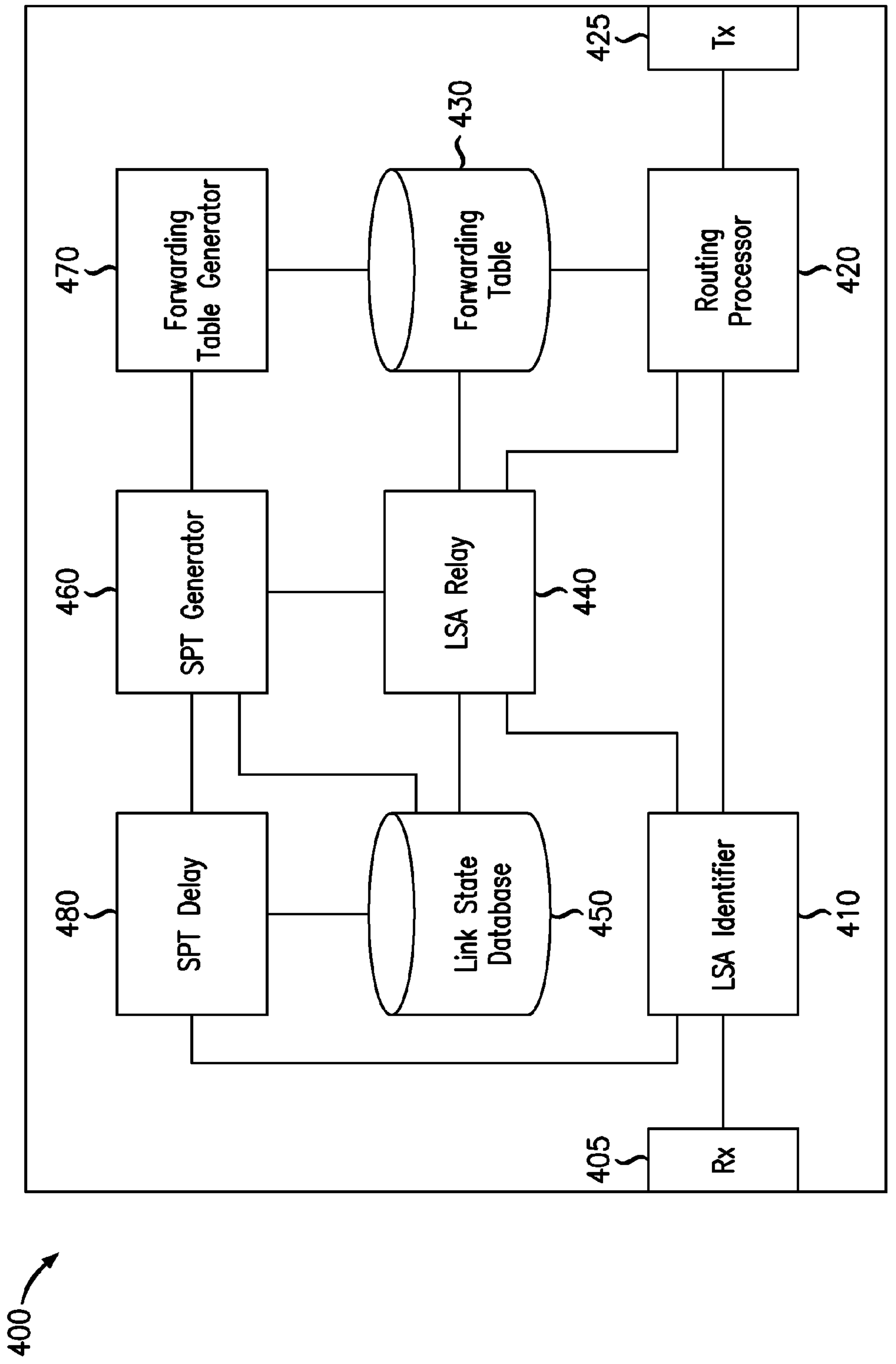

400
405
Rx
410
LSA Identifier
420
Routing Processor
425
Tx
430
Forwarding Table
440
LSA Relay
450
Link State Database
460
SPT Generator
470
Forwarding Table Generator
480
SPT Delay

FIG. 4

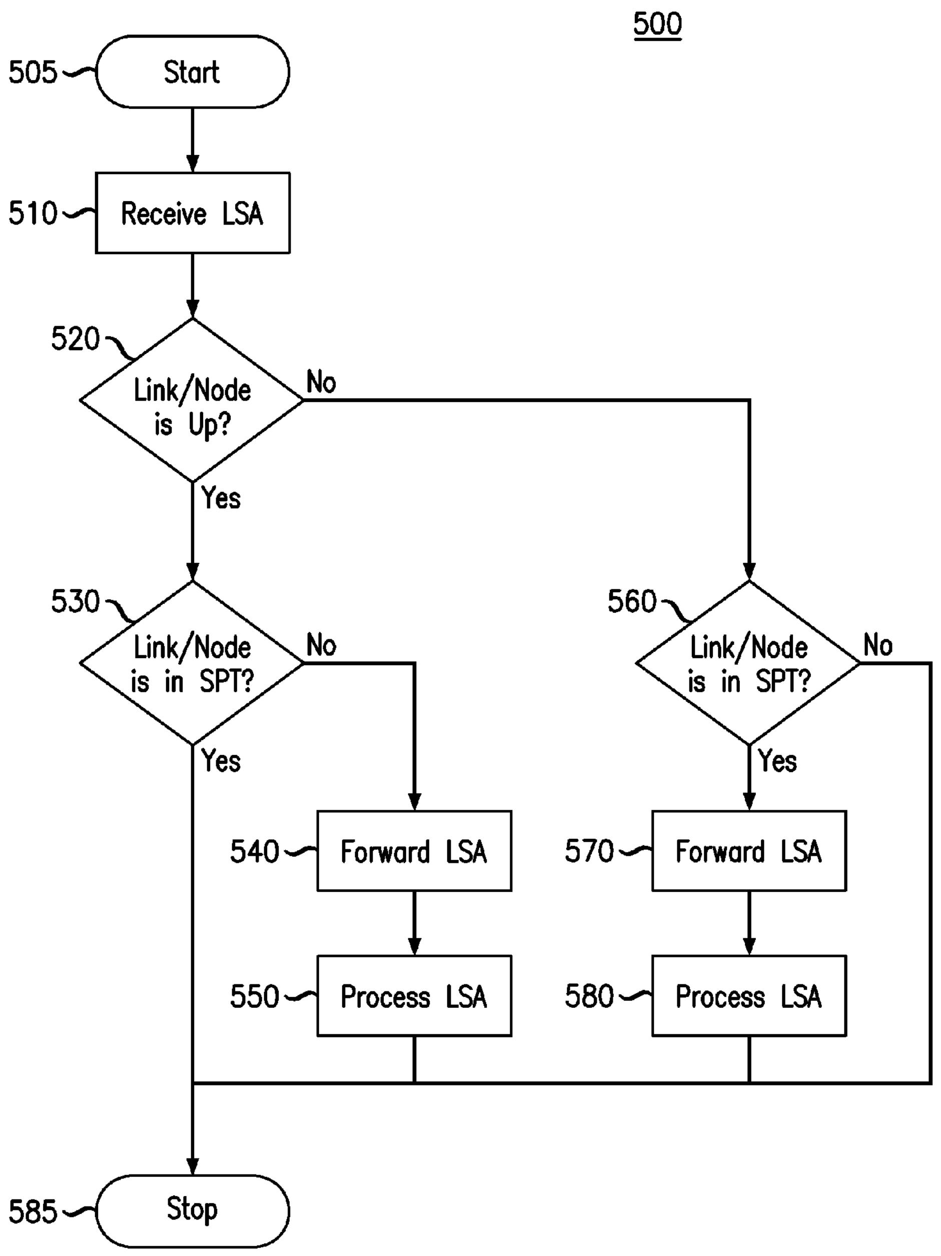

500
505
Start
510
Receive LSA
520
Link/Node is Up?
No
Yes
530
Link/Node is in SPT?
No
Yes
560
Link/Node is in SPT?
No
Yes
540
Forward LSA
570
Forward LSA
550
Process LSA
580
Process LSA
585
Stop

FIG. 5

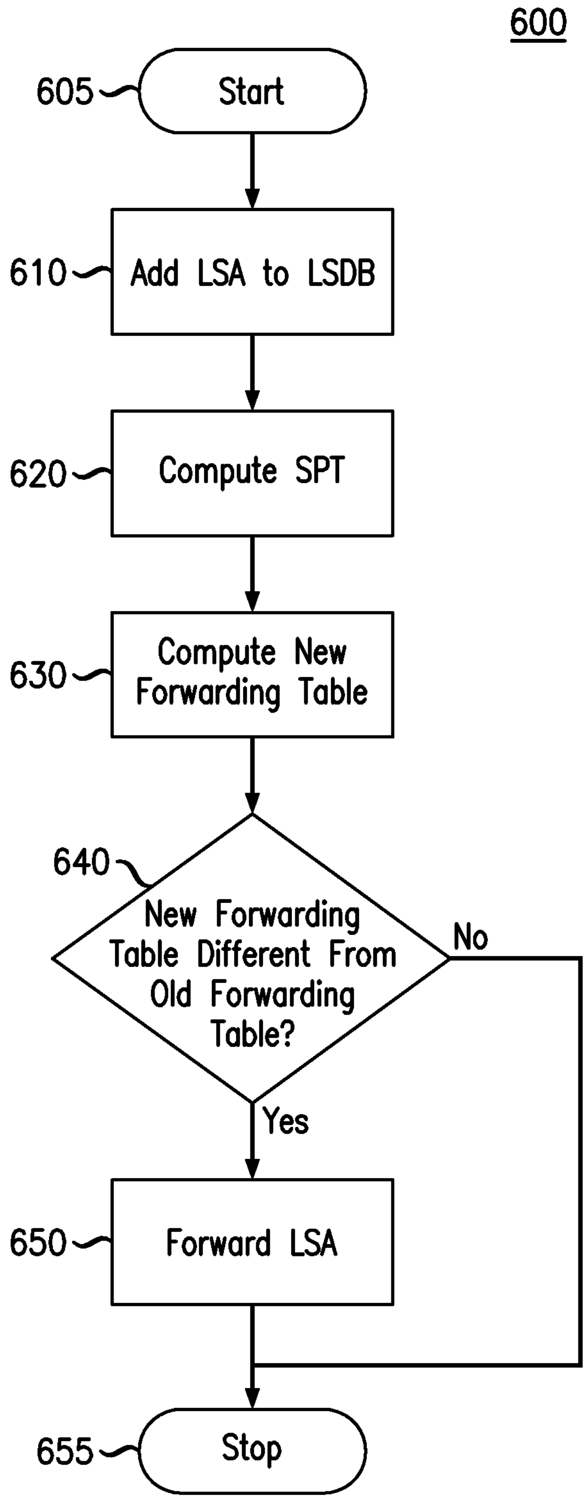

600
605
Start
610
Add LSA to LSDB
620
Compute SPT
630
Compute New Forwarding Table
640
New Forwarding Table Different From Old Forwarding Table?
No
Yes
650
Forward LSA
655
Stop

FIG. 6

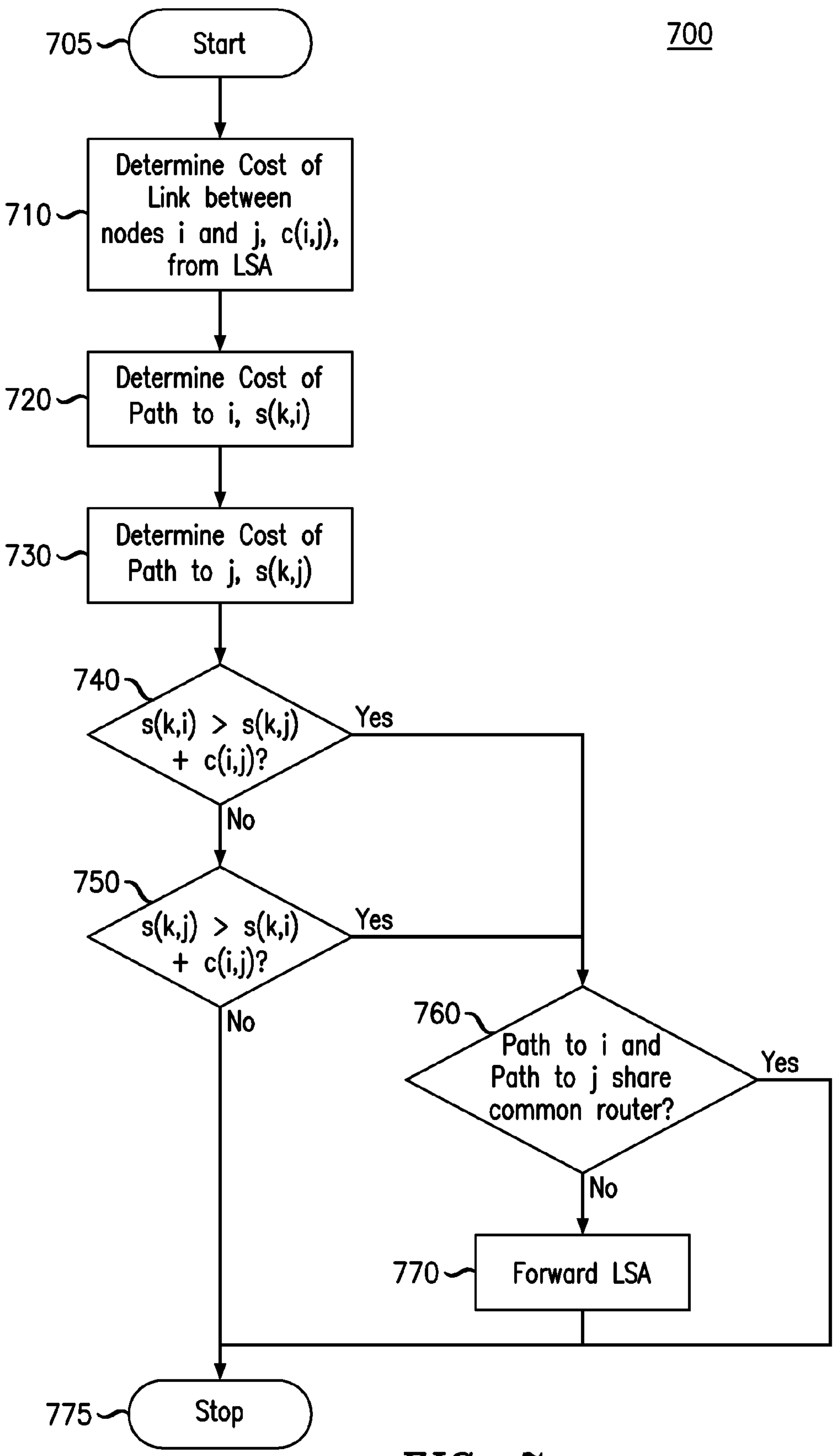

700
705 Start
710 Determine Cost of Link between nodes i and j, c(i,j), from LSA
720 Determine Cost of Path to i, s(k,i)
730 Determine Cost of Path to j, s(k,j)
740 s(k,i) > s(k,j) + c(i,j)?
Yes
No
750 s(k,j) > s(k,i) + c(i,j)?
Yes
No
760 Path to i and Path to j share common router?
Yes
No
770 Forward LSA
775 Stop

FIG. 7

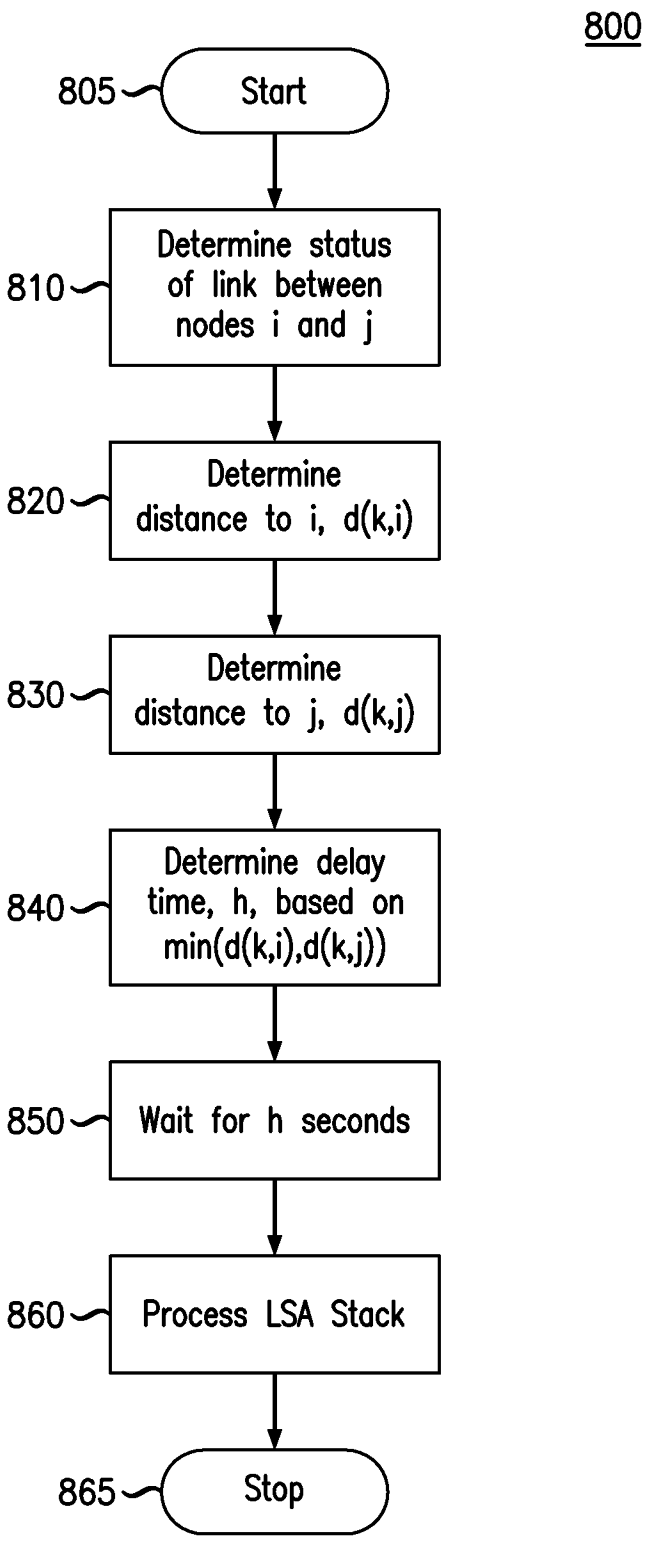

800
805
Start
810
Determine status of link between nodes i and j
820
Determine distance to i, d(k,i)
830
Determine distance to j, d(k,j)
840
Determine delay time, h, based on min(d(k,i),d(k,j))
850
Wait for h seconds
860
Process LSA Stack
865
Stop

FIG. 8

REDUCTION OF MESSAGE AND COMPUTATIONAL OVERHEAD IN NETWORKS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority as a continuation of co-pending U.S. application Ser. No. 12/945,318 filed on Nov. 12, 2010, the entire disclosure of which is hereby incorporated herein by reference for all purposes.

TECHNICAL FIELD

[0002] Various exemplary embodiments disclosed herein relate generally to network traffic routing.

BACKGROUND

[0003] Packet-switched networks are used to provide an ever-increasing amount of today's varied forms of communication. In addition to computer-to-computer communication via networks such as the Internet, packet-switched networks enable the communication of information associated with other applications such as television, telephone, and radio. Through these and other applications, end users may transmit and receive a multitude of information types over great distances.

[0004] In order to move such information from its source to its destination, packet-switched networks employ a number of interconnected routing devices. When one router receives a packet of data, the router will determine where the packet's destination is located and forward the packet to the next closest router. This next router will follow a similar procedure and, in this manner, the packet will eventually be delivered to its destination, much like a "bucket brigade."

[0005] One significant problem in packet switched networks is providing each network with the information necessary to make the determination of which "next hop" router to which each packet should be transmitted. While, in theory, this information could be manually programmed into the router, the size and dynamic nature of network topologies usually render this method impracticable. Instead, various protocols have been developed for automatically determining the best path to each destination for each router. For example, the Open Shortest Path First standard provides for routers within an autonomous system to share information regarding the state of links within the system. Using this information, each router can independently develop a forwarding table for use in determining where each received packet should be sent. When the network state changes, each router updates its forwarding table to ensure that each destination remains reachable and that each path chosen is optimal.

SUMMARY

[0006] While standards such as Open Shortest Path First (OSPF) provide a working solution to the problem of generating routing information, these standards often take a "brute force" approach. For example, in OSPF implementations, a link state advertisement (LSA) must be propagated throughout an entire "area" of the autonomous system whenever a change occurs in the network. These LSAs are then used by each node to update local forwarding tables to cope with the network change. With the potential frequency of nodes being added to the network, nodes being removed from the network, nodes entering a faulty state, nodes recovering from a faulty state, and other network changing events, a considerable amount of bandwidth may be devoted to propagating LSAs while a similarly large number of time may be used by each node to process the LSAs.

[0007] Accordingly, there is a need for a method of reducing the overhead associated with propagating and processing network update messages. In particular, it would be desirable to provide a method and network node that reduces the number of network update messages transmitted and processed.

[0008] In light of the present need for a method of reducing the overhead associated with propagating and processing LSAs or other network update messages, a brief summary of various exemplary embodiments is presented. Some simplifications and omissions may be made in the following summary, which is intended to highlight and introduce some aspects of the various exemplary embodiments, but not to limit the scope of the invention. Detailed descriptions of a preferred exemplary embodiment adequate to allow those of ordinary skill in the art to make and use the inventive concepts will follow in the later sections.

[0009] Various exemplary embodiments provide a network router that identifies irrelevant LSAs and refrains from propagating such packets. For example, such a router may use various methods to determine whether a particular received LSA will result in a change to local forwarding information. If the LSA will lead to updated routing information (e.g., changes in the router's forwarding table), the LSA may be forwarded to other nodes. If the LSA has no bearing on the routing information, however, the network node may refrain from propagating the LSA further within the network.

[0010] Various exemplary embodiments further provide a network router that reduces the amount of time spent re-computing routing information based on received LSAs. Such a router may delay the processing of LSAs to allow for the arrival and batch processing of additional LSAs. Various embodiments calculate a delay time for each LSA based on the potential relevance of the network changes described therein. For example, an LSA describing a change that is only one hop away may be delayed for less time, if any, than an LSA describing a change occurring 10 hops away.

[0011] Various exemplary embodiments relate to a method and related network node including one or more of the following: receiving, at the node, a network update message; determining whether the network update message should be propagated to other nodes; if the network update message should be propagated to other nodes, forwarding the network update message to at least one other node; and if the network update message should not be propagated to other nodes, refraining from forwarding the network update message to any other node. Various further embodiments relate to a method and related network node including one or more of the following: determining a first time period for the network update message; setting the first time period as a delay time; waiting for the delay time; and after the delay time has elapsed, computing new routing information based on the network update message.

[0012] Various exemplary embodiments relate to a network node including one or more of the following: a first interface that receives a packet from another node within the network; a second interface that transmits packets to other nodes; a network update message identifier that determines that the packet is an network update message; an network update message relay module that: determines whether the network update message should be forwarded to other nodes, if the network update message should be forwarded to other nodes, forwards the network update message to at least one other node via the second interface, and if the network update message should not be forwarded to other nodes, refrains from forwarding the network update message to any other nodes. Various further embodiments relate to a network node including one or more of the following: a first interface that receives a packet from another node within the network; a network update message identifier that determines that the packet is an network update message; a routing information delay module that: determines a first time period for the network update message, sets the first time period as a delay time, and waits for the delay time; and a routing information generator that, after the delay time has elapsed, computes new routing information based on the network update message.

[0013] It should be apparent that, in this manner, various exemplary embodiments enable reduction of overhead associated with changes in network state. In particular, by avoiding propagation of update messages that have no bearing on routing information, bandwidth overhead may be reduced. Further, by delaying the processing of received network updates, multiple network updates may be processed at a single time and processing overhead may be reduced.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] In order to better understand various exemplary embodiments, reference is made to the accompanying drawings, wherein:

[0015] FIG. **1** illustrates an exemplary network for routing data packets;

[0016] FIG. **2** illustrates an exemplary shortest path tree for determining the optimal path from one node to a number of other possible nodes;

[0017] FIG. **3** illustrates an exemplary forwarding table for determining a next hop to which a packet should be transmitted based on the packet destination;

[0018] FIG. **4** illustrates an exemplary network node for routing packets and reducing network overhead associated with link state advertisements (LSAs);

[0019] FIG. **5** illustrates an exemplary method for reducing overhead in a network associated with LSAs;

[0020] FIG. **6** illustrates an exemplary method for deciding whether to propagate an LSA;

[0021] FIG. **7** illustrates another exemplary method for deciding whether to propagate an LSA; and

[0022] FIG. **8** illustrates an exemplary method for delaying processing of a received LSA.

DETAILED DESCRIPTION

[0023] Referring now to the drawings, in which like numerals refer to like components or steps, there are disclosed broad aspects of various exemplary embodiments.

[0024] FIG. **1** illustrates an exemplary network **100** for routing data packets. Exemplary network **100** may be a packet-switched communications network for providing data transfer for various applications. Exemplary network **100** may further implement a standard for automatic updating of routing information in response to changes within the network. For example, network **100** may constitute an autonomous system implementing the Open Shortest Path First (OSPF) standard.

[0025] Exemplary network may include a number of nodes A-G **110-170**. Each node A-G **110-170** may be a router, switch, or other network equipment adapted to receive and forward data packets toward the packets' respective destinations. Each node may also be connected to a number of additional devices (not shown) such as additional network devices and end user equipment.

[0026] Nodes A-G **110-170** may each be connected to one or more other nodes A-G **110-170** via one or more links. Each link may be associated with a link cost. For example, node C **130** may be connected to node D **140** via a link having cost **2**. This link cost may be assigned based on various factors such as, for example, the geographic distance between the nodes, the number of intermediate devices between the nodes, the bit-rate associated with the link, and/or the current load on the link. Some links may be faulty and thus undesirable for forwarding packets. Such links may accordingly be assigned a very high or infinite link cost to discourage use.

[0027] During operation, the characteristics of network **100** may change. For example, a previously faulty link may be restored, as in the case of the link between node B **120** and node G **170**. Other network changes may include, for example, a link cost changing, a node or link entering a faulty state, a node or link recovering from a faulty state, a node or link being added, and/or a node or link being removed.

[0028] After such a network change, an update message may be transmitted to other nodes. For example, in the OSPF implementation of exemplary network **100**, node B **120** may transmit a link state advertisement (LSA) **180** to node C **130** to indicate that the link between node B **120** and node G **170** has recovered from a faulty state and now has a link cost of 10. Node B **120** and Node G **170** may further transmit similar or identical LSAs (not shown) to all other nodes to which they are connected. According to the OSPF standard, the LSAs will then be passed by this group of receiving nodes to all of their neighbors. In this manner, each node will receive an LSA indicating the new status of the link.

[0029] Not all LSAs may be relevant to all nodes A-G **110-170**. For example, while the restored link may be the best path for traffic directly between node B **120** and node G **170**, node C **130** may continue to use its pre-established paths to both of these nodes.

[0030] Each node A-G **110-170** may store a local representation of exemplary network **100**. Such a local representation may be constructed locally from information conveyed in the LSA messages transmitted by other nodes A-G **110-170** according to OSPF. For example, each node may store an indication of all nodes and edges in a Link State Database (LSDB). Such a representation may be used by each node A-G **110-170** to construct a shortest path tree and, ultimately, a forwarding table for use in forwarding packets to their destination.

[0031] FIG. **2** illustrates an exemplary shortest path tree (SPT) **200** for determining the optimal path from one node to a number of other possible nodes. SPT **200** may be constructed from a representation of the current state of the network, such as exemplary network **100**, using any method known to those of skill in the art. For example, a node may use Djikstra's Shortest Path Tree algorithm to construct an SPT.

[0032] SPT **200** may be an SPT constructed by node C **130** in view of exemplary network **100**. SPT **200** may include a number of node representations A-G **210-270** corresponding to nodes A-G **110-170**. SPT **200** may indicate the optimal path to each node within the network from node C **130**. For example, SPT **200** indicates that the shortest path from node C **130** to node G **170** is through node D **140**, rather than through node B **120** or some other path. Accordingly, packets received by node C **130** destined for node G **170** should be forwarded to node D **140**, according to SPT **200**. Node D **140**, in turn, may include its own routing information enabling it to forward the packet to node G **170**.

[0033] After computing SPT **200**, node C **130** may update its forwarding table to reflect the state of exemplary network **100**. In particular, node C **130** may analyze SPT **200** to determine the next hop node that should be used for each potential destination node. This information may then be stored in a forwarding table for quick access when forwarding packets.

[0034] FIG. **3** illustrates an exemplary forwarding table **300** for determining a next hop to which a packet should be transmitted based on the packet destination. Forwarding table **300** may be, for example, a table in a database stored at node C **130**. Alternatively, forwarding table **300** could be a series of linked lists, an array, or a similar data structure. Thus, it should be apparent that forwarding table **300** is an abstraction of the underlying data; any data structure suitable for storage of the underlying data may be used.

[0035] Forwarding table **300** may include a destination field **302** and a next hop field **304**. Destination field **302** may indicate a destination device with which the corresponding entry is associated while next hop field **304** may indicate which next hop device is appropriate for the associated destination device. It should be apparent that forwarding table **300** is, in some respects, a simplification. For example, forwarding table may contain additional fields such as an outgoing port number, a destination MAC address, and/or an alternate next hop. Various modifications will be apparent to those of skill in the art. It should be apparent that the data shown in exemplary table **300** is in some respects an abstraction and/or simplification; for example, destination field **302** may store an address of one or more destination nodes.

[0036] Forwarding table may include a number of entries **310**-**370**. Entry **310** may indicate that packets destined for node A **110** should be forwarded to node B **120**. Likewise, entry **320** may indicates that packets destined for node B **120** should be forwarded directly to that node. Entries **340**-**370** may indicate that packets destined for nodes D-G **140**-**170**, respectively, should be forwarded to node D **140**.

[0037] Having described the components of exemplary network **100**, a brief summary of the operation of exemplary network **100** will be provided. It should be apparent that the following description is intended to provide an overview of the operation of exemplary network **100** and is therefore a simplification in some respects. The detailed operation of exemplary network **100** will be described in further detail below in connection with FIGS. **4**-**10**.

[0038] After node C **130** has received LSA **180**, node C **130** may determine whether the LSA should be propagated to other nodes such as node A **110**, node D **140**, and/or node E **150**. Node C **130** may consult SPT **200** and determine that it is not currently using the link between node B **120** and node G **170**. Next, node C **130** may compute a new SPT based on the LSA **180** and determine that the new SPT is identical to the current SPT and, accordingly, refrain from propagating LSA **180** to any other nodes.

[0039] Node C **130** may also determine that local processing of LSA **180** should be delayed for some time period such as, for example, 100 ms. Once this 100 ms has elapsed, Node C **130** may proceed to update its routing information in view of LSA **180** and any other LSAs (not shown) that may have arrived during the delay.

[0040] FIG. **4** illustrates an exemplary network node **400** for routing packets and reducing network overhead associated with link state advertisements (LSAs). Network node **400** may correspond to one or more nodes A-G **110**-**170** in exemplary network **100**. Network node **400** may include a packet receiver **405**, a link state advertisement identifier **410**, a routing processor **420**, a packet transmitter **425**, a forwarding table storage **430**, a link state advertisement relay module **440**, a link state database **450**, a shortest path tree generator **460**, a forwarding table generator **470**, and/or a shortest path tree delay module **480**.

[0041] Packet receiver **405** may be an interface comprising hardware and/or executable instructions encoded on a machine-readable storage medium configured to receive packets from other network devices. Packet receiver **405** may include multiple ports and may receive packets from multiple network devices. For example, packet receiver **405** may receive link state advertisement packets and packets associated with regular network traffic.

[0042] Link state advertisement (LSA) identifier **410** may include hardware and/or executable instructions on a machine-readable storage medium configured to determine whether a received packet is an LSA that the node **400** should process. If the packet is an LSA, LSA identifier **410** may notify the LSA relay module **440** and/or SPT delay module **480** that a new LSA has arrived by, for example, passing the LSA to those components. Otherwise, LSA identifier may pass the packet to routing processor **420** for further routing.

[0043] It should be noted that, while various embodiments described herein relate to systems using link state advertisements constructed according to OSPF, various embodiments may work in conjunction with other standards using alternative network update messages. Accordingly, LSA identifier **410** may be viewed as a generic network update message identifier. Modifications useful for implementation in conjunction with such other standards will be apparent to those of skill in the art.

[0044] Routing processor **420** may include hardware and/or executable instructions on a machine-readable storage medium configured to route packets toward their destination. Routing processor **430** may extract a destination from each received packet and determine a next hop for that destination by using a forwarding table stored in forwarding table storage **430**. Routing processor **420** may then forward the packet, via transmitter **425**, to the appropriate next hop.

[0045] Packet transmitter **425** may be an interface comprising hardware and/or executable instructions encoded on a machine-readable storage medium configured to transmit packets to other network devices. Packet transmitter **425** may include multiple ports and may transmit packets to multiple network devices. For example, packet transmitter **425** may transmit link state advertisement packets and packets associated with regular network traffic.

[0046] Forwarding table storage **430** may be any machine-readable medium capable of storing a forwarding table. Accordingly, forwarding table storage **430** may include a machine-readable storage medium such as read-only memory (ROM), random-access memory (RAM), magnetic disk storage media, optical storage media, flash-memory devices, and/or similar storage media.

[0047] Link state advertisement (LSA) relay module **440** may include hardware and/or executable instructions on a machine-readable storage medium configured to determine whether each received LSA should be propagated to other nodes within the network. For example, in various embodiments, LSA relay module **440** may determine that only those LSAs likely to have an effect on local routing information should be propagated to other nodes. Various methods for making such a determination will be described in greater detail below with respect to FIGS. **5**-**7**.

[0048] Alternative or additional criteria may be used for determining whether to forward a received LSA. For example, LSA relay module **440** may estimate whether an LSA will affect another node's routing information and subsequently forward LSA's to those nodes likely to be affected. As another example, LSA relay module **440** may attempt to group subsequent LSAs and refrain from propagating any LSAs tending to override other LSAs. Other methods for determining the relevance of an LSA to other nodes will be apparent to those of skill in the art.

[0049] According to various alternative embodiments, rather than refraining from LSA propagation when no routing information update was necessitated by an LSA, LSA relay module **440** may construct a marked LSA and subsequently forward the marked LSA. Such construction may include constructing an entirely new LSA or simply marking a bit or field in the received LSA to produce a marked LSA. For example, LSA relay module **440** may set a bit in the header of the LSA to indicate that the LSA did not lead to a change in routing information. LSA relay module **440** may then forward the LSA to at least one other node per OSPF. Such other nodes may then take the bit into account when determining whether and how to process the LSA. For example, a node receiving such a marked LSA may determine whether the sending node is on its current path to the link or node identified by the LSA. If so, the receiving node may ignore the LSA. Otherwise, the receiving node may process the LSA as normal.

[0050] According to additional alternative embodiments, LSA relay module **440** may delay an irrelevant LSA rather than refraining from propagating the message entirely. According to such embodiments, when an LSA is judged to have no bearing on a node's routing information, the LSA may be delayed for future transmission. For example, the LSA may be queued with other delayed packets. All messages in such a queue may be transmitted to other nodes after a periodic timer indicates that a predetermined time interval has passed. As another example, such an LSA may simply be queued and transmitted whenever another LSA is received and will be propagated. The two LSAs may then be transmitted together.

[0051] Link state database (LSDB) **450** may be any machine-readable medium capable of storing a representation of the current network state. LSDB **450** may, for example, store an indication of every node and link within an autonomous system. Accordingly, LSDB **450** may include a machine-readable storage medium such as read-only memory (ROM), random-access memory (RAM), magnetic disk storage media, optical storage media, flash-memory devices, and/or similar storage media. LSDB **450** may be an independent storage device within node **400** or may be the same as forwarding table storage **430**.

[0052] Shortest path tree (SPT) generator **460** may include hardware and/or executable instructions on a machine-readable storage medium configured to generate a shortest path tree from a representation of a network. For example, SPT generator **460** may use Djikstra's algorithm or any other method known to those of skill in the art to generate a shortest path tree from data stored in LSDB **450**. After generating an SPT, SPT generator **460** may transmit the SPT to forwarding table generator **470**.

[0053] Forwarding table generator **470** may include hardware and/or executable instructions on a machine-readable storage medium configured to generate or update a forwarding table based on an SPT. For example, forwarding table generator **470** may determine whether any entries in forwarding table storage **430** should be added or modified based on the current SPT for the network node **400**. Forwarding table generator **470** may then perform such updates by, for example, adding or removing entries or modifying the next hop of one or more entries.

[0054] It should be noted that, while node **400** is described as functioning according to various aspects of OSPF, the methods described herein may be applicable to other standards. Appropriate modifications for compliance with other standards will be apparent to those of skill in the art. Accordingly, SPT generator **460** and forwarding table generator **470** may be viewed, separately or together, as a generic "routing information generator."

[0055] Shortest path tree (SPT) delay module **480** may include hardware and/or executable instructions on a machine-readable storage medium configured to delay the processing of an incoming LSA. According to various embodiments, SPT delay module **480** may generate a delay time based on various criteria associated with the LSA, wait until the delay time has elapsed, and subsequently instruct SPT generator **460** to process the LSA. This process will be described in greater detail with respect to FIGS. **5** and **8**. If, while waiting for the delay time to elapse, additional LSAs are received, SPT delay module **480** may update the delay time such that processing of the original LSA will occur either sooner or later than originally specified. At such time, SPT generator **460** may process only the first received LSA or, alternatively, all LSAs received during the delay.

[0056] FIG. **5** illustrates an exemplary method **500** for reducing overhead in a network associated with LSAs. Method **500** may be performed by the various components of network node **400** such as, for example, LSA identifier **410**, LSA relay module **440**, SPT generator **460**, forwarding table generator **470**, and/or SPT delay module **480**.

[0057] Method **500** may begin in step **505** and proceed to step **510** where node **400** may receive and identify an LSA. According to various alternative embodiments, the methods described herein may only be applied to a subset of received LSAs. For example, method **500** may apply only to LSAs of type **1**, **2**, or **8**, as defined by the OSPF standard. According to such embodiments, if node **400** identifies an LSA of another type, the LSA may be processed according to alternative methods such as those defined by OSPF.

[0058] Method **500** may then proceed to step **520**, where node **400** may determine whether the LSA indicates that a link or node is available for routing packets. If so, method **500** may proceed to step **530**, where node **400** may analyze its local routing information. For example, node **400** may determine whether the current SPT includes the node or link in question. Various embodiments may alternatively or additionally check other routing information in step **530** for the presence of the node or link identified in the LSA. For example, node **400** may refer to the forwarding table. Accordingly, step **530** may generally check a relevant network path structure for presence of the node or link. If the link or node is already in the SPT or other routing information, the LSA is determined to be of little or no relevance. Accordingly, method **500** may proceed to end in step **585** without propagating the LSA.

[0059] If, on the other hand, the link or node is not found in the current SPT, method **500** may proceed to step **540**. In step **540**, node **400** may simply forward the LSA to other nodes without further processing. Alternatively, node **400** may perform additional estimations of LSA relevance before determining whether the LSA should be forwarded. Examples of such additional procedures will be described in further detail below with respect to FIGS. **6-7**. Method **500** may then proceed to step **550** where node **400** may process the LSA to update the local forwarding table. This step may include delaying the processing for some time, as will be described in further detail with reference to FIG. **8**, below. Method **500** may then proceed to end in step **585**.

[0060] Returning to step **520**, if it is determined that the LSA does not indicate that a node or link is now available, method **500** may proceed instead to step **560**. For example, LSA may indicate that a node or link is now unavailable for packet routing. Step **560** may be similar to step **530** in that node **400** will determine whether the node or link in question is used by the SPT or other routing information. If the node or link in question is used by the SPT or other routing information, method **500** may proceed to step **570**. Step **570** may be similar to step **540**. Alternatively, step **570** may use different processing for determining whether the LSA should be forwarded. Method **500** may then proceed to step **580**, where the LSA may be processed locally, similar to step **550**. Method **500** may then end in step **585**.

[0061] If it is instead determined at step **560** that the node or link in question is not used by the SPT, method **585** may simply end in step **585**, without forwarding the LSA to any other nodes. In various alternative embodiments, the local processing of LSAs may be wholly independent LSA propagation. Accordingly, steps similar to step **550** and/or step **580** may be performed regardless of the outcome of steps **520**, **530**, **560**.

[0062] FIG. **6** illustrates an exemplary method **600** for deciding whether to propagate an LSA. Method **600** may be performed by the various components of network node **400** such as, for example, LSA relay module **440**, SPT generator **460**, and/or forwarding table generator **470**. Method **600** may correspond to step **540** and/or step **570** of method **500**. In various alternative embodiments, method **600** may be implemented in place of at least some of steps **520-580** of method **500**.

[0063] Method **600** may begin in step **605** and proceed to step **610** where node **400** may add the information carried by the previously received LSA to the link state database (LSDB) **450** or other storage. Then, in step **620**, node **400** may compute a new SPT, taking into account the newly received information. Method **600** may then proceed to step **630**, where node **400** may compute a new forwarding table or update the previous forwarding table, based on the new SPT.

[0064] In step **640**, node **400** may determine whether the newly computed or updated forwarding table is different than the previous forwarding table. If the two tables are different, thereby signifying that the LSA includes relevant network state information, method **600** may proceed to step **650** where node **400** will forward the LSA to other nodes. If, however, the LSA did not lead to a change in the forwarding table, method **600** will proceed directly from step **640** to end in step **655**.

[0065] FIG. **7** illustrates another exemplary method **700** for deciding whether to propagate an LSA. Method **700** may be performed by the various components of network node **400** such as, for example, LSA relay module **440**. For the purposes of illustration, node **400** may also be referred to as "k" during the description of method **700**. Method **700** may correspond to step **540** and/or step **570** of method **500**. In various alternative embodiments, method **700** may be implemented in place of at least some of steps **520-580** of method **500**.

[0066] Method **700** may begin in step **705** and proceed to step **710**, where node **400** will begin to analyze the previously received LSA. Node **400** may perform method **700** or portions thereof for each link relevant to the LSA. For example, the LSA may describe the status of a single link or a node to which one or more links attach. Node **400** may determine the endpoints of the link, i and j, and determine the link cost associated with the link, c(i,j). Then, in step **720**, node **400** may determine the cost of the current path to the first link endpoint, s(k,i). Likewise, in step **730**, node **400** may determine the cost of the current path to second link endpoint, s(k,j).

[0067] Beginning in step **740**, node **400** may determine whether the link provides a less costly path to any nodes and, consequently, whether the SPT should be recomputed. In step **740**, node **400** may determine whether the path to link endpoint i via the new link is less costly than the previously used path to endpoint i. Likewise, in step **750**, node **400** may determine whether the path to link endpoint j via the new link is less costly than the previously used path to endpoint j. If neither of these new potential paths are less costly than the previously used paths, method **700** may end in step **775**, without forwarding the LSA to other nodes.

[0068] If, on the other hand, either of the potential new paths are better than a previously used path, method **700** may proceed to step **760**. In various alternative embodiments, node **400** may simply forward the LSA at this point and the method may end. However, in the exemplary method **700**, node **400** additionally determines whether another node may have already propagated the LSA to the nodes to which the LSA may be relevant. Accordingly, in step **760**, node **400** may determine whether the paths to each of the link endpoints, i and j, share any common routers. If so, method **700** may simply end in step **775**.

[0069] However, if the paths share no common routers, node **400** may propagate the LSA in step **770**. Node **400** may propagate the LSA to each neighbor or, alternatively, only those neighbors that are not currently part of either of the two paths. Method **700** may then end in step **775**.

[0070] FIG. **8** illustrates an exemplary method **800** for delaying processing of a received LSA. Method **800** may be performed by the various components of network node **400** such as, for example, SPT delay module **480**. Method **800** may correspond to step **550** and/or step **580** of method **500**. In various alternative embodiments, method **800** may be implemented in place of at least some of steps **520-580** of method **500**.

[0071] Method **800** may begin in step **805** and proceed to step **820**, where node **400** may interpret the LSA to determine which nodes are located at the endpoint of each link identified by the LSA. This step may simply include reading the information previously interpreted in processing the LSA. In steps **810** and **820**, node **400** may determine the distance to each of the link endpoints, i and j, respectively. This distance metric may include the number of hops to each node, the geographic distance, the cost of the current paths to each node, and/or other information.

[0072] Node **400** may then, in step **840**, use the lesser of the two distances to determine how long node **400** should wait before processing the LSA. This determination may be made, for example, by applying a mathematical function using the determined minimum distance as a variable or by reading a table of prescribed delays associated with various possible distances.

[0073] It should be noted that other methods may be employed to determine the amount of delay for each LSA. For example, various alternative embodiments may take into account the type of LSA received, the state change indicated by the LSA, or the number of other recently received LSAs when determining a delay time.

[0074] In step **850**, node **400** may wait for the delay time to elapse. For example, node **400** may suspend the routing information update process for a time equal to the delay time. During this waiting period, additional LSAs may arrive at node **400**. Such LSAs may be placed on an LSA stack or other data structure for future processing. Further, on receipt of such additional LSAs, another instance of method **800** or a similar method may run on node **400** to update the delay time. For example, node **400** may reduce, extend, and/or refresh the original wait period based on the new LSA.

[0075] Once the delay time has elapsed, node **400** may process the received LSAs in step **860**. In various embodiments, received LSAs may be stored in a LIFO structure, such as a stack, such that the most recent LSAs will be processed first. Any LSAs overridden by a later LSA may then be ignored, further reducing the processing time associated with updating routing information. Node **400** may then generate a single SPT and update the forwarding table based on all of the received LSAs at once.

[0076] According to the foregoing description, various exemplary embodiments enable reduction of overhead associated with changes in network state. In particular, by avoiding propagation of update messages that have no bearing on routing information, bandwidth overhead may be reduced. Further, by delaying the processing of received network updates, multiple network updates may be processed at a single time and processing overhead may be reduced.

[0077] It should be apparent from the foregoing description that various exemplary embodiments of the invention may be implemented in hardware and/or firmware. Furthermore, various exemplary embodiments may be implemented as instructions stored on a machine-readable storage medium, which may be read and executed by at least one processor to perform the operations described in detail herein. A machine-readable storage medium may include any mechanism for storing information in a form readable by a machine, such as a personal or laptop computer, a server, or other computing device. Thus, a machine-readable storage medium may include read-only memory (ROM), random-access memory (RAM), magnetic disk storage media, optical storage media, flash-memory devices, and similar storage media.

[0078] The functions of the various elements shown in the FIGS., including any functional blocks labeled as "processors", may be provided through the use of dedicated hardware as well as hardware capable of executing processing steps in association with appropriate software. When provided by a processor, the functions may be provided by a single dedicated processor, by a single shared processor, or by a plurality of individual processors, some of which may be shared. Moreover, explicit use of the term "processor" or "controller" should not be construed to refer exclusively to hardware capable of executing software, and may implicitly include, without limitation, digital signal processor (DSP) hardware, network processor, application specific integrated circuit (ASIC), field programmable gate array (FPGA), read only memory (ROM) for storing software, random access memory (RAM), and non volatile storage. Other hardware, conventional and/or custom, may also be included. Similarly, any switches shown in the FIGS. are conceptual only. Their function may be carried out through the operation of program logic, through dedicated logic, through the interaction of program control and dedicated logic, or even manually, the particular technique being selectable by the implementer as more specifically understood from the context.

[0079] It should be appreciated by those skilled in the art that any block diagrams herein represent conceptual views of illustrative circuitry embodying the principles of the invention. Similarly, it will be appreciated that any flow charts, flow diagrams, state transition diagrams, pseudo code, and the like represent various processes which may be substantially represented in machine readable media and so executed by a computer or processor, whether or not such computer or processor is explicitly shown.

[0080] Although the various exemplary embodiments have been described in detail with particular reference to certain exemplary aspects thereof, it should be understood that the invention is capable of other embodiments and its details are capable of modifications in various obvious respects. As is readily apparent to those skilled in the art, variations and modifications can be effected while remaining within the spirit and scope of the invention. Accordingly, the foregoing disclosure, description, and figures are for illustrative purposes only and do not in any way limit the invention, which is defined only by the claims.

What is claimed is:

1. A method of reducing overhead in a network performed at a network node, the method comprising:
- receiving, at the node, a network update message;
- determining whether the network update message should be propagated to other nodes;
- if the network update message should be propagated to other nodes, forwarding the network update message to at least one other node; and
- if the network update message should not be propagated to other nodes, refraining from forwarding the network update message to any other node.

2. The method of claim **1**, wherein the step of determining whether the network update message should be propagated comprises:
- determining whether routing information of the node should be changed in response to the network update message;
- if routing information should be changed, determining that the network update message should be propagated to other nodes; and
- if routing information should not be changed, determining that the network update message should not be propagated to other nodes.

3. The method of claim **1**, wherein the step of determining whether the network update message should be propagated comprises:

determining whether the network update message indicates that a link is up or down;

determining whether a relevant network path structure includes the link;

if the link is up and the relevant network path structure includes the link, determining that the network update message should not be propagated to other nodes; and

if the link is down and the relevant network path structure does not include the link, determining that the network update message should not be propagated to other nodes.

4. The method of claim **3**, further comprising, if the link is down and the relevant network path structure includes the link, determining that the network update message should be propagated to other nodes.

5. The method of claim **3**, further comprising, if the link is down and the relevant network path structure includes the link:

computing new routing information based on the network update message;

determining whether the current routing information and the new routing information are different;

if the current routing information and the new routing information are different, determining that the network update message should be propagated to other nodes; and

if the current routing information and the new routing information are not different, determining that the network update message should not be propagated to other nodes.

6. The method of claim **3**, wherein the link is a link between a second node and a third node, the method further comprising, if the link is up and the relevant network path structure does not include the link:

determining a cost of a current path from the node to the second node;

determining a cost of a current path from the node to the third node;

determining a cost of the link;

determining whether the cost of the current path to the second node is greater than the sum of the cost of the current path to the third node and the cost of the link;

determining whether the cost of the current path to the third node is greater than the sum of the cost of the current path to the second node and the cost of the link; and

if the cost of the current path to the second node is not greater than the sum of the cost of the current path to the third node and the cost of the link and the current path to the third node is not greater than the sum of the cost of the current path to the second node and the cost of the link, determining that the network update message should not be propagated to other nodes.

7. The method of claim **1** further comprising:

determining a delay time for the network update message;

waiting for the delay time; and

after the delay time has elapsed, computing new routing information based on the network update message.

8. The method of claim **1**, further comprising, if the network update message should not be propagated to other nodes:

constructing a marked network update message including at least a portion of the network update message and an indication that the network update message should not be propagated; and

transmitting the marked network update message to at least one other node.

9. The method of claim **1**, wherein the step of refraining from forwarding the network update message to any other node comprises:

refraining from immediately forwarding the network update message to any other node;

storing the network update message;

waiting for a period of time; and

after the period of time has elapsed, transmitting the network update message to at least one other node along with at least one additional network update message.

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