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(54) **SYSTEMS AND METHODS FOR FORWARDING DATA UNITS IN A COMMUNICATIONS NETWORK**

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(22) Filed: **Oct. 8, 2009**

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**Related U.S. Application Data**

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(51) **Int. Cl.**
*G06F 15/173* (2006.01)
*G06F 11/00* (2006.01)

(52) **U.S. Cl.** ........ **709/238**; 370/253; 370/229; 370/412; 707/799; 709/239

(58) **Field of Classification Search** .......... 709/238–239; 707/799; 370/229, 253, 412
See application file for complete search history.

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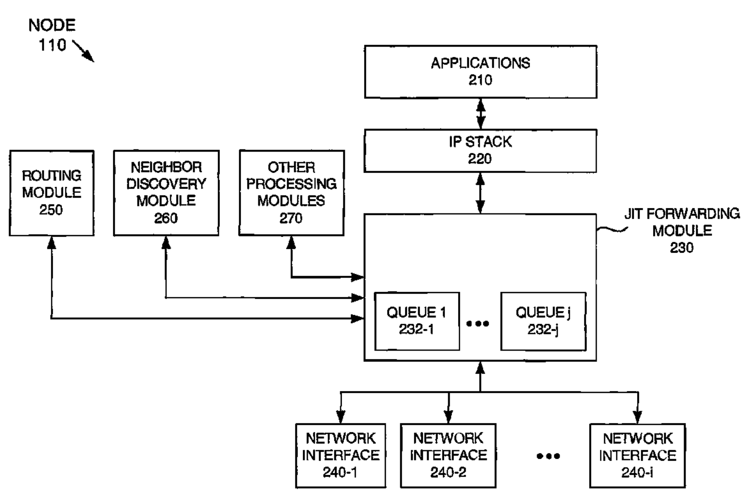
*Primary Examiner* — Alina N. Boutah
(74) *Attorney, Agent, or Firm* — Ropes & Gray LLP

(57) **ABSTRACT**

A network device (**110**) includes a forwarding module (**230**) and one or more network interfaces (**240**) that may be configured to transmit data units. The forwarding module (**230**) may be configured to identify one of the network interfaces (**240**) to transmit a data unit when the data unit is received by the network device (**110**) or generated by the network device (**110**), determine one of the network interfaces (**240**) to transmit the data unit when the data unit is ready to be transmitted by the network device (**110**), and forward the data unit to the determined network interface (**240**) for network when the determined network interface (**240**) is the identified network interface (**240**).

**30 Claims, 11 Drawing Sheets**



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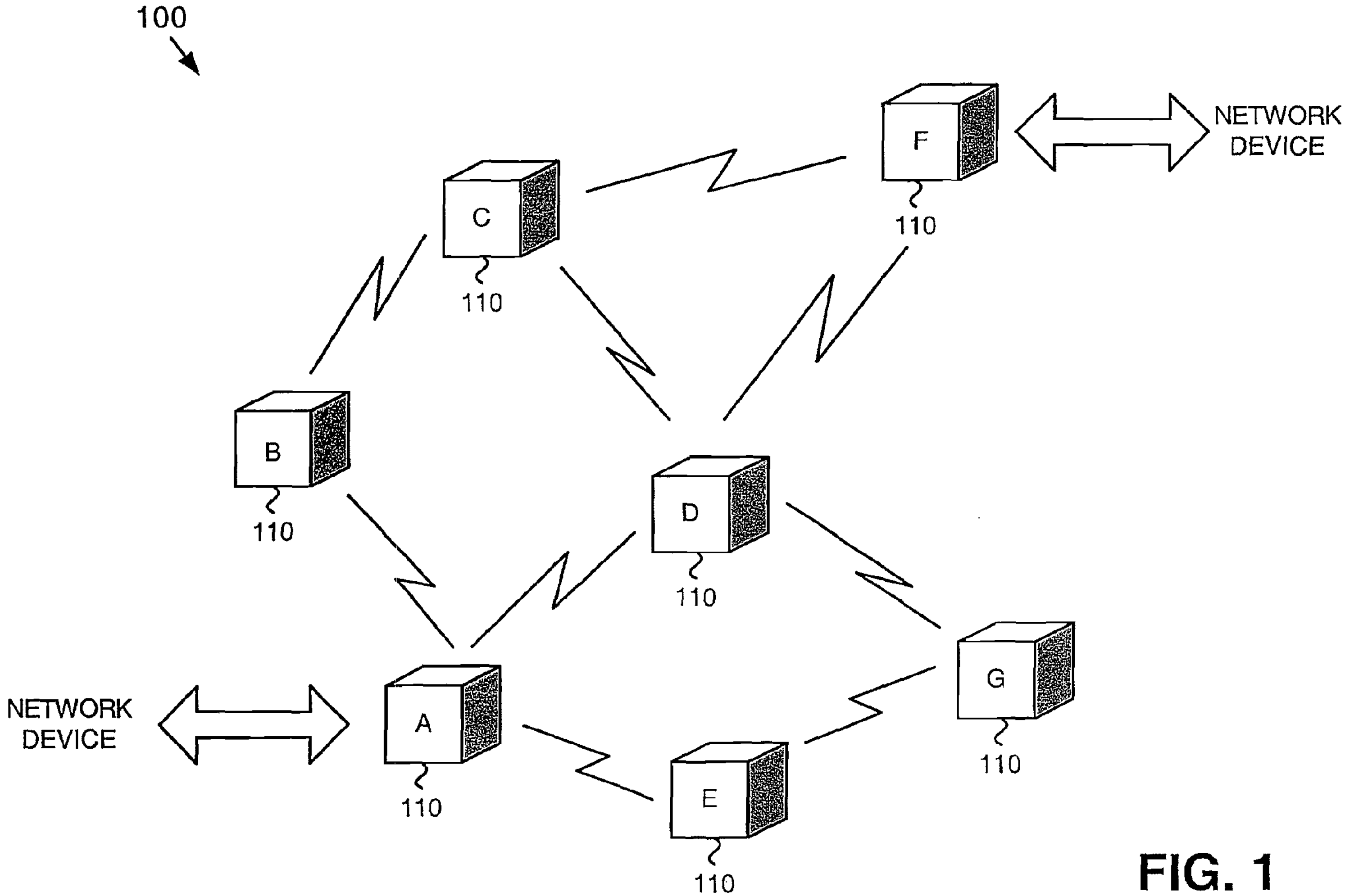

100
NETWORK DEVICE
F
110
C
110
B
110
D
110
G
110
NETWORK DEVICE
A
110
E
110

FIG. 1

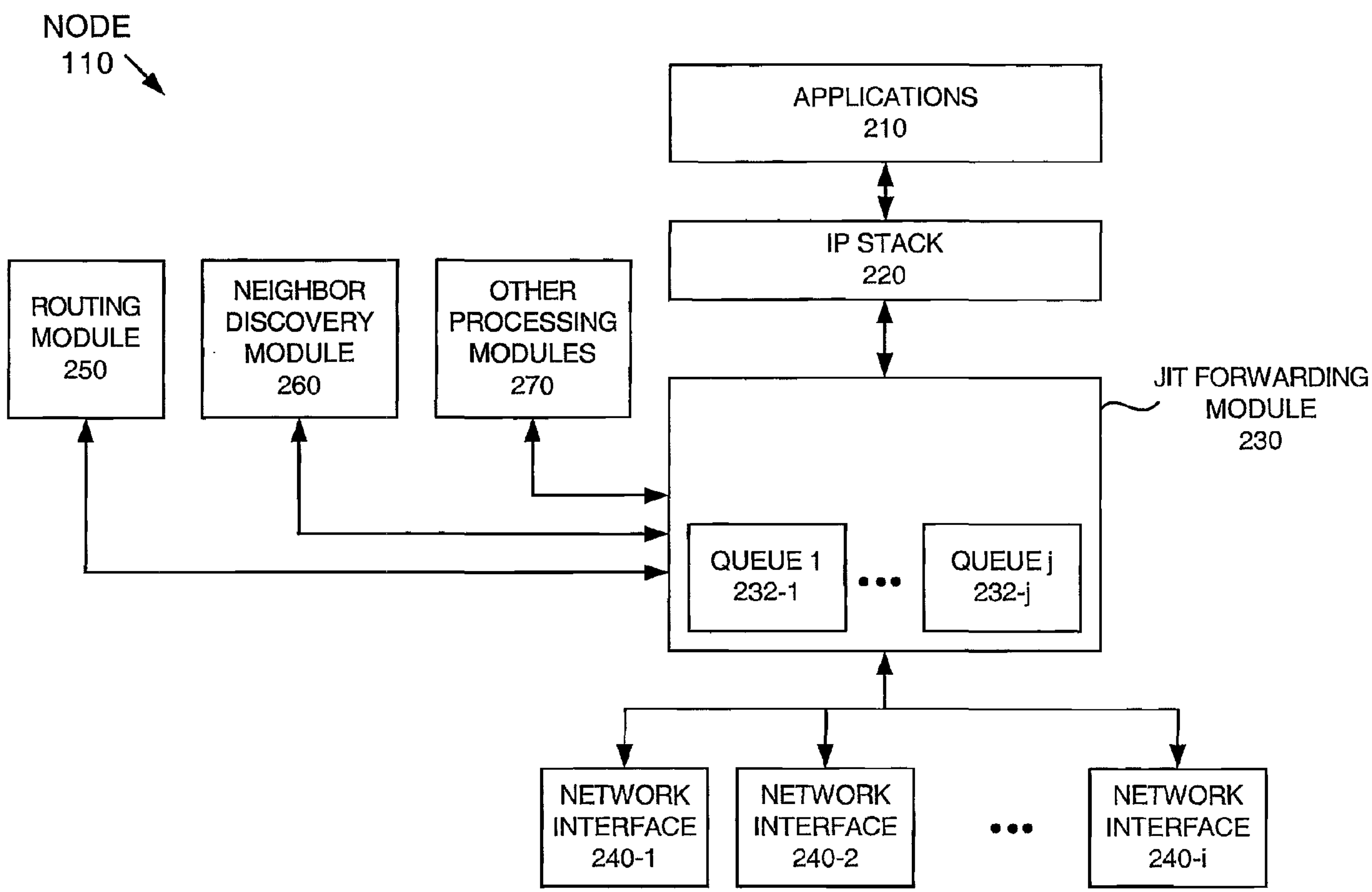

NODE
110
APPLICATIONS
210
IP STACK
220
ROUTING
MODULE
250
NEIGHBOR
DISCOVERY
MODULE
260
OTHER
PROCESSING
MODULES
270
JIT FORWARDING
MODULE
230
QUEUE 1
232-1
QUEUE j
232-j
NETWORK
INTERFACE
240-1
NETWORK
INTERFACE
240-2
NETWORK
INTERFACE
240-i

FIG. 2

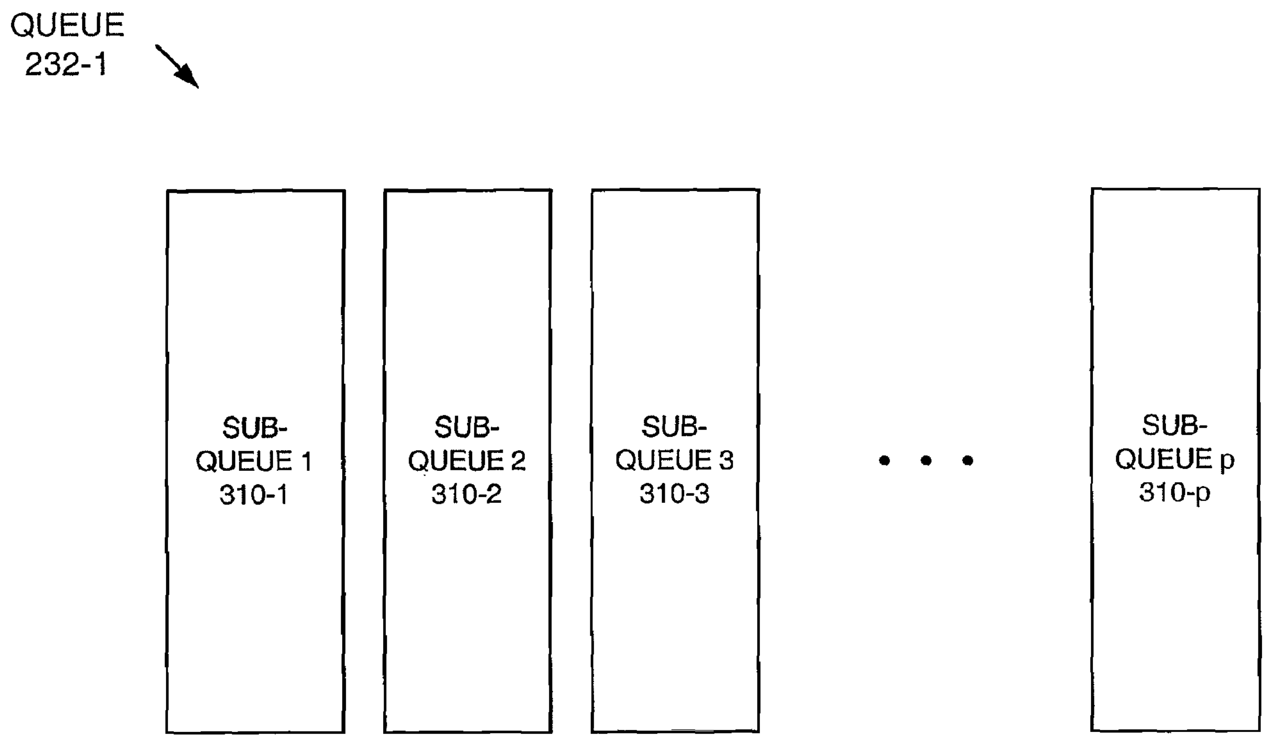

QUEUE
232-1
SUB-
QUEUE 1
310-1
SUB-
QUEUE 2
310-2
SUB-
QUEUE 3
310-3
SUB-
QUEUE p
310-p

FIG. 3

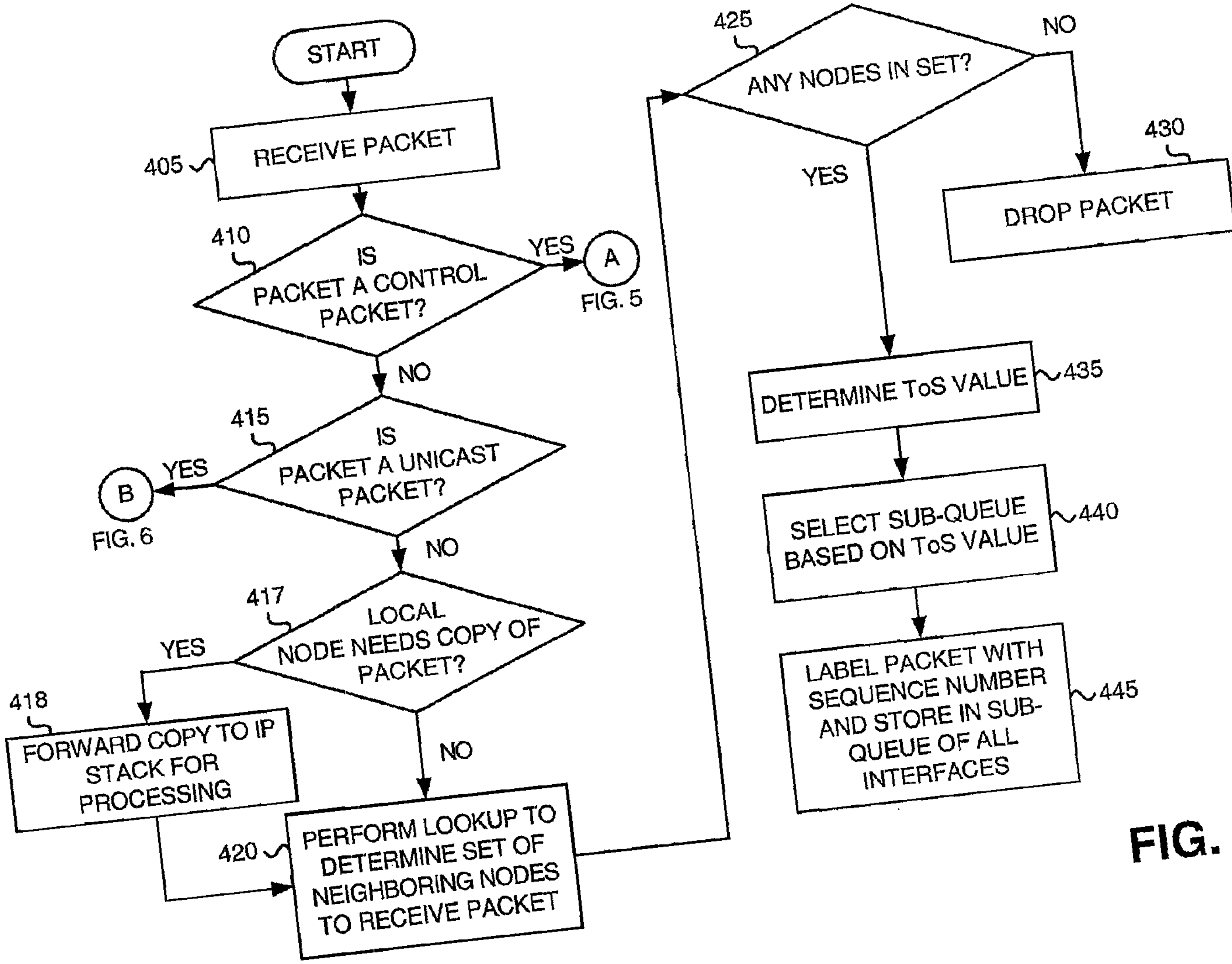

START
RECEIVE PACKET
405
IS PACKET A CONTROL PACKET?
410
YES
A
FIG. 5
NO
IS PACKET A UNICAST PACKET?
415
YES
B
FIG. 6
NO
LOCAL NODE NEEDS COPY OF PACKET?
417
YES
FORWARD COPY TO IP STACK FOR PROCESSING
418
NO
PERFORM LOOKUP TO DETERMINE SET OF NEIGHBORING NODES TO RECEIVE PACKET
420
ANY NODES IN SET?
425
NO
DROP PACKET
430
YES
DETERMINE ToS VALUE
435
SELECT SUB-QUEUE BASED ON ToS VALUE
440
LABEL PACKET WITH SEQUENCE NUMBER AND STORE IN SUB-QUEUE OF ALL INTERFACES
445

FIG. 4

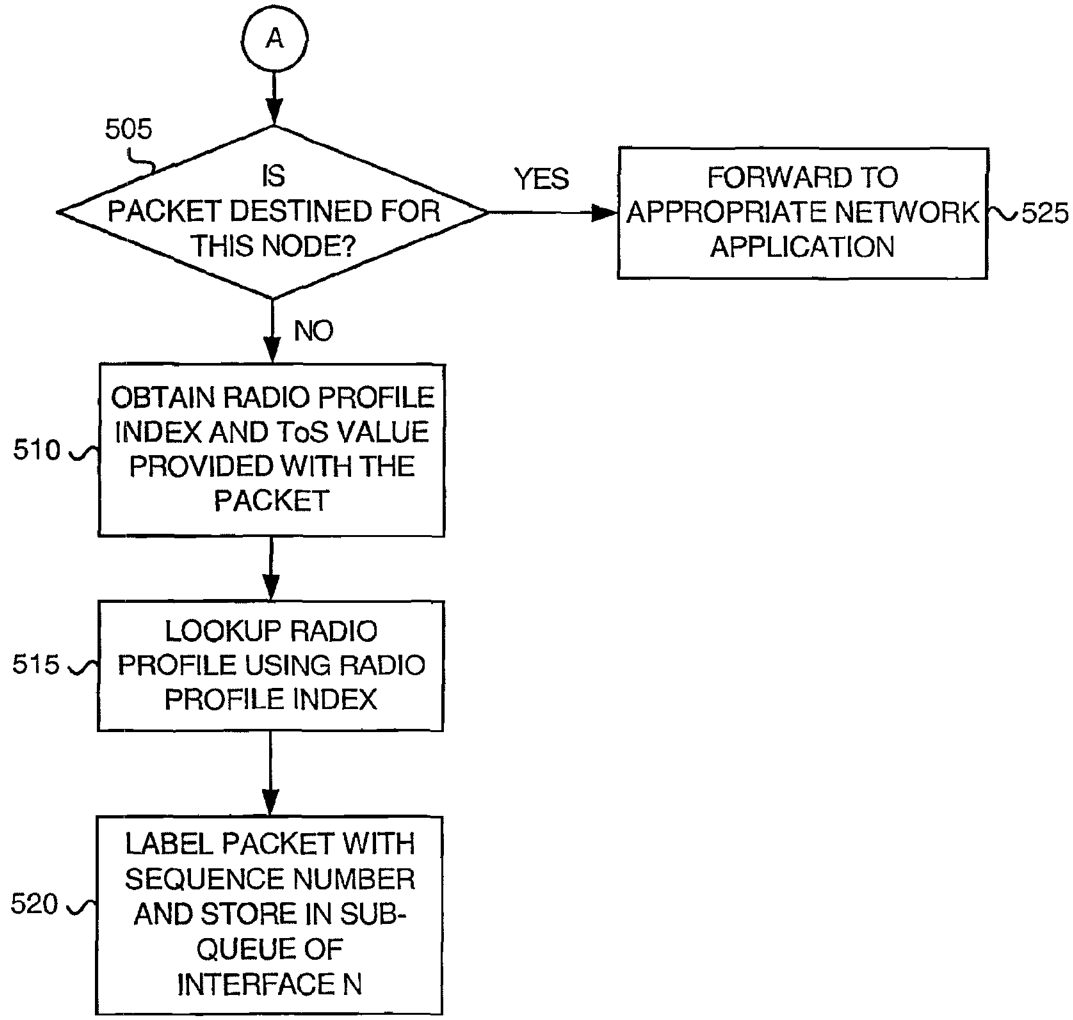

A
505
IS PACKET DESTINED FOR THIS NODE?
YES
FORWARD TO APPROPRIATE NETWORK APPLICATION
525
NO
510
OBTAIN RADIO PROFILE INDEX AND ToS VALUE PROVIDED WITH THE PACKET
515
LOOKUP RADIO PROFILE USING RADIO PROFILE INDEX
520
LABEL PACKET WITH SEQUENCE NUMBER AND STORE IN SUB-QUEUE OF INTERFACE N

FIG. 5

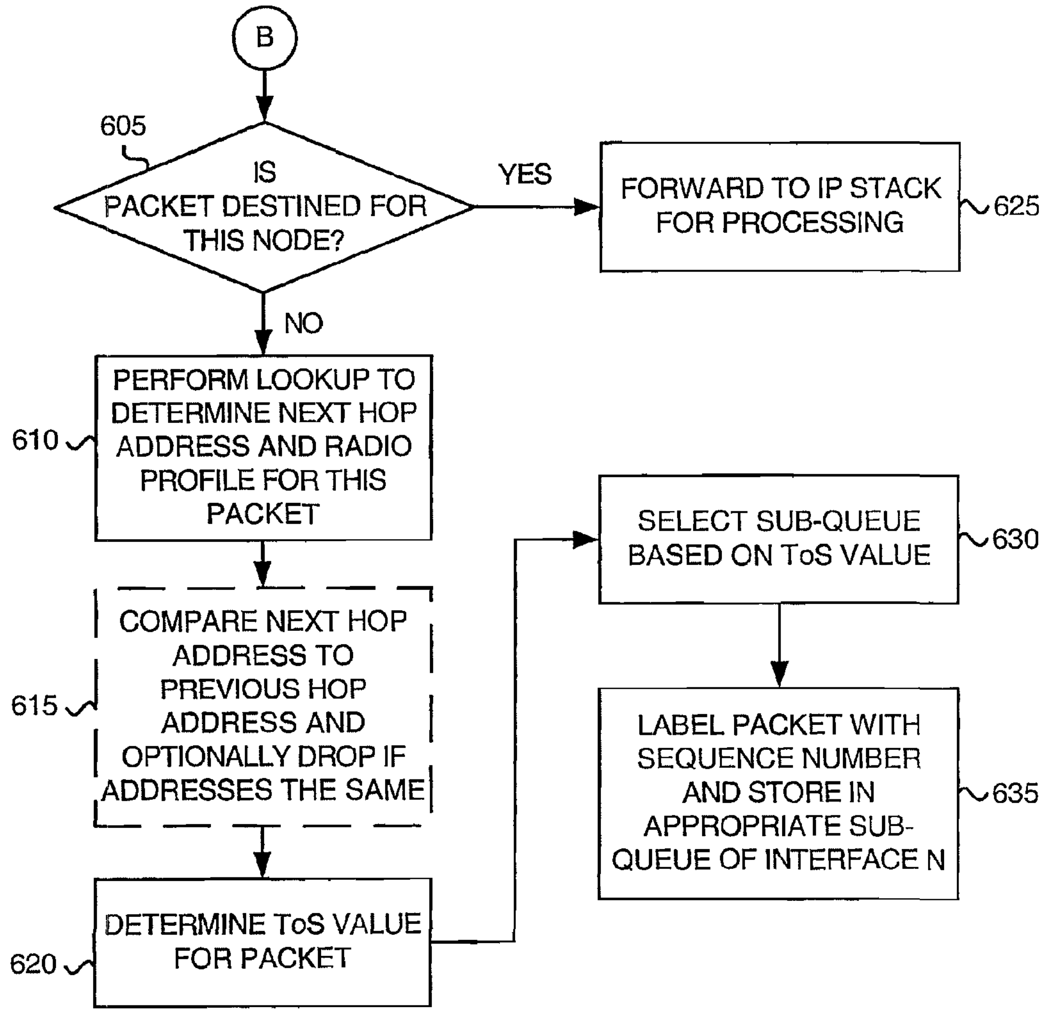

B
605
IS PACKET DESTINED FOR THIS NODE?
YES
NO
FORWARD TO IP STACK FOR PROCESSING
625
PERFORM LOOKUP TO DETERMINE NEXT HOP ADDRESS AND RADIO PROFILE FOR THIS PACKET
610
COMPARE NEXT HOP ADDRESS TO PREVIOUS HOP ADDRESS AND OPTIONALLY DROP IF ADDRESSES THE SAME
615
DETERMINE ToS VALUE FOR PACKET
620
SELECT SUB-QUEUE BASED ON ToS VALUE
630
LABEL PACKET WITH SEQUENCE NUMBER AND STORE IN APPROPRIATE SUB-QUEUE OF INTERFACE N
635

FIG. 6

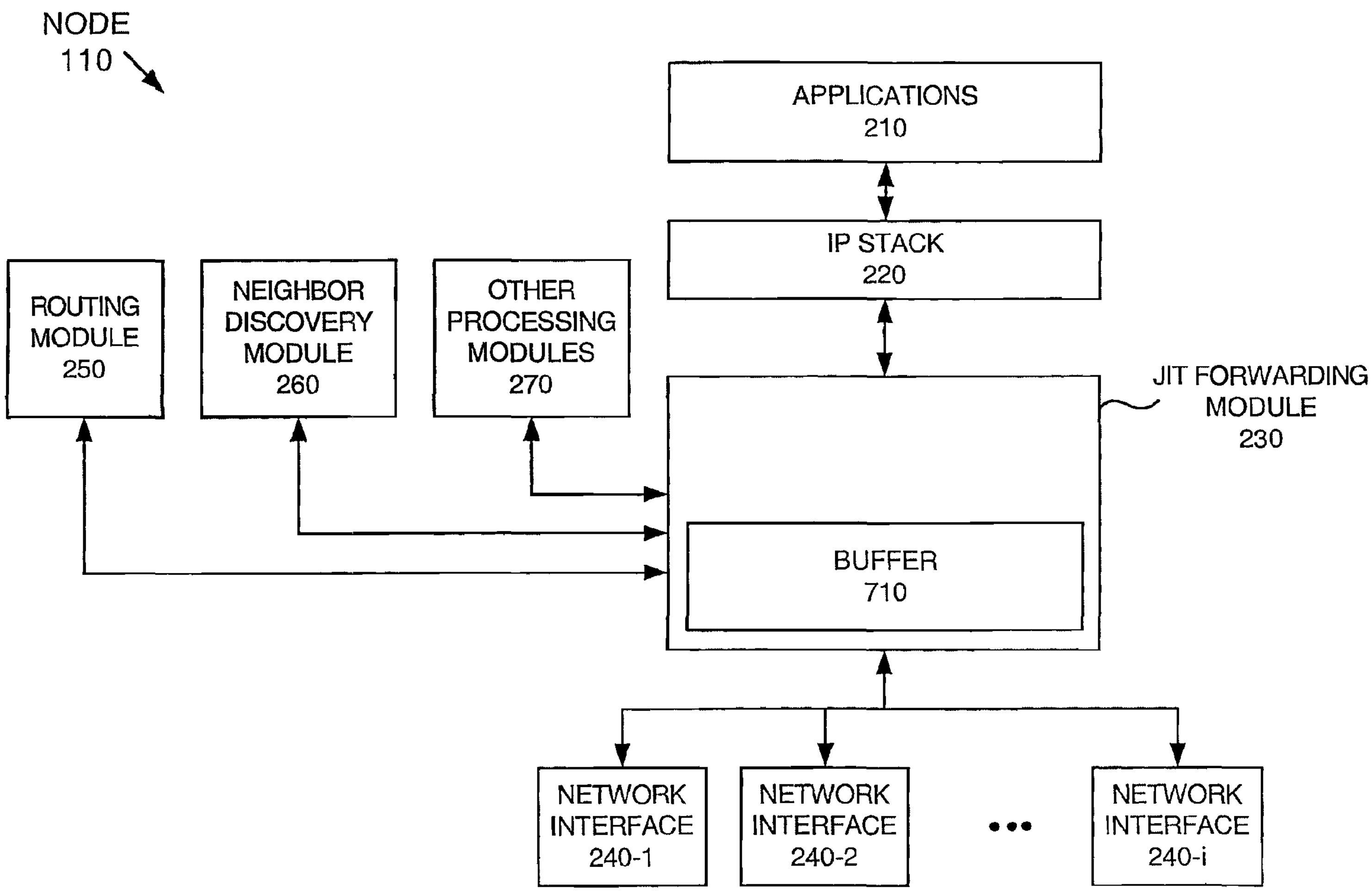
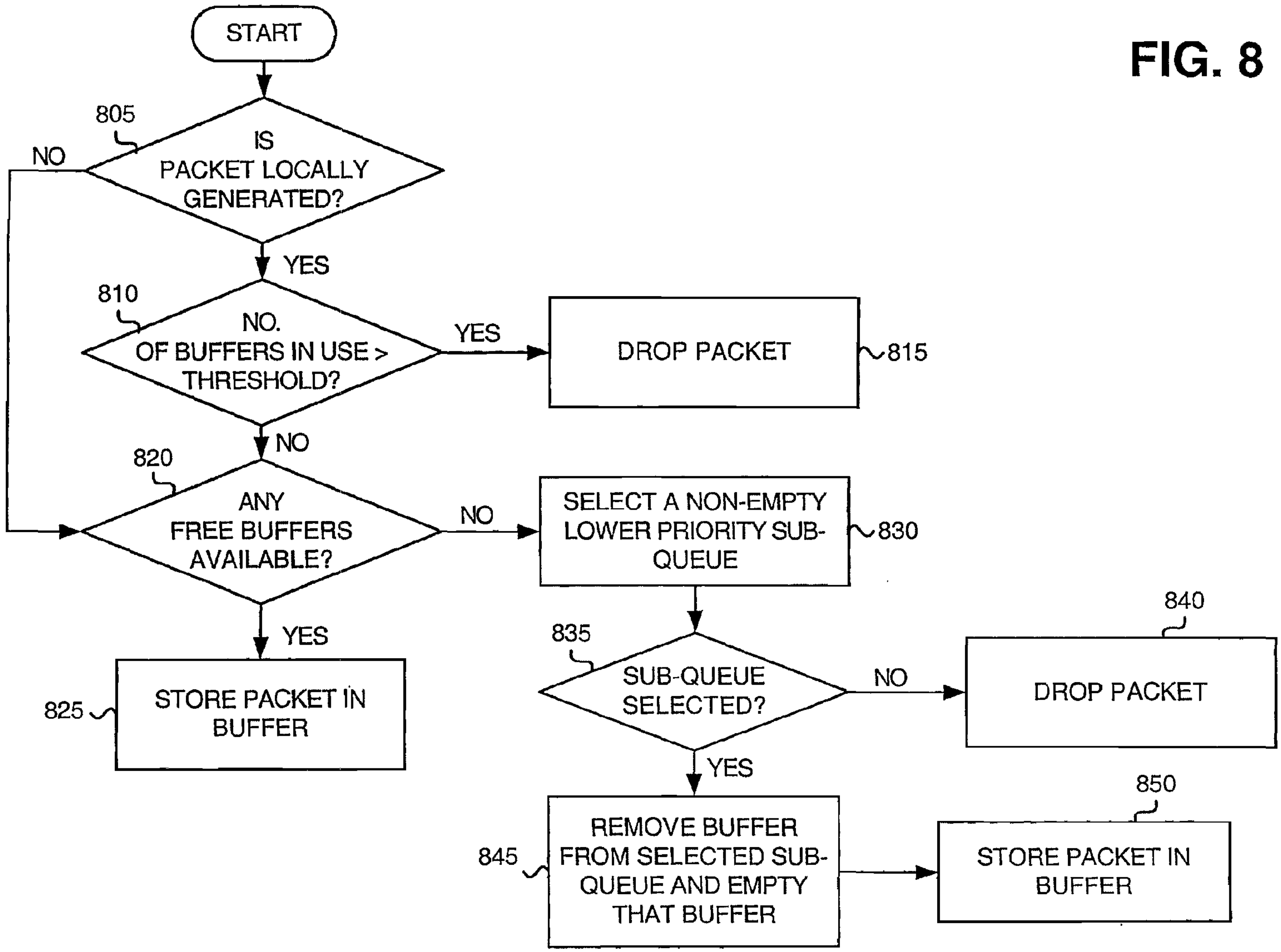

NODE
110
APPLICATIONS
210
IP STACK
220
ROUTING
MODULE
250
NEIGHBOR
DISCOVERY
MODULE
260
OTHER
PROCESSING
MODULES
270
JIT FORWARDING
MODULE
230
BUFFER
710
NETWORK
INTERFACE
240-1
NETWORK
INTERFACE
240-2
NETWORK
INTERFACE
240-i

FIG. 7

FIG. 8


START
805
IS PACKET LOCALLY GENERATED?
NO
YES
810
NO. OF BUFFERS IN USE > THRESHOLD?
YES
DROP PACKET
815
NO
820
ANY FREE BUFFERS AVAILABLE?
NO
SELECT A NON-EMPTY LOWER PRIORITY SUB-QUEUE
830
YES
825
STORE PACKET IN BUFFER
835
SUB-QUEUE SELECTED?
NO
840
DROP PACKET
YES
845
REMOVE BUFFER FROM SELECTED SUB-QUEUE AND EMPTY THAT BUFFER
850
STORE PACKET IN BUFFER

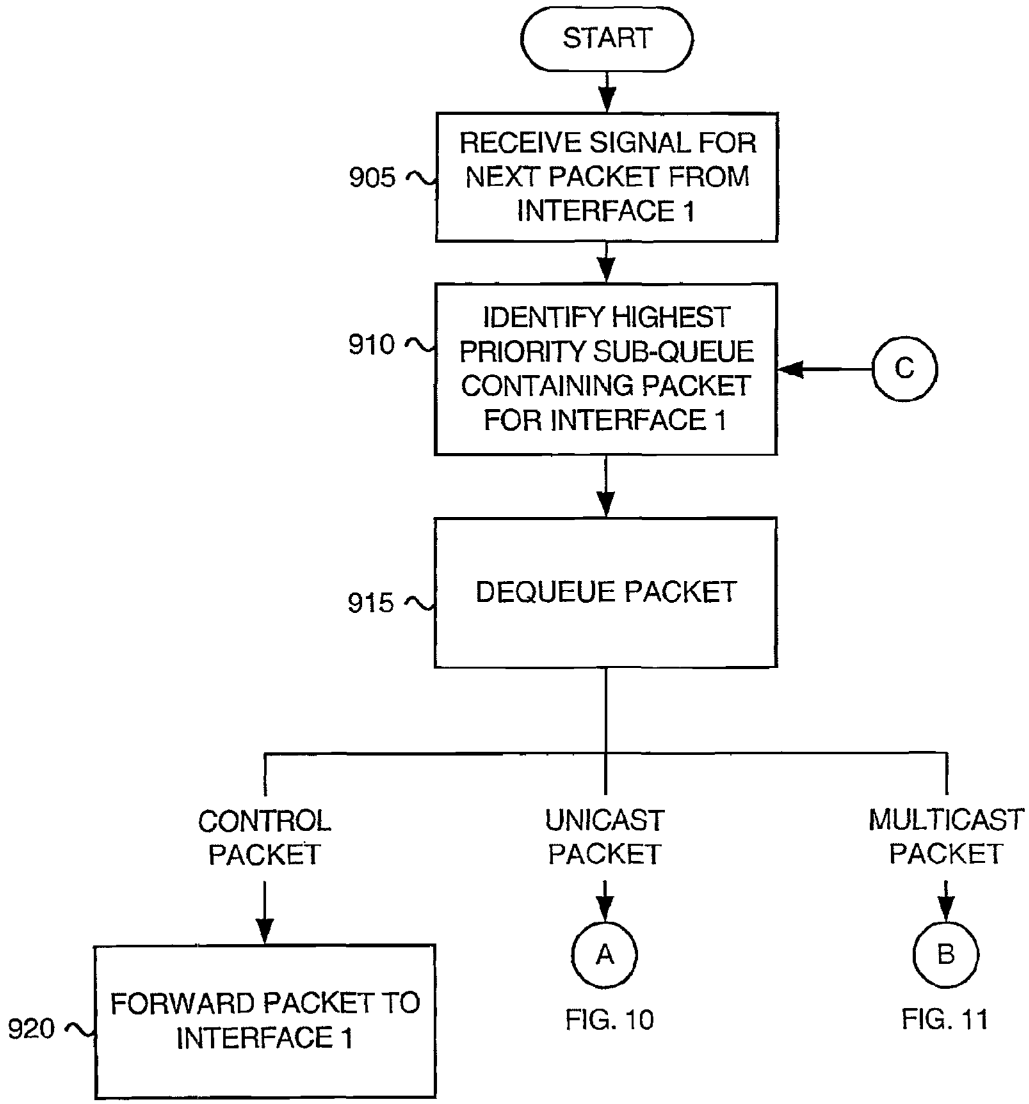

START
905
RECEIVE SIGNAL FOR NEXT PACKET FROM INTERFACE 1
910
IDENTIFY HIGHEST PRIORITY SUB-QUEUE CONTAINING PACKET FOR INTERFACE 1
C
915
DEQUEUE PACKET
CONTROL PACKET
UNICAST PACKET
MULTICAST PACKET
920
FORWARD PACKET TO INTERFACE 1
A
FIG. 10
B
FIG. 11

FIG. 9

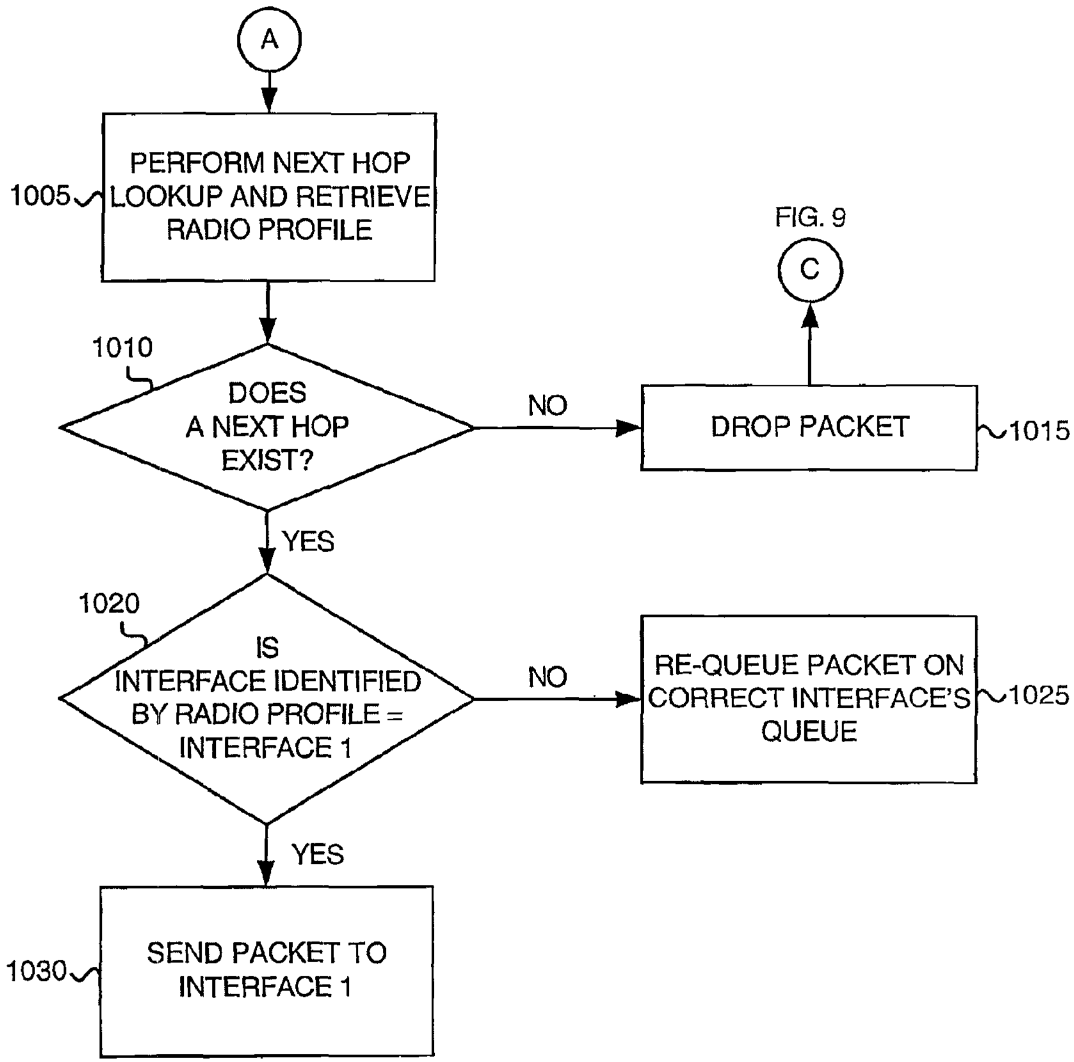

A
1005
PERFORM NEXT HOP LOOKUP AND RETRIEVE RADIO PROFILE
1010
DOES A NEXT HOP EXIST?
NO
DROP PACKET
1015
FIG. 9
C
YES
1020
IS INTERFACE IDENTIFIED BY RADIO PROFILE = INTERFACE 1
NO
RE-QUEUE PACKET ON CORRECT INTERFACE'S QUEUE
1025
YES
1030
SEND PACKET TO INTERFACE 1

FIG. 10

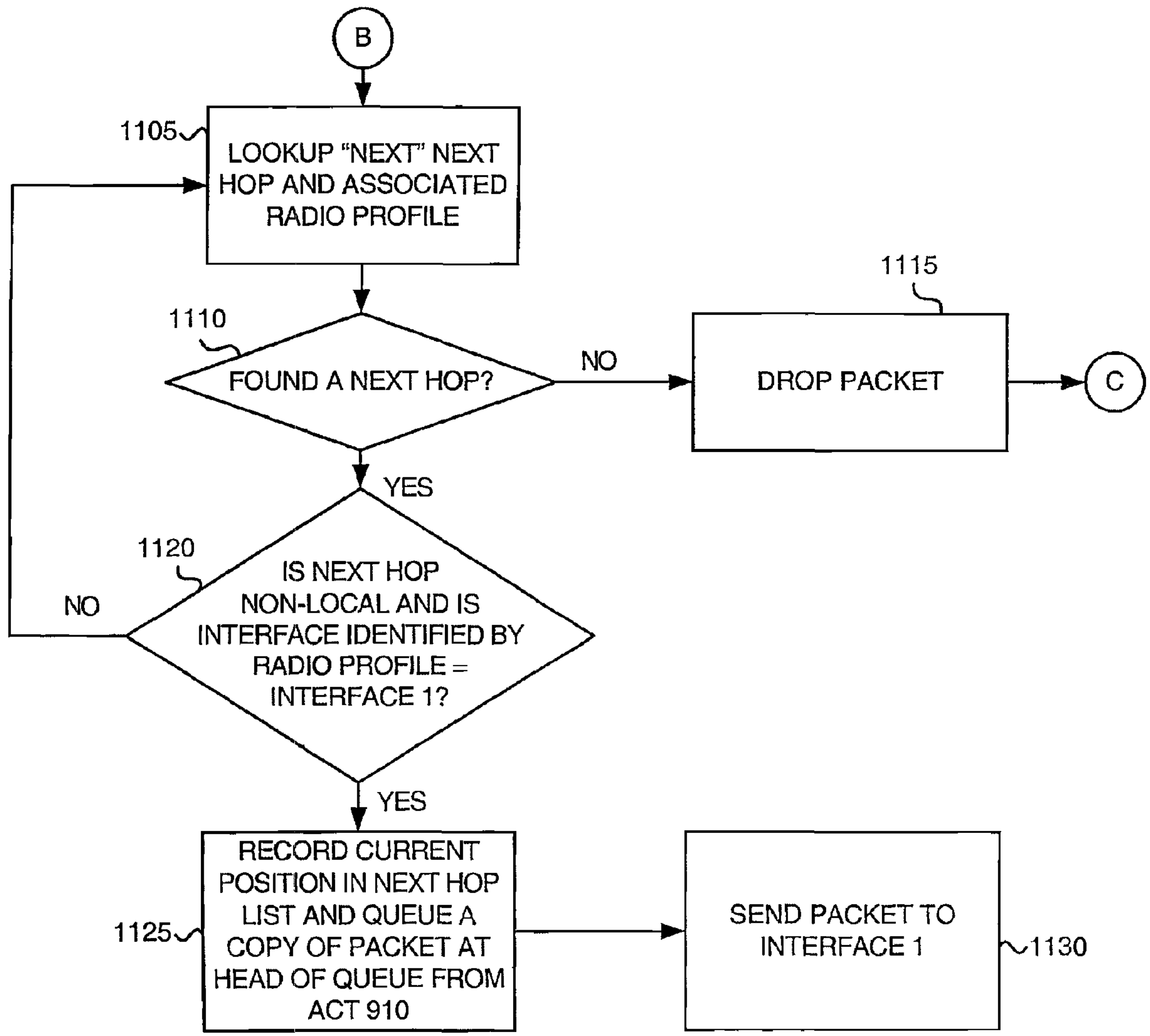

B
1105
LOOKUP "NEXT" NEXT HOP AND ASSOCIATED RADIO PROFILE
1110
FOUND A NEXT HOP?
NO
1115
DROP PACKET
C
YES
1120
IS NEXT HOP NON-LOCAL AND IS INTERFACE IDENTIFIED BY RADIO PROFILE = INTERFACE 1?
NO
YES
1125
RECORD CURRENT POSITION IN NEXT HOP LIST AND QUEUE A COPY OF PACKET AT HEAD OF QUEUE FROM ACT 910
SEND PACKET TO INTERFACE 1
1130

FIG. 11

# SYSTEMS AND METHODS FOR FORWARDING DATA UNITS IN A COMMUNICATIONS NETWORK

## CROSS-REFERENCE TO RELATED APPLICATION

This is a continuation of and claims priority to U.S. patent application Ser. No. 10/649,030, filed on Aug. 27, 2003, which is hereby incorporated herein by reference in its entirety.

## GOVERNMENT CONTRACT

The U.S. Government has a paid-up license in this invention and the right in limited circumstances to require the patent owner to license others on reasonable terms as provided for by the terms of Contract No. DAAD19-01-C-0027 awarded by the Department of the Army.

## FIELD OF THE INVENTION

The present invention relates generally to communications networks and, more particularly, to systems and methods for forwarding data units in a communications network.

## BACKGROUND OF THE INVENTION

Multi-hop networks are useful in many situations where network infrastructure either does not exist or cannot be trusted. Examples include military operations, disaster relief, and temporary offices. Multi-hop networks (also called packet radio networks, ad hoc networks, or mesh networks) typically use radio frequency (RF) transceivers to send and receive data. In a multi-hop network, nodes in the network typically include a "forwarding" module that performs the functions of:

1. Accepting packets from the lower layer radio, the upper layer Internet Protocol (IP) protocols, or the network control protocols.
2. Using the final destination(s) and type of service (ToS) bits in the packet to determine the appropriate next hop(s) in the network.
3. Determining the type of service requirements in terms of radio transmission characteristics and queuing discipline.
4. Passing the packet to the correct interface or interfaces for radio transport or dropping the packet.

In most multi-hop radio systems, this forwarding operation, which is also referred to as a switching operation, is typically faster than the radio transmission to the next-hop(s), so queues need to exist inside a node for holding packets that are waiting to be sent. In a highly mobile multi-hop network, it is not uncommon for the next-hop of a packet to change between the time the packet is initially received and processed and the time the interface is ready for transmitting it to a next-hop. In a system that has long queues between the forwarding next-hop lookup and the transmission of the packet by radio, situations can exist where packets at the head of the queue (next in line for transmission by the radio) have been designated for transmission to next-hops that are no longer reachable by the radio. This causes many re-transmissions to occur since the radio layer does not know that the next-hop is now unreachable. These re-transmissions can further delay other packets already in queue so that their next-hops may now also be unreachable by the time these packets reach the head of the queue.



Therefore, there exists a need for systems and methods that improve routing of data in mobile, multi-hop networks.

## SUMMARY OF THE INVENTION

Systems and methods consistent with the principles of the invention provide improved techniques for routing data in communications networks.

In one implementation consistent with the principles of the invention, a network device that includes one or more queues, one or more network interfaces, and a forwarding module is provided. Each queue is configured to store one or more data units. Each of the network interfaces is associated with at least one queue of the one or more queues and is configured to forward the one or more data units to other network devices. The forwarding module is configured to receive a first data unit, identify one of the network interfaces for transmitting the first data unit, and store the first data unit in a queue of the at least one queue associated with the identified network interface. The forwarding module is further configured to retrieve the first data unit from the queue associated with the identified network interface, determine one of the network interfaces for transmitting the first data unit, and forward the first data unit to the determined network interface when the determined network interface corresponds to the identified network interface.

In another implementation consistent with the principles of the invention, a method for transmitting data units from a node that includes one or more network interfaces is provided. The method includes identifying a first one of the network interfaces to transmit a data unit when the data unit is received by the node or generated by the node; determining a second one of the network interfaces to transmit the data unit when the data unit is ready to be transmitted by the node; and transmitting the data unit via the second network interface when the second network interface is the same as the first network interface.

In yet another implementation consistent with the principles of the invention, a method for storing data units in a node that includes a group of queues is provided. Each queue is associated with a priority and one or more buffers. The method includes determining whether a data unit is locally generated, where the data unit is associated with a priority; determining, when the data unit has been locally generated, whether a number of buffers in use for data units of equal or higher priority exceeds a threshold; dropping the data unit when the number of buffers in use exceeds the threshold; determining, when the data unit is not locally generated or the number of buffers in use does not exceed the threshold, if a free buffer exists; storing, when a free buffer exists, the packet in the free buffer; selecting a non-empty, lower priority queue from the plurality of queues when no free buffer exists; emptying a buffer from the selected lower priority queue; and storing the data unit in the emptied buffer.

In still another implementation consistent with the principles of the invention, a method for processing a multicast data unit in a node that includes one or more network interfaces is provided. Each of the network interfaces is associated with at least one queue. The method includes storing the multicast data unit in a memory, storing a virtual placeholder in a queue of the at least one queue associated with at least one of the one or more network interfaces, identifying, when one of the virtual placeholders reaches a head of one of the at least one queue, neighboring nodes to receive the multicast data unit, identifying, for each identified neighboring node, one network interface of the one or more network interfaces, and placing a copy of the multicast data unit at a head of a queue of the at least one queue associated with each of the identified one network interfaces.

## BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate an embodiment of the invention and, together with the description, explain the invention. In the drawings,

FIG. **1** illustrates an exemplary network in which systems and methods consistent with the principles of the invention may be implemented;

FIG. **2** illustrates an exemplary configuration of a node of FIG. **1** according to one implementation consistent with the principles of the invention;

FIG. **3** illustrates an exemplary configuration of a priority queue of FIG. **2** in an implementation consistent with the principles of the invention;

FIGS. **4-6** illustrate an exemplary process for enqueuing packets to be transmitted from the node of FIG. **2** in an implementation consistent with the principles of the invention;

FIG. **7** illustrates an exemplary alternative configuration of a node of FIG. **1** in an implementation consistent with the principles of the invention;

FIG. **8** illustrates an exemplary process for enqueuing packets to be transmitted from the node of FIG. **7** in an alternative implementation consistent with the principles of the invention; and

FIGS. **9-11** illustrate an exemplary process for dequeuing packets in an implementation consistent with the principles of the invention.

## DETAILED DESCRIPTION

The following detailed description of implementations consistent with the principles of the invention refers to the accompanying drawings. The same reference numbers in different drawings may identify the same or similar elements. Also, the following detailed description does not limit the invention. Instead, the scope of the invention is defined by the appended claims and their equivalents.

Implementations consistent with the principles of the invention may provide just-in-time forwarding decisions to ensure that data being transmitted by a node in a communications network reaches its intended destination.

While the foregoing description focuses on a multi-hop, wireless network, implementations consistent with the principles of the invention are equally applicable to wired networks, optical networks, and hybrid networks including a combination of wired, wireless, and/or optical technologies.

### Exemplary System

FIG. **1** illustrates an exemplary network **100** in which systems and methods consistent with the principles of the invention may be implemented. Network **100** may include mobile nodes **110** that may route data between network devices or networks. Seven nodes **110** have been shown for simplicity. A typical network may include more or fewer nodes than illustrated in FIG. **1**.

The network devices may include devices, such mainframes, minicomputers, personal computers, laptops, personal digital assistants, or the like, capable of transmitting data via nodes **110**. Network devices may also include routing and/or switching devices. Network devices may connect to nodes **110**, such as nodes A and F **110**, via wired, wireless, and/or optical connections.

Nodes **110** may include one or more devices for receiving and transmitting data in network **100**. A node **110** may, for example, transmit data to other nodes in the form of packets or other types of data units, such as cells. Each node **110** may also include logic that enables nodes **110** to find each other, determine paths through network **100** for data traffic from source to destination(s), and detect and repair ruptures in network **100** as nodes **110** move, as nodes fail, as battery power changes, as communication path characteristics change, etc.

FIG. **2** illustrates an exemplary configuration of a node **110** according to one implementation consistent with the principles of the invention. The configuration illustrated in FIG. **2** is provided for explanatory purposes only. Other configurations are possible. Moreover, node **110** may include other components than those illustrated in FIG. **2** that aid in receiving, processing, and/or transmitting data.

Node **110** may include a group of applications **210**, an Internet Protocol (IP) stack **220**, a just-in-time (JIT) forwarding module **230**, a group of network interfaces **240-1** through **240**-*i*, a routing module **250**, a neighbor discovery module **260**, and other processing modules **270**. Applications **210** may include a group of network applications that generates packets (or other data units) to be transmitted to network **100** and/or processes packets received from network **100**. Applications **210** allow users to interact with network **100**. Applications **210** may include telnet, file transfer protocol (ftp), e-mail, Internet Relay Chat (IRC), etc.

IP stack **220** includes the Internet Protocol. When sending packets, IP stack **220** determines how to get the packets to their destination. When receiving packets, IP stack **220** determines where the packets belong.

JIT forwarding module **230** may consult routing tables provided by routing module **250** to construct and forward packets to appropriate destinations via neighboring nodes **110** of network **100**. As illustrated in FIG. **2**, JIT forwarding module **230** may include queues **232-1** through **232**-*j* (collectively referred to hereinafter as queues **232**), where j is a positive integer greater than or equal to one. It will be appreciated that in alternative implementations consistent with the principles of the invention, another module, such as a queuing subsystem or a radio driver, acting in concert with or on behalf of (or semi-independently of) JIT forwarding module **230**, may be responsible for managing queues **232**. Moreover, in other implementations, queues **232** may be located externally to JIT forwarding module **230**.

The number of queues **232** may correspond to the number of network interfaces **240** associated with node **110**. Other mappings of groups of queues to network interfaces **240** are possible. For example, the set of queues associated with a network interface **240-1** through **240**-*i* can be arbitrarily complex (e.g., forming part of a differentiated services scheduler that supports a multiplicity of per-hop behaviors). As another example, one or more network interfaces **240** may support multiple physical or logical channels or circuits. In this situation, a different set of queues may be associated with each channel or circuit that the network interface supports.

In an alternative implementation consistent with the principles of the invention, such a network interface may be treated as if it includes a set of logical network interfaces **240**-*m* through **240**-*n* (not shown). Each logical network interface could be associated with one or more of the individual circuits, channels, or other packet classes that the (physical) network interface supports. The number of logical network interfaces associated with a single physical network interface may be fixed, or the number may vary over time, depending on the number circuits, channels, or other packet classes that presently exist.

The storage of data units (e.g., packets, cells, etc.) in queues **232** may be based on priority or something other than priority. The size of each queue **232-1** through **232**-*j* may be the same or different for network interfaces **240-1** through **240**-*i* (collectively referred to hereinafter as network interfaces **240**). In one implementation, the size of each queue **232** may be capped.

FIG. **3** illustrates an exemplary configuration of queue **232-1** in an implementation consistent with the principles of the invention. It will be appreciated that the other queues **232** may be similarly configured. As illustrated, queue **232-1** may include a group of sub-queues **310-1** through **310**-*p* (collectively referred to hereinafter as sub-queues **310**), where p is a positive integer greater than or equal to one. Each sub-queue **310** may store one or more packets for transmission via a network interface **240-1** through **240**-*i* (FIG. **2**).

In one implementation, groups of sub-queues **310** may be associated with different priorities. For example, one group of sub-queues **310** may be designated as low priority queues, a second group of sub-queues **310** may be designated as middle priority queues, and a third group of sub-queues **310** may be designated as high priority queues. Alternatively, each sub-queue **310** may be associated with a different priority level. For example, sub-queue **310-1** may be designated as a lowest priority sub-queue, sub-queue **310-2** may be designated as a higher priority sub-queue than sub-queue **310-1**, sub-queue **310-3** may be designated as a higher priority sub-queue than sub-queue **310-2**, and sub-queue **310**-*p* may be designated as a highest priority sub-queue. Other sub-queue priority designations may alternatively be used.

Returning to FIG. **2**, each network interface **240-1** through **240**-*i* may cause packets (or other data units) to be transmitted to or received from a neighboring node **110** via one or more antennas (not shown). The antennas may include, for example, a directional antenna and/or an omni-directional antenna.

Routing module **250** may manage one or more tables that are compatible with JIT forwarding module **230**. JIT forwarding module **230** may use multiple tables acquired from routing module **250** based on characteristics, such as a type-of-service (ToS) of a packet, to ultimately generate routing information, control information (e.g., a radio profile) for network interfaces **240**, and an indication of a correct queuing discipline to use with the packet. It will be appreciated that ToS is sometimes alternatively referred to as "Quality of Service" (QoS). Typically, a ToS indicator is assigned to a packet by an application to specify particular service parameters. The service parameters may include transmission power requirements, priority indicators (e.g., "urgent" or "low delay"), error ratios, resilience, transit delay, and so forth.

In one implementation consistent with the principles of the invention, routing module **250** may provide JIT forwarding module **230** with the information that it needs to determine, based on the ToS and other characteristics of a packet (which may include the type and value of a destination identifier), (1) one or more next-hop addresses that identify the next hop (i.e., neighboring node) or next hops to which a packet is to be transmitted; and (2) for each next hop, the identifier of the radio profile to be used when transmitting the packet to that next hop. JIT forwarding module **230** may use each radio profile identifier to index into a radio profile table that is designated for this particular packet. Different interfaces **240** may be associated with different radio profile structures to reflect the fact that interfaces **240** may be different types of network interfaces. JIT forwarding module **230** may forward packets to the correct network interface **240-1** through **240**-*i*, or network interfaces **240**, for transmission. Additional information regarding radio profiles and the operation of routing module **230** may be obtained from copending, commonly assigned, U.S. patent application Ser. No. 09/748,621, filed Dec. 22, 2000, and entitled "Architecture and Mechanism for Forwarding Layer Interfacing for Networks," the entire contents of which are expressly incorporated by reference herein.

Neighbor discovery module **260** may store location information for node **110** and any neighboring nodes **110** in network **100**. For example, neighbor discovery module **260** for node A **110** (FIG. **1**) may store location information for neighboring (or next hop) nodes B, D, and E **110**. Neighbor discovery module **260** may transfer next hop location data to JIT forwarding module **230**. JIT forwarding module **230** may place node **110**'s location information into messages that are to be broadcast, for example, via an omni-directional antenna or one or more directional antennas to neighboring nodes **110**.

Other processing modules **270** may include other well-known processing components that may be included in a node in a communications network, such as network **100**. Other processing modules **270** may, for example, include a location determining component, such a global positioning satellite (GPS) driver that receives position and orientation data and determines latitude, longitude, and an orientation that corresponds to the position and orientation data. The GPS driver may further, based on historical position and orientation data, determine a current heading of node **110**. Other processing modules **270** may also include a link characterization component that determines link quality and power control information related to transmitting and receiving packets to and from neighboring nodes **110** of network **100**.

## Exemplary Processing

FIGS. **4-6** illustrate an exemplary process, performed by JIT forwarding module **230**, for enqueuing packets to be transmitted from node **110** in an implementation consistent with the principles of the invention. It will be appreciated that in other implementations, some of the acts described below may be performed by another module working on behalf of or in conjunction with JIT forwarding module **230**. Processing may begin with JIT forwarding module **230** receiving a packet (act **405**, FIG. **4**). The packet may be received locally from, for example, IP stack **220**, routing module **250**, neighbor discovery module **260**, other processing modules **270**, or via an interface from a neighboring node **110**. Upon receipt of the packet, JIT forwarding module **230** may determine whether the packet is a control packet (act **410**). For example, JIT forwarding module **230** may determine that the packet is a heartbeat packet, a link state update (LSU) packet, or the like.

If the packet is a control packet, JIT forwarding module **230** may determine if the packet is destined for this particular node **110** (act **505**, FIG. **5**). JIT forwarding module **230** may make this determination by, for example, examining a destination address associated with the packet. When the destination address associated with the packet matches node **110**'s network address, then JIT forwarding module **230** may determine that the packet is destined for this node **110**. In such an event, JIT forwarding module **230** may forward the packet to the appropriate network application **210** within node **110** (act **525**).

If the packet to be processed is a control packet that is not destined for this node **110**, no next hop lookup is performed because it is assumed that all control packets are single hop only (therefore the destination address provided is either broadcast or a neighbor's address). In other implementations, control packets may be processed in a manner similar to that described below with respect to unicast and/or multicast packets. The module that forwards the control packet to JIT forwarding module **230** (e.g., module **250**, **260**, or **270**) may be responsible for explicitly specifying the radio profile index and ToS value to be used when processing this packet. Therefore, if JIT forwarding module **230** determines the control packet is destined for another node **110**, JIT forwarding module **230** may obtain the radio profile index and ToS value from the control information provided with the packet (act **510**). JIT forwarding module **230** may use the radio profile index to lookup a particular radio profile in the table associated with control packets of this particular type (act **515**). JIT forwarding module **230** may use the appropriate radio profile table provided by routing module **250**, neighbor discovery module **260**, and/or other processing modules **270**. In one implementation consistent with the principles of the invention, a unique radio profile table may be used and managed by routing table **250**, neighbor discovery module **260**, and each module within other processing modules **270**. The radio profile identifies the particular network interface **240-1** through **240-*i*** that should receive this packet. It is assumed hereinafter that network interface N **240** is to receive this control packet, where $1 \leqq N \leqq i$. The ToS value may specify, among other things, the priority to be given to this control packet. In one implementation consistent with the principles of the invention, control packets are given a "highest priority" queuing discipline, so that they are guaranteed to have absolute priority over other types of traffic.

Once the network interface lookup is performed (via the radio profile), JIT forwarding module **230** may assign a sequence number to the packet and store the packet in the appropriate sub-queue **310** that is associated with interface N **240** (act **520**). As will be described in additional detail below, the sequence number allows JIT forwarding module **230** to reorder packets within priority queues **232**. Therefore, node **110** need not transmit this sequence number to other nodes **110** once the packet has left queues **232**. In one implementation, the sequence number is a 32-bit value that is shared among all network interfaces **240**. Since the packet is a control packet, JIT forwarding module **230** may, for example, store the packet in the highest priority sub-queue p **310** within queue N **232** associated with interface N **240**.

If, in act **410** (FIG. **4**), JIT forwarding module **230** determines that the packet is not a control packet, JIT forwarding module **230** may determine if the packet is a unicast packet (act **415**). If the packet is a unicast packet, JIT forwarding module **230** may determine if the packet is destined for this node **110** (act **605**, FIG. **6**). JIT forwarding module **230** may make this determination by, for example, examining a destination address associated with the packet. When the destination address associated with the packet matches node **110**'s network address, then JIT forwarding module **230** may determine that the packet is destined for this node **110**. In such an event, JIT forwarding module **230** may forward the packet to IP stack **220** within node **110** for processing (act **625**).

If the packet is a unicast packet that is destined for another node, JIT forwarding module **230** may perform a lookup to determine the next hop address and the radio profile to use for this packet (act **610**). As set forth above, the radio profile specifies which network interface **240-1** through **240-*i*** is to be used to transmit the packet. It will be appreciated that other techniques (e.g., dedicated tables, part of the next hop table, etc.) may be used to identify the appropriate network interface **240-1** through **240-*i*** from which a packet is to be transmitted. If the next hop address lookup indicates that there is no next hop, JIT forwarding module **230** may drop the packet.

JIT forwarding module **230** may optionally compare the determined next hop address to the previous hop address (act **615**). If the two addresses are equal, this may indicate that the packet is in a loop. JIT forwarding module **230** may optionally drop the packet (act **615**). In many network topologies, loops are short-lived and dropping packets that are in a loop may result in dropping packets that may actually become routable within a very short amount of time. Therefore, in other implementations consistent with the principles of the invention, JIT forwarding module **230** may not perform act **615**. Alternatively or in conjunction with act **615**, JIT forwarding module **230** may base decisions whether to drop the packet on a time to live (TTL) value associated with the packet.

JIT forwarding module **230** may determine a ToS value for the packet (act **620**). If the packet has been generated by this particular node **110**, JIT forwarding module **230** may determine a ToS value for the packet, assigning a default ToS value if unable to determine a ToS value (e.g., for non-IP data). For IP data, JIT forwarding module **230**, or alternatively, a convergence layer or module above JIT forwarding module **230** may, for example, determine a ToS value by examining the ToS byte in the IP header. If the packet is mid-path (i.e., node **110** is an intermediate node along the path toward the packet's destination), JIT forwarding module **230** may, for example, obtain the ToS value for the packet from the ToS field in the packet's header.

JIT forwarding module **230** may select a queuing discipline for the packet based on the ToS value (act **630**). Various techniques for differentially treating packets are possible. For example, some systems may provide a set of prioritized first-in, first-out (FIFO) queues. In these situations, the queuing discipline returned can be the particular priority sub-queue **310** into which the packet is to be inserted. In one implementation, all nodes **110** may have the same, pre-configured, ToS-to-queuing discipline mapping.

JIT forwarding module **230** may assign a sequence number to the packet and store the packet in the appropriate sub-queue **310** that is associated with interface N **240** (act **635**). As indicated above, the sequence number allows JIT forwarding module **230** to reorder packets within queues **232**.

In an alternative implementation consistent with the principles of the invention, JIT forwarding module **230** may ignore the next hop address lookup operation (act **610** in FIG. **6**), and instead may place the unicast packet on a priority sub-queue **310** associated with a network interface **240-1** through **240-*i*** even if no next hop was specified. JIT forwarding module **230** may distribute such unicast packets among network interfaces **240** so that no single network interface becomes unfairly overburdened. When the unicast packet finally gets to the head of sub-queue **310** for transmission, an appropriate next hop may have become available.

If, in act **415** (FIG. **4**), JIT forwarding module **230** determines that the packet is not a unicast packet (JIT forwarding module **230** may then determine the packet to be a multicast packet), JIT forwarding module **230** may determine whether the local node needs a copy of the packet (act **417**). If the local node needs a copy of the packet, JIT forwarding module **230** may forward a copy of the packet to IP stack **220** for processing (act **418**). It will be appreciated based on the following description that acts **417** and **418** may alternatively be performed between acts **425** and **435**. If the local node does not need a copy of the packet (act **417**) or after JIT forwarding module **230** forwards a copy of the packet to IP stack **220** (act **418**), JIT forwarding module **230** may perform a lookup to determine the set of neighboring nodes **110** that are to receive the packet (act **420**). The set of neighboring nodes **110** may contain an indication of whether this particular node **110** should receive a copy of the multicast packet. If this is a transit packet and this particular node **110** is to receive a copy of the packet, JIT forwarding node **230** may forward a copy of the packet to IP stack **220** for processing.

JIT forwarding module **230** may determine whether there are any neighboring nodes **110** identified in the set of neighboring nodes **110** (act **425**). If there are no nodes **110** identified in the set, JIT forwarding module **230** may drop the packet (act **430**). As an alternative, JIT forwarding module **230** may, in response to receiving a multicast packet, enqueue a copy of the packet on a sub-queue **310** in all queues **232**, even if no neighboring nodes **110** are identified in act **425**. The rationale is that by the time one or more of these packets make it to the head of a sub-queue **310**, the next hop table might have changed such that a neighboring node **110** should be receiving a packet at this time. In this way, JIT forwarding module **230** may avoid dropping packets that this node **110** is to relay.

If the set of neighboring nodes **110** identifies one or more neighboring nodes **110** to receive the packet, JIT forwarding module **230** may determine a ToS value for the packet (act **435**). If JIT forwarding module **230** is unable to determine a ToS value because, for example, the packet contains non-IP data, JIT forwarding module **230** may assign a default value. For IP data, JIT forwarding module **230**, or alternatively, a convergence layer or module above JIT forwarding module **230** may, for example, determine a ToS value by examining the ToS byte in the IP header. As described above, a ToS value may be included in the header of packets, so it can be easily obtained during forwarding operations at intermediate nodes **110** in network **100**.

JIT forwarding module **230** may select a queuing discipline for the packet based on the ToS value (act **440**). All copies of this packet, irrespective to which neighboring node **110** this packet is to be transmitted, may be handled with the selected queuing discipline. Alternatively, the queuing discipline may be selected on a per-network-interface basis. JIT forwarding module **230** may assign a sequence number to the packet and store the packet in the appropriate sub-queue **310** for each network interface **240-1** through **240-*i***, regardless of the specific neighboring nodes **110** identified to receive the packet (act **445**). The possibility exists that, during the time when the multicast packet is enqueued and later de-queued, a neighboring node **110** may become reachable via a network interface **240-1** through **240-*i*** that was not reachable when JIT forwarding module **230** determines the set of neighboring nodes **110** to receive the packet, described in act **420** above. In this way, all reachable neighboring nodes **110** will receive a copy of the packet when the packet is later transmitted by this particular node **110**. In an alternative implementation consistent with the principles of the invention, act **445** may alternatively enqueue a copy of the packet on those network interfaces through which one of the designated neighboring nodes is presently reachable. In this case, JIT forwarding module **230** may, in act **445**, consult the radio profile associated with each neighboring node, or employ alternate means, to determine the appropriate subset of network interfaces **240** to which a copy of the packet should be enqueued.

In an alternative implementation, individual queues **232** and sub-queues **310** may be implemented in JIT forwarding module **230** in the form of one or more buffer pools (or virtual buffer pools). FIG. **7** illustrates an exemplary alternative configuration of node **110** in an implementation consistent with the principles of the invention. As illustrated, each queue **232-1** through **232-*j*** may be served by a buffer pool within buffer pools **710** that is distinct from the pool used by queues **232** associated with other network interfaces **240**. Buffer pools **710** may include a set of one or more buffer pools, each of which could be an actual pool of buffers or, alternatively, a virtual pool allocated from a centrally-managed pool. In this implementation, a pool of a finite size within buffer pools **710** may be assigned for each network interface **240-1** through **240-*i***. In this way, different buffers for a particular buffer pool assigned to a network interface **240-1** through **240-*i*** may act as different sub-queues **310** for that interface **240-1** through **240-*i***. The size B of each buffer pool may be configurable on a per network interface **240-1** through **240-*i*** basis. In one implementation consistent with the principles of the invention, each buffer within a buffer pool may store a single packet of a maximum size appropriate for network **100** (e.g., 1500 bytes for an Ethernet environment).

FIG. **8** illustrates an exemplary process, performed by JIT forwarding module **230**, for enqueuing packets to be transmitted from node **110** in this alternative implementation consistent with the principles of the invention. It will be appreciated that in other implementations, some of the acts described below may be performed by another module working on behalf of or in conjunction with JIT forwarding module **230**. Processing may begin with JIT forwarding module **230** receiving a packet to queue for network interface N **240**. In response, JIT forwarding module **230** may determine whether the packet has been locally generated (act **805**). JIT forwarding module **230** may determine, for example, that a packet has been locally generated if, for example, it was supplied by IP stack **220** or by a control application **210** running on node **110**.

If the packet has been locally generated, JIT forwarding module **230** may determine if the number of already enqueued packets at equal or higher priorities (or number of buffers in the virtual buffer pool for interface N from buffer **710** at equal or higher priority) exceeds a configurable local threshold W (act **810**). In one implementation consistent with the principles of the invention, the threshold W may be configurable on a per-network interface **240-1** through **240-*i*** basis so as to prevent locally generated floods from pushing out mid-path packets that have already been the recipient of investment of time and energy by network **100**. If the packet is locally generated and the number of buffers in use for network interface N **240** exceeds threshold W, JIT forwarding module **230** may drop the packet (act **815**). In an alternative implementation consistent with the principles of the invention, transit and locally-originated packets may be treated equally, in which case acts **805** and **810** may be bypassed.

If the packet has not been locally generated or the number of buffers in use for network interface N **240** at equal or higher priority does not exceed threshold W, JIT forwarding module **230** may determine if any free buffers for interface N **240** are available (act **820**). If a free buffer exists, JIT forwarding module **230** may store the packet in the available buffer (act **825**).

If no free buffers for interface N **240** are available, JIT forwarding module **230** may steal a buffer from a lower priority sub-queue **310** for network interface N **240**. JIT forwarding module **230** may examine sub-queues **310** starting with the lowest configured priority and ending with the priority one less than that of the current packet. JIT forwarding module **230** may select the first of those lower-priority sub-queues **310** that contains at least one buffer (act **830**). If JIT forwarding module **230** is unable to select a sub-queue **310** (act **835**), JIT forwarding module **230** may drop the packet (act **840**). If, on the other hand, JIT forwarding module **230** is able to select a sub-queue **310** (act **835**), JIT forwarding module **230** may remove a buffer from that sub-queue and drop the packet that was occupying that buffer (act **845**). Then, JIT forwarding module **230** may store the current packet in that buffer (act **850**).

When choosing a buffer to remove from the selected lower-priority sub-queue **310**, JIT forwarding module **230** may remove the buffer from the tail of the sub-queue. Alternatively, JIT forwarding module **230** may, for example, remove a buffer from the head of the sub-queue or may perform random early drop (RED) in which a random packet is dropped. JIT forwarding module **230** may record statistics about any buffer shortages.

FIGS. **9-11** illustrate an exemplary process for dequeuing packets, performed by JIT forwarding module **230**, in an implementation consistent with the principles of the invention. It will be appreciated that in other implementations, some of the acts described below may be performed by another module working on behalf of or in conjunction with JIT forwarding module **230**. Processing may begin with JIT forwarding module **230** receiving a signal from a network interface **240-1** through **240-*i***, such as network interface **240-1**, indicating that network interface **240-1** is ready to transmit the next packet (act **905**, FIG. **9**). In response, JIT forwarding module **230** may identify the highest priority sub-queue **310** within queue **232-1** containing a packet for network interface **240-1** (act **910**). JIT forwarding module **230** may dequeue the packet at the head of the highest priority sub-queue **310** (act **915**).

If no sub-queue **310** presently contains a packet for network interface **240-1**, in one implementation consistent with the principles of the invention, JIT forwarding module **230** may record the fact that network interface **240-1** is ready to accept the next packet for transmission. Then, when a packet is later enqueued on any sub-queue **310** associated with network interface **240-1**, JIT forwarding module **230** may continue with act **910** (FIG. **9**).

If the packet is control traffic, or user data traffic targeted directly at a particular network interface (rather than at the forwarding layer), JIT forwarding module **230** may forward the packet to network interface **240-1** after adding/manipulating headers as appropriate (act **920**). It will be appreciated that the radio profile index and the ToS bits may be held along with the packet while the packet is stored in sub-queue **310**.

If the packet is a unicast packet, JIT forwarding module **230** may perform another next hop lookup on the packet and retrieve the radio profile for this packet (act **1005**, FIG. **10**). JIT forwarding module **230** may determine if a next hop exists (act **1010**). If the lookup operation specifies "no next-hop," JIT forwarding module **230** may drop the packet and processing may return to act **910** (FIG. **9**) with JIT forwarding module **230** identifying the highest priority sub-queue **310** containing a packet for network interface **240-1**. In this situation, the final destination may have become unreachable in the time that the packet was waiting in sub-queue **310**.

Optionally, JIT forwarding module **230** may determine whether the packet is in a loop. To do so, JIT forwarding module **230** may compare the newly evaluated next hop address to the previous hop address. JIT forwarding module **230** may drop the packet if it is determined to be in a loop. Alternatively or in conjunction with the above, JIT forwarding module **230** may make drop decisions based on a TTL value associated with the packet.

JIT forwarding module **230** may determine if the network interface identified in the radio profile retrieved in act **1005** matches network interface **240-1** (the network interface requesting a packet in act **905**) (act **1020**). It will be appreciated that as an alternative or in addition to the above, JIT forwarding module **230** may use other techniques for identifying the network interface. If the network interface is not the correct network interface (e.g., the network interface identified in the radio profile does not match network interface **240-1** that requested a packet in act **905**), JIT forwarding module **230** may requeue the packet on the correct sub-queue **310** in network interface **240**'s queue **232** (act **1025**). JIT forwarding module **230** may enqueue the packet at the correct location in new priority queue **232** using the sequence number associated with the packet. That is, when enqueueing, JIT forwarding module **230** may search through new queue **232** for the correct position (e.g., the correct sub-queue **310** and the correct location within the sub-queue). When FIFO queues are used, JIT forwarding module **230** may scan the appropriate sub-queue **310** within new queue **232** for an insertion point where sequence numbers ahead of the requeued packet will be smaller, and sequence numbers behind the requeued packet will be larger. Placement of the packet within the new sub-queue **310** may also take into consideration sequence number rollover. As an alternative to requeuing a single packet, JIT forwarding module **230** may perform next hop address lookup operations on the first M packets (where M may be a configurable value) in sub-queue **310** (or the entire sub-queue **310**), so that a number of packets could potentially be requeued at the same time.

If the network interface identified in the radio profile matches network interface **240-1** that requested a packet in act **905**, JIT forwarding module **230** may forward the packet to network interface **240-1** (act **1030**). Since the next hop node **110** for this packet may have changed between the original enqueue and this dequeue operation, JIT forwarding module **230** may pass the newest next hop address and radio profile to network interface **240-1** and not the original next hop address and radio profile that were determined when the packet was enqueued.

If the packet is a multicast packet, JIT forwarding module **230** walks through the list (or set) of next hops, as designated in the forwarding tables for the multicast packet, until either the end of the list is reached or a neighboring node has been found whose associated network interface matches the network interface (i.e., network interface **240-1**) requesting a packet. It should be appreciated that the list of next hops for this multicast packet, and the radio profile associated with each of these next hops, may change at any time.

This iterative process will now be described in further detail. JIT forwarding module **230** looks up the next hop and associated radio profile for this multicast packet (act **1105**, FIG. **11**). If JIT forwarding module **230** reaches the end of the list of next hops (act **1110**), JIT forwarding module **230** may drop the packet (act **1115**) and processing may return to act **910** (FIG. **9**) with JIT forwarding module identifying the highest priority sub-queue **310** containing a packet for network interface **240-1**.

If a next hop is found in the next hop list (act **1110**), JIT forwarding **230** may determine if the next hop is non-local (act **1120**), since if the local node needs a copy of this packet, it has already been supplied in act **418** (FIG. **4**). JIT forwarding **230** may also determine if the next hop is associated with the network interface (i.e., network interface **240-1**) requesting service (act **1120**). It may be appreciated that the next hop list for this packet may contain next hops associated with network interfaces other than **240-1**. To determine if the next hop is associated with network interface **240-1**, JIT forwarding module **230** may determine if the network interface identified in the radio profile associated with this next hop (as identified in act **1105**) matches network interface **240-1**. JIT forwarding module **230** may use alternative or additional means to determine if the next hop is associated with the desired network interface **240-1**.

If, in act **1120**, JIT forwarding module **230** determines that the necessary criteria have not been met, processing may return to act **1105**. If, one the other hand, a suitable next hop is found (act **1120**), JIT forwarding module **230** may make a copy of the multicast packet and queue that copy on the head (i.e., front) of the appropriate sub-queue **310** (i.e., the sub-queue selected in act **910**) for network interface **240-1** (act **1125**). JIT forwarding **230** may also record the current position in the next hop list (act **1125**), so that JIT forwarding module **230** may continue on from that point the next time network interface **240-1** requests a packet and JIT forwarding module **230** selects the current packet (e.g., as in FIG. **9**, acts **910** and **915**) for processing.

JIT forwarding module **230** may forward the multicast packet to network interface **240-1** (act **1130**). In an alternative implementation, JIT forwarding module **230** may, after making a copy of the multicast packet in act **1125**, instead save the multicast packet, and send the copy in act **1130**.

In some situations, it may be important to limit the total number of copies of a multicast packet that are sent, even at the expense of missing neighboring nodes that may be added to the forwarding tables during the time that a multicast packet is being processed. As a modification to the above processing, JIT forwarding module **230** may, at the time that a multicast packet reaches the head of a sub-queue **310** for the first time and was dequeued, record all of the neighboring nodes currently associated with that multicast packet, and then only consider those original neighboring nodes as eligible next hops when the associated network interface **240** requests additional packets.

In other situations, it may be important to increase the likelihood that all of the neighboring nodes that the forwarding tables indicate should receive a copy of a multicast packet are, in fact, sent a copy. If the association between next hops and network interfaces **240** is changing rapidly, and one of the network interfaces, e.g. **240**-*i*, is significantly faster than another, e.g. **240**-*j*, it is possible to lose multicast packets that might otherwise be deliverable. This could occur when a copy of a multicast packet on network interface **240**-*i*'s highest priority sub-queue **310** arrives at the head of the sub-queue **310**, but all the lookup operations specify transmission on network interface **240**-*j*. Some time later a copy of the same multicast packet may arrive at the head of network interface **240**-*j*'s highest priority sub-queue **310**, but the forwarding tables may have changed and all lookup operations now specify network interface **240**-*i*. One way of averting this situation would be a "scorecard" approach, where JIT forwarding module **230** records which of the next hops for a multicast packet have already been sent a copy. The scorecard could be used to ensure that JIT forwarding module **230** requeues a copy of the multicast packet for the current network interface (e.g., **240**-*i*) associated with any given next hop (in a manner similar to FIG. **10**, acts **1020** and **1025**), until that next hop is sent exactly one copy of the packet. At some point, a lookup operation might indicate that a given next hop is no longer reachable via any of the network interfaces **240**, in which case JIT forwarding module **230** might cease attempting to send the packet to that next hop. It may be appreciated that the "scorecard" approach, in addition to increasing the likelihood that all designated next hops will receive a copy of a multicast packet, also reduces the likelihood that a neighboring node will receive extra copies of the packet.

In an alternative implementation consistent with the principles of the invention, node **110** may include a separate queue or memory for storing multicast packets. In this situation, JIT forwarding module **230** may store a virtual placeholder for each multicast packet in a sub-queue **310** of one or all of queues **232**. When the first of the one or more virtual placeholders for a multicast packet gets to the head of a sub-queue **310** and is dequeued, JIT forwarding module **230** may retrieve the multicast packet from the separate queue or memory, identify all next hops that need to receive a copy of the multicast packet, and identify all network interfaces **240** that are associated with at least one of the identified next hops. JIT forwarding module **230** may then place at least one copy of the multicast packet at the head of a sub-queue **310** of at least one queue **232** associated with each of the identified network interfaces **240**. When any remaining virtual placeholder for the same multicast packet later reaches the head of a sub-queue **310** and is dequeued, JIT forwarding module **230** may ignore that virtual placeholder, since copies of the multicast packet have already been enqueued and dequeued, wherever needed. An advantage of this alternative implementation is that all multicast neighbors for all network interfaces **240** are determined at the same time.

## CONCLUSION

Implementations consistent with the principles of the invention provide just-in-time forwarding decisions to ensure that data being transmitted by a node in a communications network reaches its intended destination.

The foregoing description of exemplary embodiments of the present invention provides illustration and description, but is not intended to be exhaustive or to limit the invention to the precise form disclosed. Modifications and variations are possible in light of the above teachings or may be acquired from practice of the invention. For example, while series of acts have been described with regard to FIGS. **4-6** and **8-11**, the order of the acts may be varied in other implementations consistent with the present invention. Moreover, non-dependent acts may be implemented in parallel.

No element, act, or instruction used in the description of the present application should be construed as critical or essential to the invention unless explicitly described as such. Also, as used herein, the article "a" is intended to include one or more items. Where only one item is intended, the term "one" or similar language is used.

The scope of the invention is defined by the claims and their equivalents.

What is claimed is:

**1**. A method for transmitting data units from a node in a communications network, the method comprising:

placing a data unit in a first transmission queue associated with a network interface of the node based at least in part on initial forwarding information that specifies information related to transmitting the data unit from the node to a second node in the communication network, wherein the second node is distinct from and physically separated from the node;

determining, at the node, that the data unit has reached a head of the first transmission queue;

upon the data unit reaching the head of the first transmission queue, altering, at the node, the initial forwarding information based at least in part on updated routing information; and transmitting the data unit from the node using the altered forwarding information.

2. The method of claim **1**, wherein altering the forwarding information comprises changing a next hop node for reaching a ~destination node.

3. The method of claim **2**, comprising determining an initial next hop node for inclusion in the initial forwarding information prior to placing the data unit in the first transmission queue.

4. The method of claim **1**, comprising moving the data unit to the head of a second transmission queue associated with a second network interface of the node based on the altered forwarding information.

5. The method of claim **1**, wherein altering the forwarding information comprises obtaining a different radio profile for use in transmitting the data unit.

6. The method of claim **1**, comprising:

upon the data unit reaching the head of the first transmission queue:

resolving a multicast address associated with the data unit to determine a plurality of multicast recipients,

identifying a network interface for forwarding the data unit to each of the plurality of recipients of the data unit, and

placing a copy of the data unit at a head of a queue associated with each identified network interface.

7. The method of claim **6**, wherein altering the forwarding information comprises, for each copy of the data unit, updating a next hop address to reflect the corresponding next hop node for the respective multicast recipients.

8. The method of claim **6**, wherein the node comprises a plurality of network interfaces, the method comprising, prior to the data unit reaching the head of the first transmission queue, placing the data unit in a second transmission queue associated with a second network interface.

9. The method of claim **8**, comprising, prior to placing the data unit in the first transmission queue or the second transmission queue, resolving a multicast address associated with the data unit to determine a plurality of multicast recipients, and determining which network interfaces are to be used to forward the data unit to each multicast recipient.

10. The method of claim **1**, wherein placing a data unit in a first transmission queue comprises storing a copy of the data unit in the first transmission queue.

11. The method of claim **1**, wherein placing a data unit in a first transmission queue comprises storing the data unit in a memory and storing a placeholder in the first transmission queue.

12. The method of claim **1**, wherein the network interface transmits the data unit over an ad hoc network.

13. A network device for transmitting data units from a node in a communications network, the network device comprising:

a first transmission queue for storing a data unit;

a network interface associated with the first transmission queue and configured to forward the data unit to other network devices; and

a forwarding module configured to: place the data unit in the first transmission queue of the network interface based at least in part on initial forwarding information that specifies information related to transmitting the data unit from the node to a second node in the communication network, wherein the second node is distinct from and physically separated from the node;

determine, at the network device, that the data unit has reached a head of the first transmission queue;

alter, at the network device, the initial forwarding information based at least in part on updated routing information, in response to determining that the data unit has reached the head of the first transmission queue; and

transmit the data unit from the network device using the altered forwarding information.

14. The network device of claim **13** wherein, when altering the forwarding information, the forwarding module is further configured to change a next hop node for reaching a destination node.

15. The network device of claim **14**, wherein the forwarding module is further configured to determine an initial next hop node for inclusion in the initial forwarding information prior to placing the data unit in the first transmission queue.

16. The network device of claim **13**, wherein the forwarding module is further configured to move the data unit to the head of a second transmission queue associated with a second network interface of the node based on the altered forwarding information.

17. The network device of claim **13** wherein, when altering the forwarding information, the forwarding module is further configured to obtain a different radio profile for use in transmitting the data unit.

18. The network device of claim **13**, wherein the forwarding unit, upon determining that the data unit has reached the head of the first transmission queue, is further configured to: resolve a multicast address associated with the data unit to determine a plurality of multicast recipients,

identify a network interface for forwarding the data unit to each of a plurality of multicast recipients of the data unit, and place a copy of the data unit at a head of a queue associated with each identified network interface.

19. The network device of claim **18**, wherein, when altering the forwarding information, the forwarding module is configured to, for each copy of the data unit, update a next hop address to reflect the corresponding next hop node for the respective multicast recipients.

20. The network device of claim **18**, wherein the forwarding module is configured to place the data unit in a second transmission queue associated with a second network interface, prior to the data unit reaching the head of the first transmission queue, and

wherein, prior to placing the data unit in the first transmission queue or the second transmission queue, the forwarding module is further configured to:

resolve a multicast address associated with the data unit to determine a plurality of multicast recipients, and

determine which network interfaces are to be used to forward the data unit to each multicast recipient.

21. The network device of claim **13**, wherein the network interface is configured to transmit the data unit over an ad hoc network.

22. A non-transitory computer-readable medium containing instructions that, when executed by at least one processor of a node, causes the at least one processor to perform a method for transmitting data units from a node in a communications network, the method comprising:

placing a data unit in a first transmission queue associated with a network interface of the node based at least in part on initial forwarding information that specifies information related to transmitting the data unit from the node to a second node in the communication network, wherein the second node is distinct from and physically separated from the node;

determining, at the node, that the data unit has reached a head of the first transmission queue;

upon the data unit reaching the head of the first transmission queue, altering, at the node, the initial forwarding information based at least in part on updated routing information; and

transmitting the data unit from the node using the altered forwarding information.

**23**. The non-transitory computer-readable medium of claim **22**, wherein altering the forwarding information comprises changing a next hop node for reaching a destination node.

**24**. The non-transitory computer-readable medium of claim **23**, wherein the method further comprises: determining an initial next hop node for inclusion in the initial forwarding information prior to placing the data unit in the first transmission queue.

**25**. The non-transitory computer-readable medium of claim **22**, wherein the method further comprises: moving the data unit to the head of a second transmission queue associated with a second network interface of the node based on the altered forwarding information.

**26**. The non-transitory computer-readable medium of claim **22**, wherein altering the forwarding information comprises obtaining a different radio profile for use in transmitting the data unit.

**27**. The non-transitory computer-readable medium of claim **22**, wherein the method further comprises:

upon the data unit reaching the head of the first transmission queue: resolving a multicast address associated with the data unit to determine a plurality of multicast recipients,

identifying a network interface for forwarding the data unit to each of the plurality of recipients of the data unit, and

placing a copy of the data unit at a head of a queue associated with each identified network interface.

**28**. The non-transitory computer-readable medium of claim **27**, wherein altering the forwarding information comprises, for each copy of the data unit, updating a next hop address to reflect the corresponding next hop node for the respective multicast recipients.

**29**. The non-transitory computer-readable medium of claim **27**, wherein the node comprises a plurality of network interfaces, the method comprising:

prior to the data unit reaching the head of the first transmission queue, placing the data unit in a second transmission queue associated with a second network interface; and

prior to placing the data unit in the first transmission queue or the second transmission queue, resolving a multicast address associated with the data unit to determine a plurality of multicast recipients, and determining which network interfaces are to be used to forward the data unit to each multicast recipient.

**30**. The non-transitory computer-readable medium of claim **22**, wherein the network interface transmits the data unit over an ad hoc network.

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