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(54) **RELIABLE NEIGHBOR NODE DISCOVERY**

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(Continued)

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Reissue of:

(Continued)

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Filed: **Mar. 8, 2010**

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U.S. Applications:

(62) Division of application No. 11/402,826, filed on Apr.  
13, 2006, now Pat. No. 7,706,340.

(57) **ABSTRACT**

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**H04H 20/16** (2008.01)

(52) **U.S. Cl.**  
USPC ..... **370/338; 370/232; 370/255; 370/445;**  
**370/449**

Methods and systems for reliable neighbor discovery in wireless ad hoc networks are provided herein. In one aspect, embodiments of the present invention provide methods and systems for analyzing the quality of a communication link. In embodiments, several factors affecting link quality may be incorporated in the analysis, and basic and/or complex statistical and/or probabilistic analysis may be used. In another aspect, embodiments of the present invention provide methods and systems for neighbor node discovery that adapt to network and/or node operating conditions and that dynamically maintain a neighbor node set at a given node according to these conditions. In a further aspect, embodiments of the present invention extend the utility of neighbor node discovery beyond the customary role of data routing support into the problem of deploying an ad hoc network by providing a display module for displaying node connectivity information.

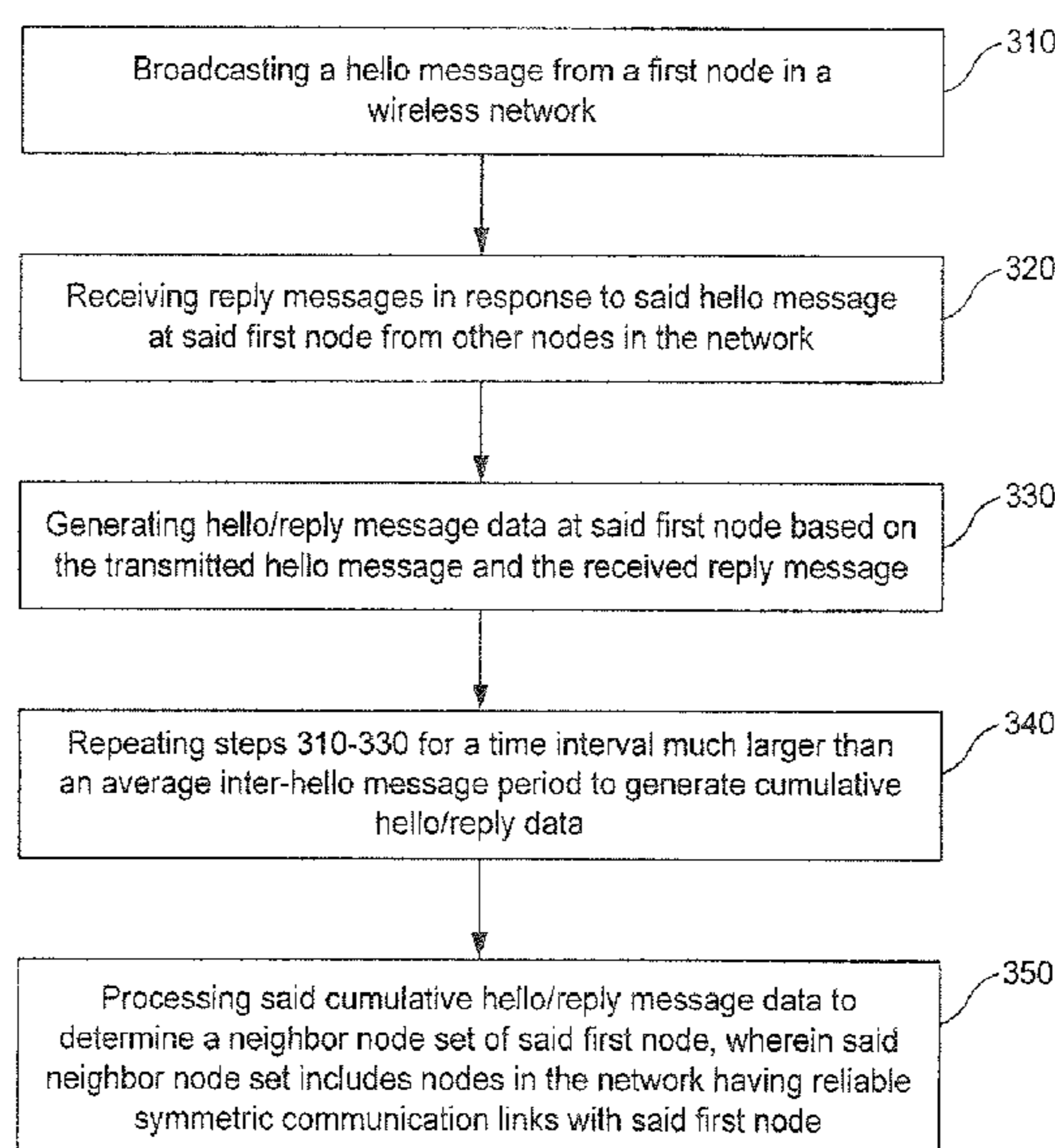
(58) **Field of Classification Search**  
CPC ..... **H04L 12/28; H04L 41/12**  
See application file for complete search history.

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**24 Claims, 5 Drawing Sheets**



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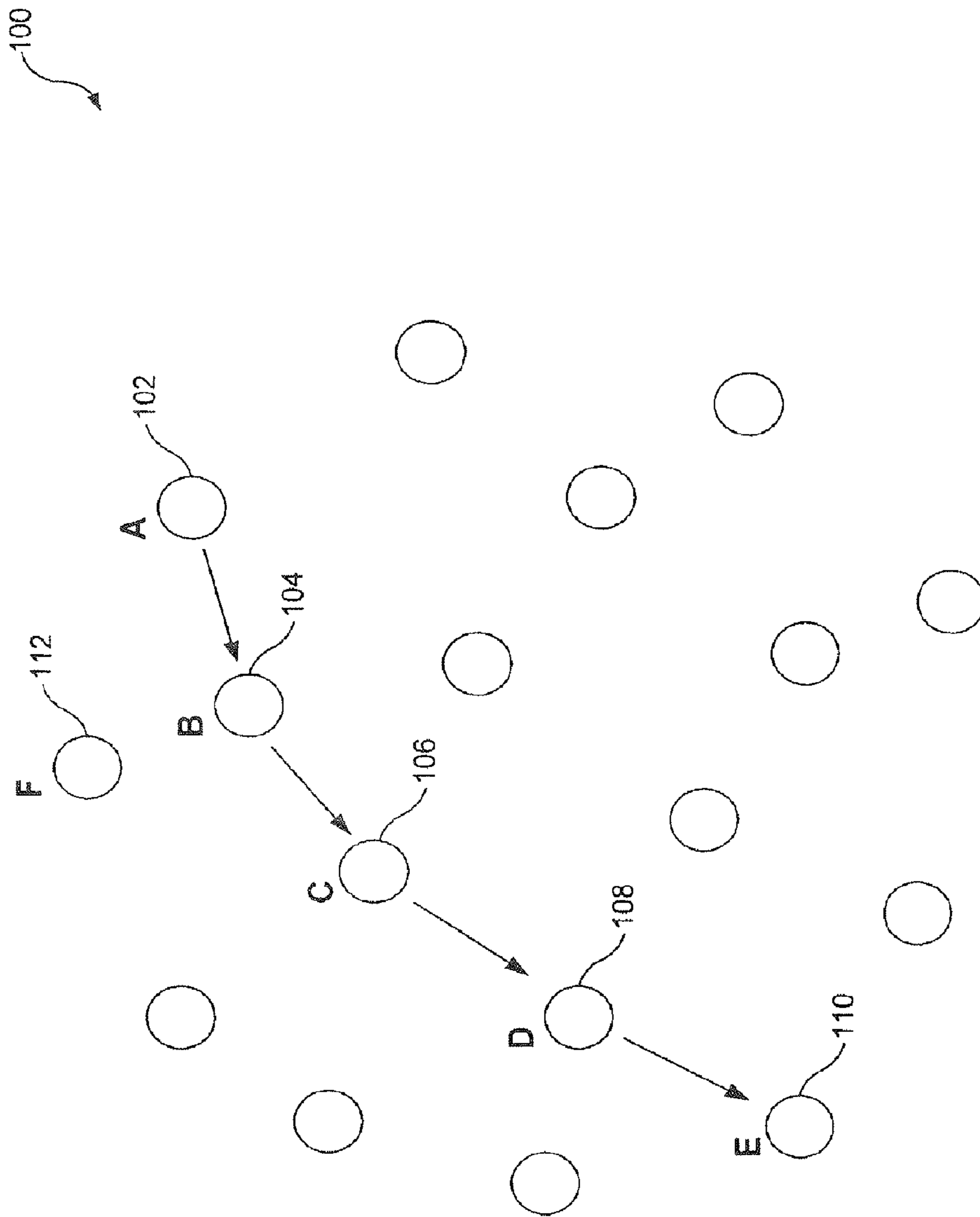


FIG. 1

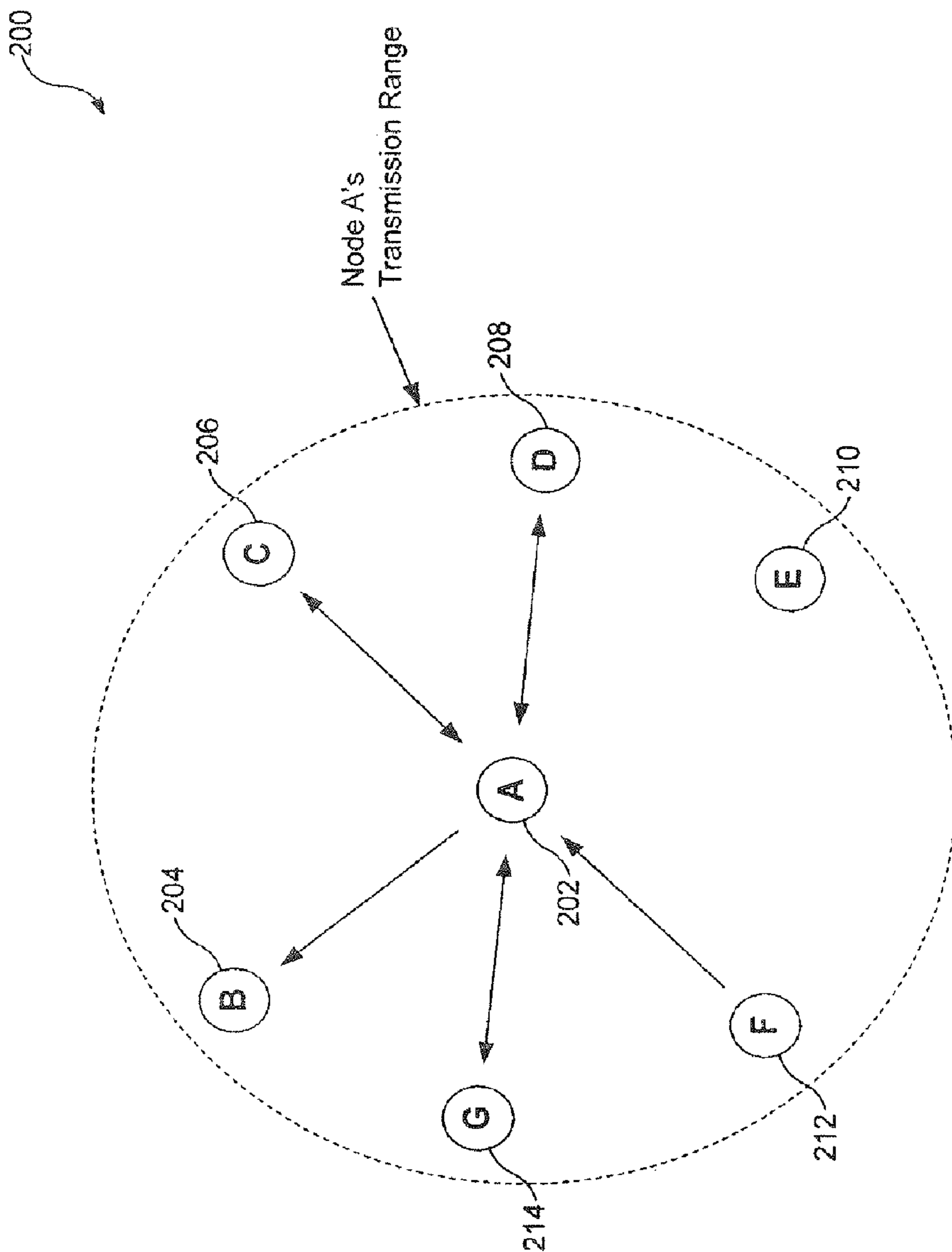


FIG. 2

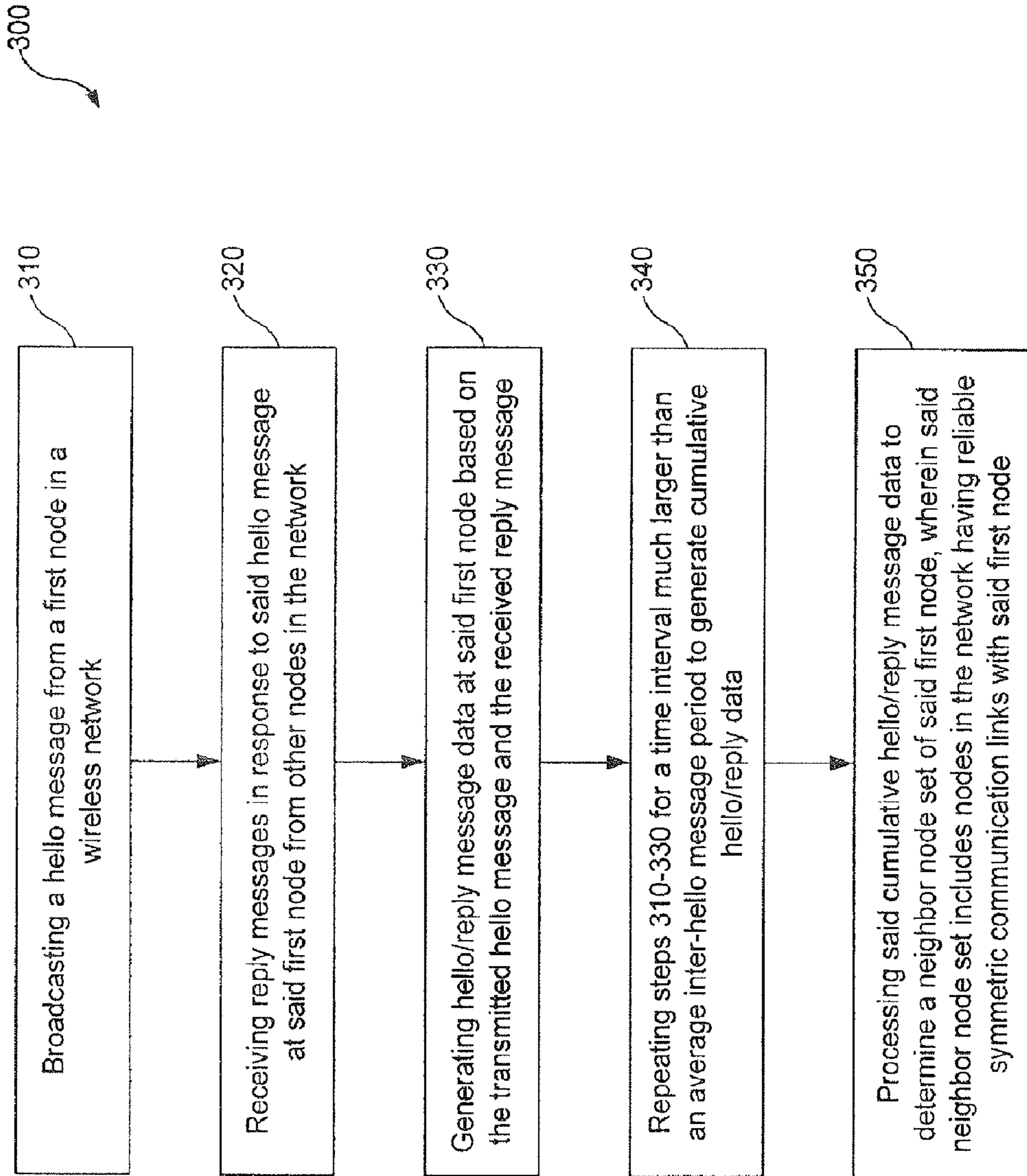


FIG. 3



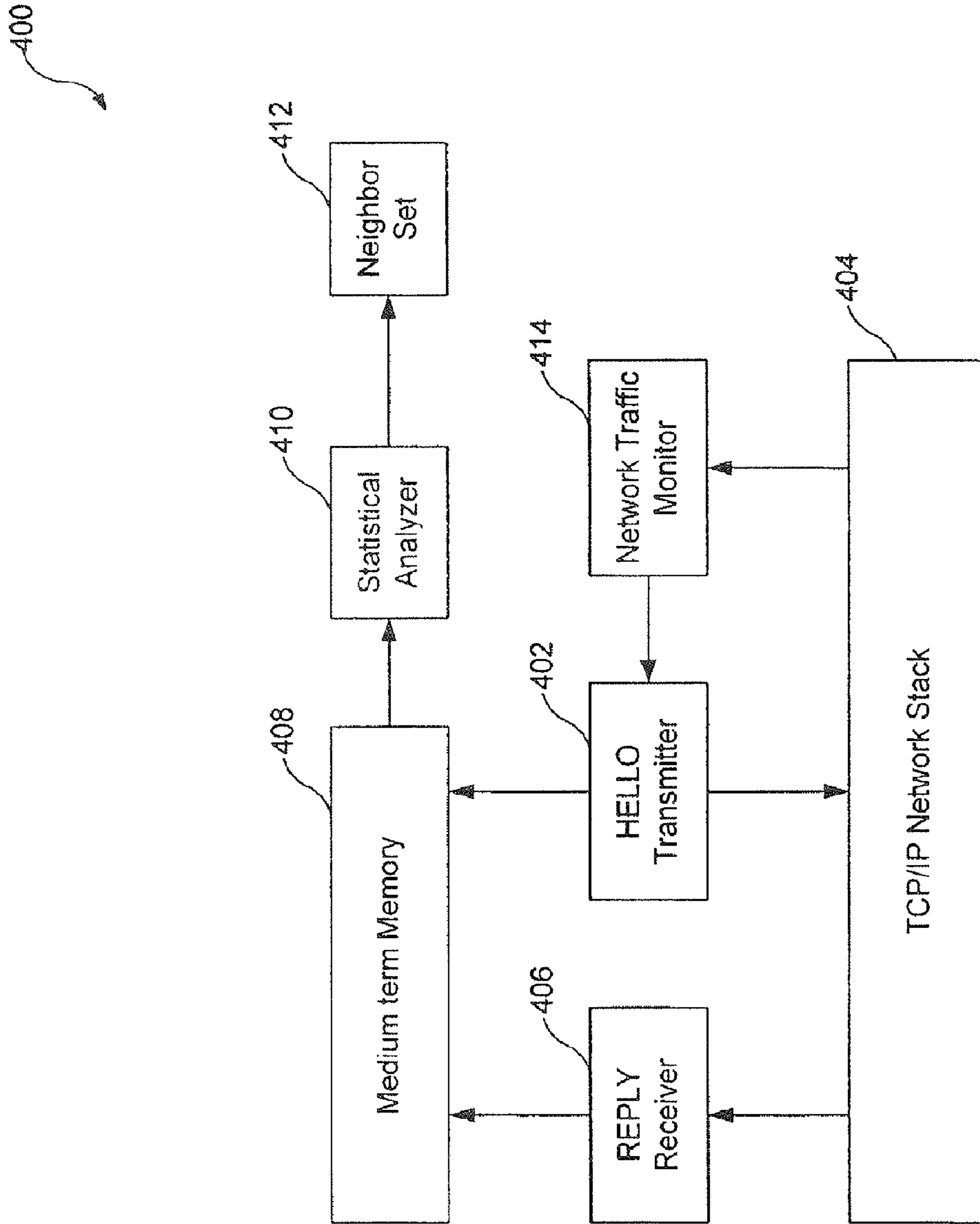


FIG. 4

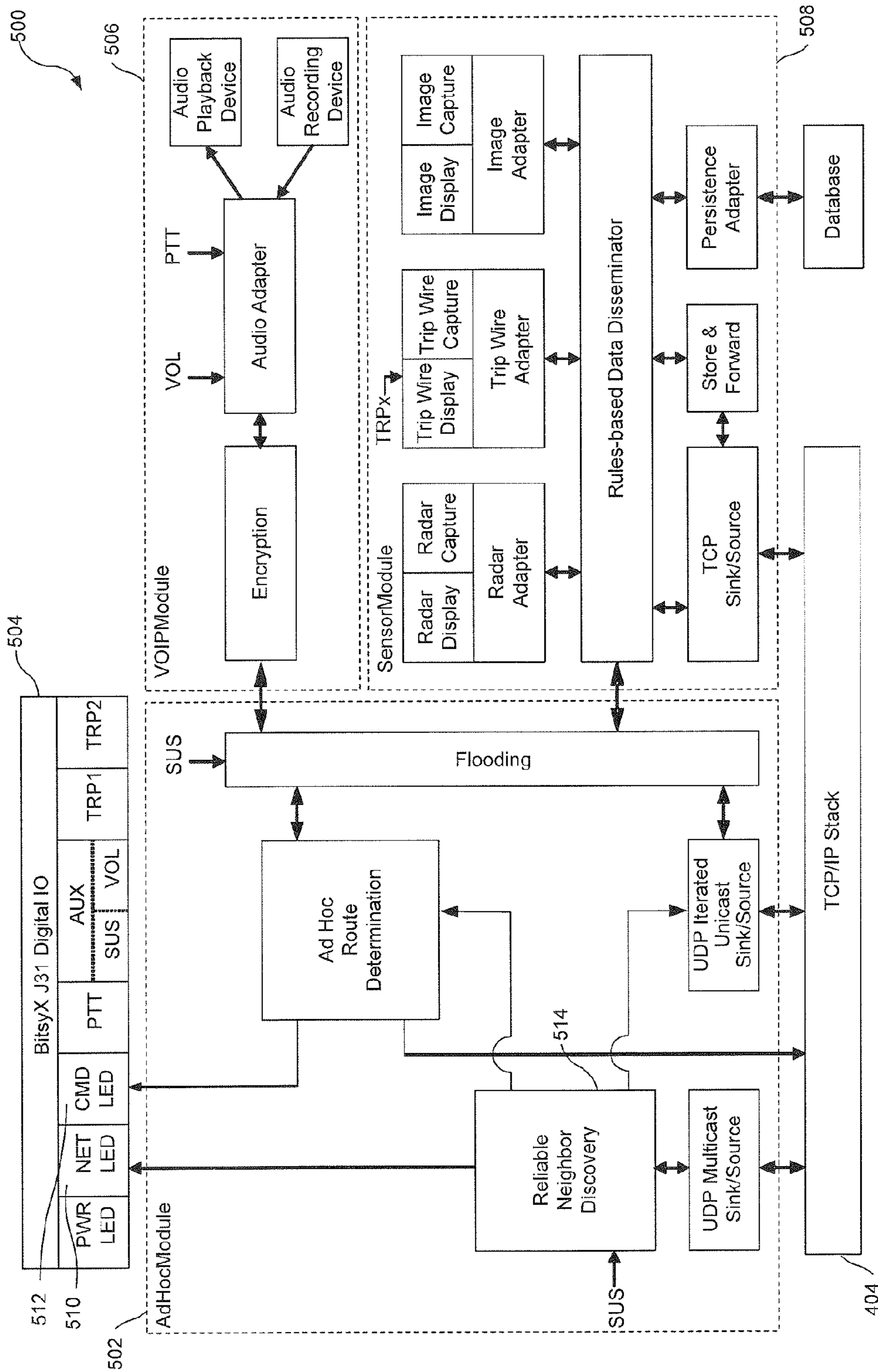


FIG. 5



**RELIABLE NEIGHBOR NODE DISCOVERY**

**Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue; a claim printed with strikethrough indicates that the claim was canceled, disclaimed, or held invalid by a prior post-patent action or proceeding.**

*Notice: More than one reissue application has been filed for the reissue of U.S. Pat. No. 8,064,421. The reissue applications are application Ser. Nos. 13/458,874, and 13/458,989 (the present application), both which were filed on Apr. 27, 2012.*

**CROSS-REFERENCE TO RELATED APPLICATIONS**

[This application is a Divisional Application of co-pending U.S. patent application Ser. No. 11/402,826, filed Apr. 13, 2006, titled "Reliable Neighbor Node Discovery," now allowed, which is incorporated herein by reference in its entirety.] *This Application is a broadening reissue of U.S. patent application Ser. No. 12/719,512 filed Mar. 8, 2010, entitled "Reliable Neighbor Node Discovery," and issued as U.S. Pat. No. 8,064,421, which is a Divisional Application of U.S. patent application Ser. No. 11/402,826, filed Apr. 13, 2006, titled "Reliable Neighbor Node Discovery," and issued as U.S. Pat. No. 7,706,340, each of which is incorporated herein by reference in its entirety.*

Statement under MPEP 310. 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. W15P7T-05-C-F600, awarded by the U.S. Army.

**FIELD OF THE INVENTION**

The present invention relates generally to wireless ad hoc networking. More particularly, the invention relates to methods and systems for reliable neighbor discovery in wireless ad hoc networks.

**BACKGROUND OF THE INVENTION**

Over the last decade, multihop routing for wireless ad hoc networks has been the focus of numerous research efforts. With a multitude of routing protocols having been proposed, a common challenge is faced in the ability of the protocol to adapt to the expected but unpredictable topological changes in wireless ad hoc networks.

In the literature, this is known as routing topology control and is defined as the act of computing and maintaining a connected topology among network nodes, based on which data routing may be performed in the network.

While topology control continues to receive considerable research attention, an essential element at the basis thereof—neighbor node discovery—remains severely overlooked and is often simplistically treated in the design of routing protocols. Neighbor node discovery relates to the process by which a network node detects and dynamically maintains a neighbor node set, wherein the neighbor node set includes network nodes with which direct symmetric communication links are present. By direct it is meant that there is no need to communicate through intermediate nodes.

Conventional methods for neighbor node discovery rely on a simple hello-reply exchange for detecting a neighbor node. However, while this approach may work in simulation, in practice, the success or failure of a single exchange does not accurately describe the presence or absence of a reliable communication link between two nodes.

What is needed therefore are methods and systems for reliable neighbor node discovery to support efficient data routing in wireless ad hoc networks.

**BRIEF SUMMARY OF THE INVENTION**

Methods and systems for reliable neighbor discovery in wireless ad hoc networks are provided herein.

In one aspect, embodiments of the present invention provide methods and systems for analyzing the quality of a communication link using only network-level data transmission and reception. In embodiments, several factors affecting link quality may be incorporated in the analysis, and basic and/or complex statistical and/or probabilistic analysis means may be used.

In another aspect, embodiments of the present invention provide methods and systems for neighbor node discovery that adapt to network and/or node operating conditions and that dynamically maintain a neighbor node set at a given node according to these conditions.

In a further aspect, embodiments of the present invention extend the utility of neighbor node discovery beyond the customary role of data routing support into the problem of deploying an ad hoc network by providing a display module for displaying node connectivity information.

Further embodiments, features, and advantages of the present invention, as well as the structure and operation of the various embodiments of the present invention, are described in detail below with reference to the accompanying drawings.

**BRIEF DESCRIPTION OF THE DRAWINGS/FIGURES**

The accompanying drawings, which are incorporated herein and form a part of the specification, illustrate the present invention and, together with the description, further serve to explain the principles of the invention and to enable a person skilled in the pertinent art to make and use the invention.

FIG. 1 is an example illustration of a wireless ad hoc network.

FIG. 2 is an example illustration of the neighbor node discovery problem.

FIG. 3 is a process flowchart for reliable neighbor node discovery.

FIG. 4 is a block diagram of a system for reliable neighbor node discovery.

FIG. 5 is a block diagram of a wireless device having a neighbor node discovery module.

The present invention will be described with reference to the accompanying drawings. The drawing in which an element first appears is typically indicated by the leftmost digit(s) in the corresponding reference number.

**DETAILED DESCRIPTION OF THE INVENTION****Wireless Ad Hoc Networks**

Wireless ad hoc networks consist of geographically distributed nodes that communicate with one another over a wireless medium. Wireless ad hoc networks date back to



Packet Radio Networks (PRNs) and Survivable Radio Networks (SRNs) developed by DARPA in the early 1970s and in the 1980s.

Today, with the ever increasing popularity of mobile telephony and personal digital assistants, a number of potential commercial applications of wireless ad hoc networks have been brought to the forefront. Examples of such applications include disaster relief, conferencing, home networking, sensor networking, personal area networking, and embedded computing applications.

Unlike wireless networks with infrastructure, such as cellular networks for example, ad hoc networks have no fixed infrastructure. Accordingly, ad hoc network nodes are envisioned to self-configure into a network, whereby network control may be distributed among all the nodes in the network.

Further in contrast to cellular networks, data communication in wireless ad hoc networks is peer-to-peer. In other words, data communication may take place between any two nodes in an ad hoc network. However, given the lack of infrastructure and the characteristically limited node capabilities in an ad hoc network, data communication must generally be performed in a multihop fashion.

Accordingly, a data packet in an ad hoc network may have to traverse multiple nodes in the network before reaching its intended destination. FIG. 1 is an example illustration of a wireless ad hoc network 100. Wireless ad hoc network 100 includes a plurality of nodes that communicate wirelessly with each other. Nodes that are within communication (transmission and reception) range of each other are said to be neighbor nodes, and may communicate using direct links with one another. Non-neighbor nodes employ intermediate nodes to communicate according to a multihop routing scheme. For example, as shown in FIG. 1, node A 102 communicates with non-neighbor node E 110 in 4 hops using intermediate nodes B 104, C 106, and D 108. On the other hand, node A 102 may communicate directly with node F 112 given that node F 112 is within communication range thereof. In practice, the ability to support communication between two particular nodes is a complicated function of the nodes and their environment, depending not only on the inter-node distance but also the presence of obstructions in the intervening space, interference at either node, individual node characteristics (including antenna gain, antenna orientation, and radio data rate), and other nearby nodes (through their use of the same radio bandwidth to carry network traffic). Therefore, the ability to communicate can quickly appear or disappear with changing conditions, especially when the nodes are mobile.

#### Neighbor Discovery in Wireless Ad Hoc Networks

As described above, reliable neighbor node discovery is essential for accurate routing topology control in wireless ad hoc networks, and subsequently for supporting efficient routing protocols for these networks.

In the art, neighbor node discovery remains severely overlooked, and the majority of routing protocols for wireless ad hoc networks rely on simple hello-reply exchange schemes for performing neighbor node discovery.

A drawback of these schemes is clearly that a simple hello-reply exchange is, in practice, not sufficient to accurately describe the condition of a communication link. FIG. 2 is an example 200 that illustrates the complexity of the neighbor node discovery problem.

Example 200 illustrates a wireless node A 202 having six adjacent nodes B 204, C 206, D 208, E 210, F 212, and G 214. For illustration purposes only, the transmission range of node A 202 is shown as a uniform circle that includes nodes B 204,

C 206, D 208, E 210, F 212, and G 214. In practice, the transmission range of a wireless node is not a uniform circle as shown in FIG. 2, for the reasons described above. A single-ended arrow from node A 202 to node B 204 denotes a one-way communication link from A 202 to B 204. A double-ended arrow between nodes A 202 and C 206 denotes a two-way communication link between A 202 and C 206. Accordingly, the link between A 202 and B 204 is said to be asymmetric. The link between A 202 and C 206 is a symmetric link.

A variety of factors determine whether a given communication link is symmetric or asymmetric. For the purpose of routing in the majority of ad hoc networking applications, neighbor node discovery entails discovering nodes with which reliable symmetric communication links are present. By this it is meant that network traffic can be communicated from a node to its neighbor with high probability of reception by the neighbor.

In example 200, nodes B 204, C 206, D 208, E 210, F 212, and G 214 are all theoretically within node A's transmission range. In practice, however, not all of nodes B 204, C 206, D 208, E 210, F 212, and G 214 may be able to successfully receive data packets broadcast by node A 202 with high probability. For example, receiver sensitivity at node F 212 may preclude node F 212 from successfully receiving data packets broadcast from node A 202 which have low signal-to-noise SNR ratio. On the other hand, moving objects in the neighborhood of node E 210 or mobility of node E 210 may prevent reliable communication between nodes A 202 and E 210.

Accordingly, in example 200, the neighbor node set of node A 202 includes nodes C 206, D 208, and G 214. However, due to volatility of conditions in wireless ad hoc networks, the neighbor node set is not a fixed set and will vary according to changes in network conditions, environmental conditions, and node mobility.

In addition to the above mentioned factors, which may be uncontrollable by a network designer, other controllable factors that affect link quality exist, such as dynamic radio characteristics like packet size, data rate and transmission power.

For example, the data transmission rate used in communicating over a link may determine that link's error rate, and subsequently the quality of the link. Further, a link's error rate may vary according to the size of packets being transmitted over that link. For example, smaller data packets are generally less prone to bit errors and have a lower probability of colliding with other packets being broadcast in the network than larger data packets.

Accordingly, link quality is a complex function of various factors, both controllable and uncontrollable, and may not be accurately described by the success or failure of a simple hello-reply exchange as is done in the art. Further, efficient data routing in an ad hoc network requires that a certain level of confidence is established about the persistence in quality of a communication link before adopting that link in routing.

The present invention provides methods and systems for reliable neighbor node discovery.

In one aspect, embodiments of the present invention provide schemes that encompass a variety of factors, as described above, in the determination of link quality.

In another aspect, embodiments of the present invention provide measures to analyze the persistence of a communication link before making a decision about the reliability of that link. In embodiments, basic and/or complex statistical and/or probabilistic analysis may be used.

In a further aspect, embodiments of the present invention provide methods and systems for neighbor node discovery



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that adapt to network and/or node operating conditions and that dynamically maintain a neighbor node set at a given node according to these conditions.

Methods and Systems for Reliable Neighbor Node Discovery

Methods and systems for reliable neighbor node discovery will now be provided. In the description below, various parameters for measuring link quality, which may be employed in embodiments of the present invention, will be described. Equivalent parameters and/or parameters that may be used for the equivalent purpose of evaluating link quality also exist. Accordingly, it should be understood that methods and systems according to the present invention should not be limited to those using the parameters described herein, and that schemes using equivalent and/or other parameters are also within the scope of the present invention.

Further, in the course of the description below, various methods and systems for generating hello/reply message statistics and for analyzing said statistics are provided. The present invention is not limited to the methods and systems provided herein. As equivalent ones exist, they are also within the scope of the present invention. This similarly applies to hello/reply message data, hello/reply message statistics, statistical decision parameters, hello/reply message characteristics, and network conditions as described below.

FIG. 3 is a process flowchart 300 for reliable neighbor node discovery in a wireless network having a plurality of nodes. Process flowchart 300 begins in step 310, which includes broadcasting a hello message from a node in the network. In an embodiment, the node has several network nodes within transmission range thereof, which may be able to successfully receive packets broadcast by the node. Further, nodes successfully receiving the broadcast hello message may reply to acknowledge the reception of the message and to notify the broadcasting node of their presence.

Accordingly, step 320 includes receiving at the broadcasting node reply messages in response to the broadcast hello message from other nodes in the network. In an embodiment, reply messages may be broadcast in the network or directly unicast to the broadcasting node. A reply message received at the broadcasting node from another node in the network indicates that a communication link might exist between the two nodes; however, the quality and utility of that link remains to be established.

Upon receiving reply messages, step 330 includes generating hello/reply message data at the broadcasting node based on the broadcast hello message and the received reply messages. In an embodiment, the generated hello/reply message data may include any type of data that may be used to infer link quality information between the broadcasting node and its neighboring nodes. For example, the generated hello/reply message may include, among other parameters, hello/reply message characteristics, origin addresses of the received reply messages, latencies associated with the received reply messages, and/or a variable-length dummy payload to pad the message to a size commensurate with desired traffic packets.

According to embodiments of the present invention, hello/reply message characteristics may include, among other parameters, hello/reply message size, hello/reply message frequency, hello/reply message error rates as a function of packet size and radio transmission rate, and/or equivalents thereof, each of which may be used to estimate link quality for data transmission. For example, as described above, link quality varies according to message size in that shorter messages are typically more likely to be received successfully over a noisy link than longer messages. Accordingly, as hello/reply messages are typically of smaller size than data mes-

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sages, it is important to take into account message size when inferring link quality for data message transmission.

Similarly, hello/reply message error rates as well as latencies associated with the received reply messages may be used as indicators of link quality.

Referring back to FIG. 3, step 340 includes repeating steps 310-330 for a time interval much larger than an average inter-hello message period to generate cumulative hello/reply data. The average inter-hello message period represents an average time duration between two consecutive hello message broadcasts, and may be specified as a function of network and/or node operating conditions as well as the specific ad hoc networking application. In an embodiment, the time interval of step 340 is of sufficient duration to encompass several hello/reply exchanges and to generate a reasonably large sample of hello/reply data, which may be used to accurately analyze link quality. For example, the neighbors of a node carried by a pedestrian might be expected to change over the course of a second; in that case, the average inter-hello message period would be on the order of a tenth of a second.

Step 350 includes processing the cumulative hello/reply data to determine a neighbor node set of the broadcasting node. The neighbor node set includes network nodes with which the broadcasting node has reliable symmetric communication links. In an embodiment, step 350 further includes generating hello/reply message statistics based on the cumulative hello/reply data. In an embodiment, the generated hello/reply message statistics include, among other parameters, average reply message latencies, reply message arrival probabilities, and/or equivalent measures thereof as a function of the varied parameters, such as message size, data rate, and transmit power.

In another embodiment, step 350 further includes monitoring network conditions and generating statistical decision parameters for analyzing the generated hello/reply message statistics. In an embodiment, the statistical decision parameters are generated based on, among other parameters, hello/reply message characteristics (described above), network conditions, and/or node operating conditions.

According to embodiments of the present invention, network conditions include network traffic conditions, network loading conditions, network connectivity conditions, and/or network volatility conditions. Different parameters and/or measures may be used to describe each of the noted network conditions as understood by a person skilled in the art. Node operating conditions may include, among other parameters, current neighbor node set, physical layer characteristics, and/or node receiver sensitivity.

As understood by a person skilled in the relevant art(s), each of the above noted parameters may affect link quality and can be used to infer information about link quality for data transmission. For example, a node's current neighbor node set may affect the probability of packet collision when communicating with the node. On the other hand, a node's physical layer may treat broadcast hello messages differently than unicast data messages (802.11, for example, transmits broadcast packets at a lower rate and without clear-to-send protection), resulting in different message reception rates for broadcast and unicast messages.

According to embodiments of the present invention, statistical decision parameters may be generated so as to incorporate any number of parameters that may affect link quality for data transmission. Further, statistical decision parameters as well as the type of analysis used may vary in complexity according to network and/or node operating conditions. For example, simple threshold analysis based on a decision threshold may be sufficient for network conditions that vary



slowly. On the other hand, adaptive trend analysis based on more complex statistical decision parameters may be needed for rapidly changing network conditions.

Accordingly, to meet the typically volatile conditions of wireless ad hoc networks, embodiments of the present invention further include adjusting the hello/reply message characteristics, the statistical decision parameters, and/or the analysis type according to network and/or node operating conditions. This results in adaptive methods and systems for neighbor node discovery that track changes in network and/or node conditions, and that dynamically adjust the link quality analysis and input parameters thereof accordingly.

FIG. 4 is a block diagram of a system 400 for reliable neighbor node discovery that implements process flowchart 300 of FIG. 3. System 400 represents components of a neighbor node discovery module connected to a network interface. In an embodiment, system 400 may be part of a wireless node in a wireless ad hoc network.

System 400 includes a HELLO transmitter module 402, a REPLY receiver module 406, a medium term memory 408, a statistical analyzer module 410, a neighbor set module 412, a TCP/IP network stack 404, and a network traffic monitor 414. The operation of system 400 according to process flowchart 300 will now be described.

HELLO transmitter module 402 generates and forwards a hello message to TCP/IP Network Stack 404. In an embodiment, HELLO transmitter module 402 may generate hello messages according to an inter-hello message period. The inter-hello message period may be fixed or variable and may be specified as a function of network conditions.

Each generated hello message includes information for identifying the wireless node in the network. For example, the hello messages include a network address of the wireless node. Further, the hello messages may be of fixed or variable size. In an embodiment, HELLO transmitter 402, upon forwarding a hello message to TCP/IP network stack 404, saves message characteristics of the hello message in medium term memory 408.

TCP/IP network stack 404 connects system 400 to the wireless network. Accordingly, upon receiving the hello message from HELLO transmitter module 402, TCP/IP network stack 404 disseminates the hello message in the network. In an embodiment, TCP/IP network stack 404 performs a one-hop broadcast of the generated hello message. This means that the hello message is not forwarded by other nodes in the network that may receive it. In another embodiment, TCP/IP network stack 404 may notify HELLO transmitter module 402 of the precise time when the hello message is transmitted. HELLO transmitter module 402 may then record that information in medium term memory 408.

If the node using system 400 is within communication range of other network nodes, system 400 may receive reply messages from other nodes in the network. This is done by TCP/IP network stack 404 receiving reply messages and forwarding them to REPLY receiver module 406. REPLY receiver module 406 extracts information from the received reply messages, and forwards the extracted information to medium term memory 408 to be saved. In an embodiment, the extracted information includes message characteristics of reply messages as described above. In another embodiment, REPLY receiver 406 may compute latencies associated with communication links to neighbor nodes by examining receipt timestamps included in the received reply messages.

Network traffic monitor 414 monitors traffic through TCP/IP network stack 404, and may generate measures of network conditions based on the monitored traffic. In an embodiment, network traffic monitor 414 infers network loading condi-

tions by monitoring traffic through TCP/IP network stack 404. In another embodiment, network traffic monitor 414 may generate traffic pattern (traffic burstiness, for example) data based on monitoring TCP/IP network stack 404.

Network traffic monitor 414 may communicate the generated data and/or information to HELLO transmitter 402, which may examine and save the data in medium term memory 408. In an embodiment, HELLO transmitter 402 may adjust certain characteristics of hello messages based on data received from network traffic monitor 414 such as message length, data rate, and transmission rate.

Following several inter-hello message periods, medium term memory 408 contains a sufficient amount of hello/reply data to generate meaningful statistics for describing link quality between the wireless node and neighbor nodes thereof. In an embodiment, statistical analyzer 410 uses data saved in medium term memory 408 to generate hello/reply statistics that may be used to analyze link quality. In an embodiment, the hello/reply statistics include average reply message latencies, reply message arrival probabilities, and/or equivalent measures thereof as a function of the varied parameters, such as message size, data rate, and transmit power.

Further, statistical analyzer 410 generates statistical decision parameters for analyzing the generated hello/reply statistics. In an embodiment, statistical decision parameters may be generated so as to incorporate any number of parameters that may affect link quality for data transmission. In another embodiment, statistical decision parameters may vary according to the type and complexity of analysis used by analyzer 410. For example, in a wireless ad hoc network having slowly changing conditions, a simple threshold analysis may be sufficient to analyze link quality. Accordingly, generating statistical decision parameters, in this case, involves applying a threshold to a count of successful exchanges having the desired characteristics (length, data rate, etc.) to determine whether a link can be classified as reliable or not. Generally, more sophisticated statistical analysis is required and may include, but is not limited to, maximum likelihood analysis, maximum a priori analysis, fuzzy logic analysis, and hidden Markov model analysis.

Statistical analyzer 410 analyzes the reliability of neighbor communication links based on the generated hello/reply message statistics and using the generated statistical decision parameters. As discussed above in the description of process flowchart 300, several factors, including network conditions and node operating conditions, may be incorporated in this statistical analysis. Subsequently, statistical analyzer 410 determines the set of neighbor nodes with which reliable symmetric communication links are present, and stores this set in neighbor set module 412. Neighbor set module 412 includes a means for exposing the neighbor node set to users via visual or audible indicators and/or application processes via memory and/or or file-based mechanisms.

FIG. 5 is a block diagram of an example wireless device 500 having a neighbor node discovery module according to the present invention. Wireless device 500 includes an ad hoc networking module 502, a voice-over-ip (VOIP) module 506, a sensor module 508, and a display module 504.

Ad hoc networking module 502 includes a neighbor discovery module 514, which represents a reliable neighbor node discovery module as described above with respect to FIG. 4. The neighbor node discovery module adaptively generates and maintains a neighbor node set of wireless device 500. Ad hoc networking module 502 may also include a data routing module (illustrated using the Ad Hoc Route Determination module in FIG. 5) that determines routing paths from wireless device 500 to other nodes in the network. In an



embodiment, the data routing module uses the neighbor node set generated by neighbor discovery module 514 in concert with neighbor node sets from other nodes to determine the routing paths either proactively or reactively.

VOIP module 506 and sensor module 508 represent data generation and/or reproduction modules. For example, VOIP module 506 includes an audio recording device for generating data for transmission and an audio playback device for reproducing data received from the network. Similarly, sensor module 508 includes several data generation components such as the data capture components and several data reproduction components such as the data display components.

Display module 504 displays network connectivity information of the wireless device, which can be used by a user of the device and/or the network. Display module 504 includes one or more light emitting diodes (LEDs). In an embodiment, display module 504 includes a first LED 510 for indicating whether the neighbor node set is empty or not. In other words, the first LED 510 indicates whether the wireless device has any network nodes within reliable communication range. In another embodiment, display module 504 includes a second LED 512 to indicate whether a command node, which may include a central control entity of the network, is included in the neighbor node set of the wireless device. The second LED 512 may be useful in ad hoc networking applications that use command nodes, such as team communication applications, or data exfiltration/storage nodes, such as wireless sensor networking applications. Display module 504 is controlled by neighborhood module 514 based on the generated neighbor node set.

Display module 504 represents a novel feature according to the present invention. Indeed, display module 504 significantly simplifies the process of deploying an ad hoc network when the goal is to have a fully connected network with no partitions. In an embodiment, display module 504 can be used to determine where to place relay nodes in the network in order to maintain full connectivity in the network. Placement based on timely indication of reliable neighbors can be done conveniently and accurately by users with minimal training and without the need for sophisticated test equipment, such as radio frequency spectrum analyzers.

#### CONCLUSION

While various embodiments of the present invention have been described above, it should be understood that they have been presented by way of example only, and not limitation. It will be apparent to persons skilled in the relevant art that various changes in form and detail can be made therein without departing from the spirit and scope of the invention. Thus, the breadth and scope of the present invention should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.

What is claimed is:

**[1.** A wireless device for use in a wireless ad hoc network, comprising:

a wireless network interface that connects said wireless device to said wireless ad hoc network;

a neighbor node discovery module that generates a neighbor node set of said wireless device; and

a display module that displays network connectivity information of said wireless device;

wherein said neighbor node discovery module comprises:

a transmitter configured to generate and forward a plurality of HELLO messages to said wireless network interface according to a specified messaging rate,

wherein said plurality of HELLO messages are characterized by one or more of variable HELLO message packet sizes and variable transmission data rates;

a receiver configured to receive at least one REPLY message from said wireless network interface in response to each of said plurality of HELLO messages;

a memory configured to store cumulative HELLO/REPLY message data generated based on said plurality of HELLO messages and REPLY messages received in response thereto; and

a statistical analyzer module configured to analyze said cumulative HELLO/REPLY message data stored in said memory to generate said neighbor node set of said wireless device.]

**[2.** The wireless device of claim 1, wherein said neighbor node discovery module further comprises:

a network traffic monitor configured to monitor traffic through said wireless network interface and to generate information regarding network conditions based on the monitored traffic.]

**[3.** The wireless device of claim 2, wherein said network traffic monitor communicates the generated information regarding network conditions to said transmitter, wherein said transmitter adjusts characteristics of said HELLO message based on said generated information.]

**[4.** The wireless device of claim 1, wherein said transmitter is configured to generate said HELLO message according to an inter-hello message period.]

**[5.** The wireless device of claim 4, wherein said inter-hello message period is set according to network conditions.]

**[6.** The wireless device of claim 1, wherein said transmitter is configured, upon forwarding said HELLO message to said wireless network interface, to store information regarding said HELLO message in said memory.]

**[7.** The wireless device of claim 1, wherein said receiver is configured to extract information from said REPLY message and to store said extracted information in said memory.]

**[8.** The wireless device of claim 1, wherein said statistical analyzer module is configured to analyze said information stored in said memory to generate HELLO/REPLY statistics.]

**[9.** The wireless device of claim 1, wherein said neighbor node discovery module controls said display module based on the generated neighbor node set.]

**[10.** The wireless device of claim 1, wherein the display module comprises one or more light emitting diodes (LEDs), wherein one of said LEDs is on when said neighbor node set is non-empty and is off when said neighbor node set is empty.]

**[11.** The wireless device of claim 10, wherein another one of said LEDs is on when said neighbor node set includes a command node of said wireless ad hoc network and is off when said neighbor node set does not include said command node.]

**12.** A method for ad hoc wireless networking, the method comprising:

*broadcasting a plurality of hello messages to nodes in an ad hoc wireless network using a wireless network interface of a broadcasting node, wherein the plurality of hello messages vary with respect to one or more of packet size and data transmission rate;*

*generating cumulative hello/reply message data in response to receiving replies to the hello messages from one or more of the nodes in the ad hoc wireless network, including a first node; and*

*processing, at the broadcasting node, the cumulative hello/reply message data to determine whether to include a*



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communication link with the first node in a neighbor node set of the broadcasting node, whereby the neighbor node set comprises nodes in the ad hoc wireless network having reliable communication links with the broadcast-  
ing node.

13. The method of claim 12, further comprising:  
determining an inter-hello message period; and  
broadcasting the plurality of hello messages according to  
the inter-hello message period.

14. The method of claim 13, wherein the broadcasting node  
is mobile, the method further comprising:  
determining the inter-hello message period based upon a  
rate of change of the broadcasting node.

15. The method of claim 13, wherein a node other than the  
broadcasting node is mobile, the method further comprising:  
determining the inter-hello message period based upon a  
rate of change of the node relative to the broadcasting  
node.

16. The method of claim 12, further comprising:  
removing the first node from the neighbor node set of the  
broadcasting node in response to processing, at the  
broadcasting node, the cumulative hello/reply message  
data.

17. The method of claim 12, further comprising:  
determining a route in the ad hoc wireless network to a  
node that is not in the neighbor node set of the broad-  
casting node, the route comprising a node that is in the  
neighbor node set of the broadcasting node.

18. The method of claim 17, wherein determining the route  
comprises accessing a neighbor node set of another node in  
the ad hoc wireless network.

19. The method of claim 12, further comprising:  
determining whether to include the communication link  
with the first node in the neighbor set of the broadcasting  
node based upon one of a reply latency and a reply  
probability of the first node in the cumulative hello/reply  
message data.

20. The method of claim 19, wherein the reply probability is  
based upon an error rate of the cumulative hello/reply mes-  
sage data as a function of one or more of packet size and data  
rate of the plurality of broadcast hello messages.

21. The method of claim 19, wherein the reply latency is  
based upon a reply latency of the cumulative hello/reply  
message data as a function of one or more of packet size and  
data rate of the plurality of broadcast hello messages.

22. The method of claim 19, further comprising:  
determining whether to include the communication link  
with the first node in the neighbor node set of the broad-  
casting node using one of a threshold comparison and  
adaptive trend analysis.

23. A method for ad hoc wireless networking, the method  
comprising:

broadcasting a plurality of hello messages on an ad hoc  
wireless network using a wireless network interface of a  
broadcasting node;

varying a transmission power of one or more of the plural-  
ity of hello messages;

generating cumulative hello/reply message data in  
response to receiving replies to the hello messages from  
one or more nodes in the wireless ad hoc network,  
including a first node, wherein the cumulative hello/  
reply message data comprises reply characteristics as a  
function of transmission power of the broadcast hello  
messages; and

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processing at the broadcasting node, the cumulative hello/  
reply message data to determine whether to include a  
communication link with the first node in a neighbor  
node set of the broadcasting node, whereby the neighbor  
node set comprises nodes in the ad hoc wireless network  
having reliable communication links with the broadcast-  
ing node; and

generating hello/reply message statistics comprising one  
or more of reply message latency and reply message  
probability using the cumulative hello/reply message  
data.

24. The method of claim 23, further comprising:  
determining whether to include the communication link  
with the first node in the neighbor node set of the broad-  
casting node using one of a threshold comparison, maxi-  
mum likelihood analysis, maximum a priori analysis,  
fuzzy logic analysis, and hidden Markov model analysis.

25. The method of claim 23, further comprising:  
determining an inter-hello message period; and  
broadcasting the plurality of hello messages according to  
the inter-hello message period.

26. The method of claim 25, wherein the inter-hello mes-  
sage period is based upon one or more of a velocity of the  
broadcasting node and a velocity of a node in the ad hoc  
wireless network relative to the broadcasting node.

27. The method of claim 23, further comprising:  
removing the first node from the neighbor node set of the  
broadcasting node in response to processing, at the  
broadcasting node, the cumulative hello/reply message  
data.

28. The method of claim 23, further comprising:  
determining a route to a node in the ad hoc wireless net-  
work that is not in the neighbor node set of the broad-  
casting node.

29. The method of claim 28, wherein determining the route  
comprises accessing a neighbor node set of another node in  
the ad hoc wireless network.

30. A method for ad hoc wireless networking, the method  
comprising:

determining an inter-hello message period of a broadcast-  
ing node based upon one of network conditions and  
operating conditions of the broadcasting node;

broadcasting a plurality of hello messages according to the  
inter-hello period using a wireless network interface of  
the broadcasting node, wherein broadcasting comprises  
varying one or more of a packet size and data transmis-  
sion rate of one or more of the broadcast hello messages;  
generating cumulative hello/reply message data in  
response to receiving replies to the broadcast hello mes-  
sages from a first node in the ad hoc wireless network;  
and

processing, at the broadcasting node, the cumulative hello/  
reply message data to determine whether to include a  
communication link with the first node in a neighbor  
node set of the broadcasting node, whereby the neighbor  
node set comprises nodes in the ad hoc wireless network  
having reliable communication links with the broadcast-  
ing node.

31. A method for ad hoc wireless networking, the method  
comprising:

broadcasting a plurality of hello messages on an ad hoc  
wireless network using a wireless network interface of a  
broadcasting node;

varying a transmission power of one or more of the plural-  
ity of hello messages;

generating cumulative hello/reply message data in  
response to receiving replies to the hello messages from



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one or more nodes in the wireless ad hoc network, including a first node, wherein the cumulative hello/reply message data comprises reply characteristics as a function of transmission power of the broadcast hello messages;

5 processing at the broadcasting node, the cumulative hello/reply message data to determine whether to include a communication link with the first node in a neighbor node set of the broadcasting node, whereby the neighbor node set comprises nodes in the ad hoc wireless network having reliable communication links with the broadcast-

10 ing node;

determining an inter-hello message period, wherein the inter-hello message period is based upon one or more of a velocity of the broadcasting node and a velocity of a node in the ad hoc wireless network relative to the broadcasting node; and

15 broadcasting the plurality of hello messages according to the inter-hello message period.

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32. The method of claim 31, further comprising: determining whether to include the communication link with the first node in the neighbor node set of the broadcasting node using one of a threshold comparison, maximum likelihood analysis, maximum a priori analysis, fuzzy logic analysis, and hidden Markov model analysis.

33. The method of claim 31, further comprising: removing the first node from the neighbor node set of the broadcasting node in response to processing, at the broadcasting node, the cumulative hello/reply message data.

34. The method of claim 31, further comprising: determining a route to a node in the ad hoc wireless network that is not in the neighbor node set of the broadcasting node.

35. The method of claim 34, wherein determining the route comprises accessing a neighbor node set of another node in the ad hoc wireless network.

\* \* \* \* \*