



- (51) International Patent Classification:  
*H04W 84/10* (2009.01)
- (21) International Application Number:  
PCT/IB2013/003117
- (22) International Filing Date:  
8 November 2013 (08.11.2013)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:  
61/717,289 23 October 2012 (23.10.2012) US
- (71) Applicant: KING ABDULLAH UNIVERSITY OF SCIENCE AND TECHNOLOGY [SA/SA]; 4700 King Abdullah University of Science and Technology, Thuwal, 23955-6900 (SA).
- (72) Inventor: BADER, Ahmed; 30 Jiryas Haddadin Street, Tla'a Al-Ali District, Amman (JO).
- (81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT,

HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

**Published:**

- without international search report and to be republished upon receipt of that report (Rule 48.2(g))
- with information concerning request for restoration of the right of priority in respect of one or more priority claims (Rules 26bis.3 and 48.2(b)(vii))



WO 2014/076577 A2

(54) Title: AN IMPROVED PACKET STRUCTURE

(57) Abstract: A multihop network transmits a packet including a RACH area and a hop number. The RACH area includes a list of subcarriers. A source node in the network dynamically determines the size of the RACH area. A node in the network performs an open-loop transmit power control.

## AN IMPROVED PACKET STRUCTURE

### CLAIM OF PRIORITY

[0001] This application claims the benefit of prior U.S. Provisional Application No. 61/717,289, filed on October 23, 2012, which is incorporated by reference in its entirety.

### TECHNICAL FIELD

[0002] The present invention relates to a multihop network such as a wireless sensor network.

### BACKGROUND

[0003] Mobile multihop networks have been considered lately as viable alternatives for the delivery and sharing of multimedia content between users. Performance of such networks is typically measured in terms of conflicting objectives, namely: end-to-end latency, end-to-end energy consumption, and network throughput. Subsequently, this calls for a packet delivery protocols which are able to establish a careful balance between these objectives. Recently, a packet forwarding protocol has been developed to meet such objectives. See Bader, Ahmed et al., "An Efficient Multi-Carrier Position-Based Packet Forwarding Protocol for Wireless Sensory Network," IEEE Transaction on Wireless Communications, Volume 11, no. 1 (January 2012), the content of which is incorporated by reference in its entirety.

[0004] For example, the protocol is built using orthogonal frequency division multiplexing (OFDM) for the physical (PHY) layer. Furthermore, the protocol utilizes position-based channel access techniques in conjunction with the OFDM PHY. This allows all eligible relays at a given hop to access the channel concurrently. Due to this property, the protocol is labelled as "multi-relay." The protocol is indifferent to mobility since it does not mandate relays to have knowledge of the network topology. The use of OFDM makes it also quite resilient to fast fading environments and thus well-suited for mobility.

## SUMMARY

[0005] One aspect of present invention provides a multihop network having a plurality of nodes. The nodes may be a source, a destination, or a relay which both receives and transmits data. The data includes a packet having a random access channel (RACH) area and a hop number.

[0006] The RACH area includes a list of subcarriers and a relay number. A node, such as a relay, randomly selects one of the subcarriers and modulates it with a time-domain signal.

[0007] A node (such as a relay) of the multihop network receiving the packet extracts the relay number, and thereby obtains the number of prior relays. Further, the node scans the subcarriers, and, in a case that a subcarrier having an energy level meeting or exceeding a predetermined amount is detected, the number of relays is incremented.

[0008] Further, the node in the multihop network is an OFDM wireless communication device.

[0009] In another aspect of the present invention, a source node of the multihop network dynamically allocates a size of the RACH area. The node listens to a RACH area during a packet transmission at a second hop for a number of nodes of the second hop. The node receives a number of nodes at a destination stage transmitted by a destination node. The source node determines a size of the RACH area based on the number of nodes of the second hop and the number of nodes at the destination stage.

[0010] Further, the size of the RACH area set is constant for a plurality of hops.

[0011] In another aspect of the present invention, a relay of the multihop network scans the subcarriers in a RACH area to estimate a number of previous-hop relays. The relay further receives or transmits a packet including a hop number. The node determines a transmit power level based on the number of previous-hop relays and the hop number.

[0012] Further, such determination is made using a lookup table.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

- [0013] Figure 1 illustrates a packet having a RACH area.
- [0014] Figure 2 shows the probability of the estimated count matching the real relay count.
- [0015] Figure 3 is the flow chart for dynamic resource allocation.
- [0016] Figures 4 is the flow chart for open-loop power control

### **DETAILED DESCRIPTION OF THE SYSTEM**

[0017] A multihop network includes a plurality of communication devices. An example is a wireless communication device. In a wireless sensor network, each of the communication devices is also a sensor.

[0018] The communication device is referred to as a node. A node transmitting data is a source node. Nodes that transmit or retransmit the data are also called relays.

[0019] Aspects of present invention provide, inter alia, enhancements in the packet structure which enable dynamic allocation of resources throughout the packet forwarding process. One aspect provides nodes with the ability to closely estimate the number of relays of the ongoing packet transmission. Another aspect provides a dedicated field for the hop number. The enhancements allow a source node to perform dynamic allocation of random access channel (RACH) slots, and allow relays subsequent to the source node to perform open-loop power control.

[0020] The ability of nodes to estimate the number of relays at a given hop helps to understand the underlying node density. With this, nodes are able to undertake well-informed and more efficient resource allocation approaches. For instance, the nodes are now able to adjust the size of the RACH area in a way that does not compromise end-to-end delay performance but achieves better L2 throughput. (I.e., Layer 2 of the 7-layer OSI network model. Layer 2 corresponds to the Data Link layer.) Similarly, an open-loop power control scheme that is aware of the underlying density can reduce energy consumption while maintaining a minimum level of end-to-end delay.

[0021] The improved packet structure is illustrated in Figure 1. The packet 100 introduces a separate field for the hop number. See FIG. 1, “i.” The source node sets the value of this field to 1. Every hop, relays increment this field by 1. Thus, the packet is relayed from source to destination over multiple hops, nodes in between the source and destination act as repeaters. The number of hops corresponds to the number of times the packet was transmitted before it reached the destination. So, indeed the transmission from the source node comprises the first hop. The transmission one of whose receivers is the destination is the last hop.

[0022] The other modification is done to the first OFDM symbol of the RACH area (110). The RACH 110 includes slots 120 and subcarriers 130.

[0023] As shown in the Figure, there are  $V_{N_c}$  subcarriers. Each subcarrier is now accessible to relays. Each relay randomly selects one of those subcarriers and modulates it with a time-domain pulse. Next-hop nodes will scan through  $V_{N_c}$  subcarriers using a simple energy detector. Detection of any subcarrier holding substantial energy will increment the hop number by one. A subcarrier is considered to have been modulated by a relay if the energy measured on that subcarrier exceeds a certain preset threshold. The value of such a threshold is determined according to the desired probability of detection and probability of false alarm.

[0024] For example, a multihop network may have multiple relays concurrently transmit the same packet. E.g., in the 4<sup>th</sup> hop of the packet towards the destination, 8 relays may be concurrently transmitting the packet. What they will do is to increment the hop number field in the packet structure by 1 such that the field contains the value 5. A receiver now will utilize the information on the  $V_{N_c}$  subcarriers and will reach the conclusion that there were 8 relays in the 4<sup>th</sup> hop.

[0025] Since  $V_{N_c}$  is relatively large, the probability of no collision is also relatively high. In other words, the estimated count is not far from reality. This is further demonstrated in Figure 2. Relays modulate their position information by randomly selecting one of the designated RACH slots  $b_1 . . . b_B$ , as explained in the “An Efficient Multi-Carrier Position-Based Packet Forwarding Protocol for Wireless Sensory Network,” article. Nodes choosing unique slots are labelled within this context as “resolvable.”

[0026] The feature of dynamic allocation of RACH resources is discussed herein. A flowchart is shown in FIG. 3.

[0027] The size of the RACH area in terms of number of OFDM symbols is determined by the source node and is maintained throughout the packet's journey towards the destination. The number of nodes in the 2nd hop ( $K_2$ ) as well as the last hop ( $K_q$ ) are taken into consideration by the source node. The source node makes an estimate of  $K_2$  by listening to the RACH area (e.g., receiving and detecting signals in the RACH area) during the packet transmission at the second hop. (FIG. 3, 210). As a receiver in the last hop, the destination may conveniently construct an estimate of  $K_q$ . The value of  $K_q$  is sent back to the source in a separate packet. (FIG. 3, 220). It can be shown that through simulation that the series

$$\{K_i\}_{i=1}^q$$

is generally an increasing monotone such that

$$\max\{K_i\}_{i=1}^q = K_q$$

As such, knowledge of  $K_2$  and  $K_q$  only is sufficient for the source node on the evolution of the number of relays hop after hop.

[0028] Thus, the intensity of relays involved in forwarding the packet is a direct indication of the network node density. Consequently, the source can make an educated estimate on an optimized RACH allocation. In this invention, the source node will increase the size for the RACH area if it happens to be in a dense network. (FIG. 3, 230). This will ensure that the number of non-resolvable relays each hop is reduced. As a result, the probability of having relays which offer non-positive progress is reduced. This can be shown to result in saving energy consumed per packet. It also downsizes the interference footprint per packet particularly for narrow forwarding strip widths. This is true since adjustment in the size of the RACH area typically impact  $K_{i-}$  much more than  $K_i$ . In other words, it does not really affect the number relays offering positive progress. Further, the impact of those  $K_{i-}$  relays is only a small portion compared to  $K_i$ . As such, the number of hops  $q$  does not increase a lot. Subsequently, the end-to-end delay is only marginally affected. The dynamic allocation approach described above is suited for

traffic with short length packets, e.g. video streaming. Any savings in terms of packet overhead proves to be really valuable.

**[0029]** The feature of open-loop power control, which is performed by each relay, is discussed herein. The flow chart is shown in FIG. 4.

**[0030]** The first objective is that, in case of high node density, end-to-end delay target can be easily met at lower transmit power levels. Therefore, it is beneficiary to reduce power levels so as to avoid large interference footprints and consequently enhance the network throughput performance. On the other hand, in case of low node density, increasing the power level becomes mandatory to maintain the end-to-end delay within acceptable ranges.

**[0031]** The second objective here is to preserve energy; a precious resource for mobile terminals. Reducing transmit power reduces substantial the energy consumption causing only marginal impact on the delay performance.

**[0032]** A relay makes an estimate of the number of previous-hop relays by scanning the respective subcarriers within the RACH area. (FIG. 4, 310). For example, the packet is a data structure along the time dimension and the frequency dimension. The smallest unit in this packet is one time slot by one frequency subcarrier. Thus, in this example, the term "area" is defined by time-frequency unit. It also takes note of the hop number. (FIG. 4, 320). The latter is important simply because it qualifies whether a large number of relays corresponds to high density or is simply due to the packet having traversed many hops already. We recall here that the number of relays increases every hop. Using this information, the transmit power level is set based on preset look-up tables. (FIG. 4, 330). For example, the look-up table includes two columns: : the first is the number of relays, the second is the transmit power corresponding to the number of relays. Generally speaking, the larger the number of relays the smaller the transmit power would be. The determination of the optimal transmit power levels is an offline task done by the network designer taking into consideration various parameters such as PHY bit rate, target packet error rate, end-to-end delay, end-to-end energy consumption, ...etc.

**WHAT IS CLAIMED IS:**

1. A multihop network having a plurality of nodes relaying data, comprising:  
one of the plurality of nodes transmits or receives a packet including a RACH area;  
wherein the packet includes a hop number.
2. The multihop network of claim 1, wherein the RACH area further includes a list of subcarriers.
3. The multihop network of claim 2, wherein the RACH area further includes position information of a node transmitted the packet in a previous hop.
4. The multihop network of claim 3, wherein the node randomly selects one of the RACH area subcarriers.
5. The multihop network of claim 4, wherein the node modulates the selected subcarrier with a signal.
6. The multihop network of claim 5, wherein the signal is a time-domain signal.
7. The multihop network of claim 2, wherein a second node in the multihop network scans the RACH area subcarriers.
8. The multihop network of claim 7, wherein the second node in the multihop network scans subcarriers for energy levels.
9. The multihop network of claim 8, wherein in a case that the second node detects a subcarrier having an energy level meeting or exceeding a predetermined amount, the hop number is incremented.
10. The multihop network of claim 1, wherein the node is a wireless communication device.
11. The multihop network of claim 10, wherein the node is an OFDM wireless communication device.
12. A communication device transmits or receives data, wherein  
the data includes a packet including a RACH area;  
and wherein the packet includes a hop number.
13. The communication device of claim 12, wherein the RACH area further includes a list of subcarriers.
14. The communication device of claim 13, wherein the RACH area further includes position information of a communication device previously transmitted the data.



15. The communication device of claim 13, wherein the communication device transmits the data including the packet, and randomly selects one of the subcarriers.
16. The communication device of claim 15, wherein the communication device modulates the selected subcarrier with a signal.
17. The communication device of claim 16, wherein the signal is a time-domain signal.
18. The communication device of claim 12, wherein the communication device is a wireless communication device.
19. The communication device of claim 18, wherein the communication device is an OFDM wireless communication device.
20. The communication device of claim 15, wherein the communication device receives the data including the packet and scans the subcarriers.
21. The communication device of claim 20, wherein the communication device scans the subcarriers for energy levels.
22. The communication device of claim 20, wherein in a case that the communication device detects a subcarrier having an energy level meeting or exceeding a predetermined amount, the hop number is incremented.
23. A method for operating a multihop network, comprising:
  - transmitting a packet including a RACH area;
  - and wherein the packet includes a hop number.
24. The method according to claim 23, wherein the RACH area further includes a list of subcarriers.
25. The method according to claim 24, wherein the RACH area further includes position information of a communication device previously transmitted the data.
26. The method according to claim 23, further comprising:
  - selecting randomly, by a communication device in the multihop network, one of the subcarriers.
27. The method according to claim 26, further comprising:
  - modulating, by the communication device, the selected subcarrier with a signal.
28. The method according to claim 27, wherein the signal is a time-domain signal.
29. The method according to claim 25, wherein the communication device is a wireless communication device.

30. The method according to claim 29, wherein the communication device is an OFDM wireless communication device.
31. The method according to claim 27, further comprising:
  - receiving, by the communication device, the packet;
  - scanning, by the communication device, the subcarriers.
32. The method according to claim 31, wherein the communication device scans the subcarriers for energy levels.
33. The method according to claim 32, wherein in a case that the communication device detects a subcarrier having an energy level meeting or exceeding a predetermined amount, the hop number is incremented.
34. A source node in a multihop network, comprising:
  - a circuit that listens to a RACH area during a packet transmission at a second hop for a number of nodes of the second hop;
  - a circuit receives a number of nodes at a destination stage transmitted by a destination node; and
  - a circuit that determines a size of the RACH area based on the number of nodes of the second hop and the number of nodes at the destination stage.
35. The source node according to claim 34, wherein the size of the RACH area is constant for a plurality of hops.
36. A method to dynamically allocate a size of a RACH area of a packet, comprising:
  - listening, by a source node of a multihop network, a RACH area during a packet transmission at a second hop for a number of nodes of the second hop;
  - receiving, by the source node, a number of nodes at a destination stage transmitted by a destination node; and
  - determining a size of the RACH area based on the number of nodes of the second hop and the number of nodes at the destination stage.
37. The method according to claim 36, wherein the RACH area is constant for all hops.
38. A relay of a multihop network, comprising:
  - a circuit that scans subcarriers in a RACH area to estimate a number of previous-hop relays;
  - a circuit that receives or transmits a packet including a hop number; and
  - a circuit that determines a transmit power level based on the number of previous-hop relays and the hop number.

39. The relay according to claim 38, wherein the transmit power level is determined based on a lookup table.
40. A method for open-loop transmit power control, comprising;  
scanning, by a relay in a multihop network, subcarriers in a RACH area,  
estimating, by the relay, a number of previous hop relay based on the scanning;  
receiving and transmitting a packet including a hop number;  
determining a transmit power level based on the number of previous-hop relays and the hop number.
41. The method according to claim 40, wherein the transmit power level is determined based on a lookup table.

1/4

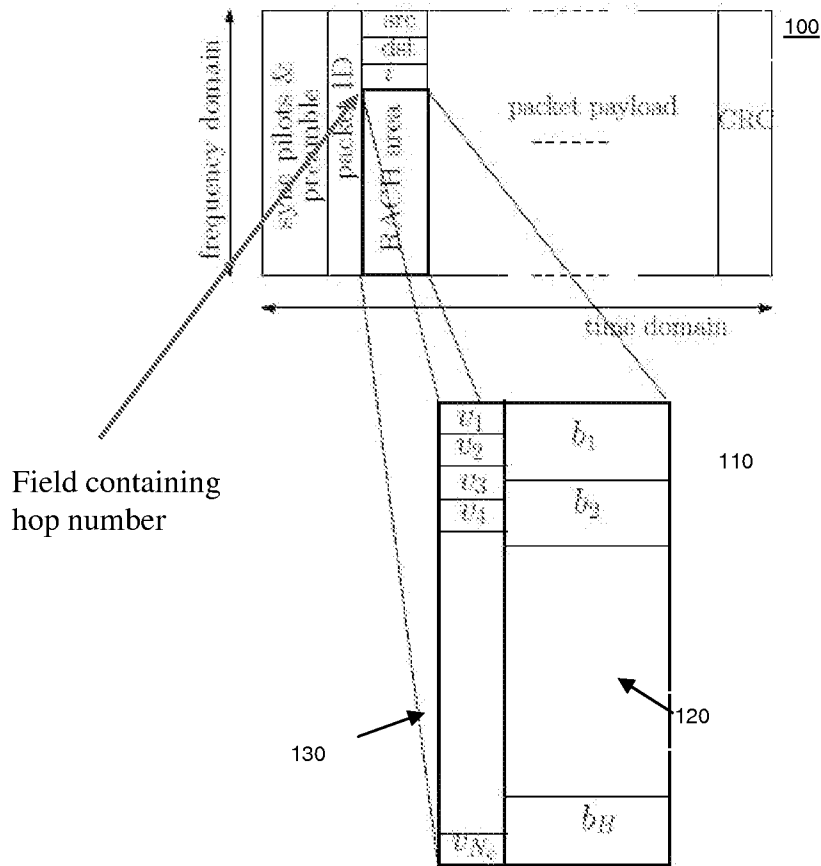


FIG. 1

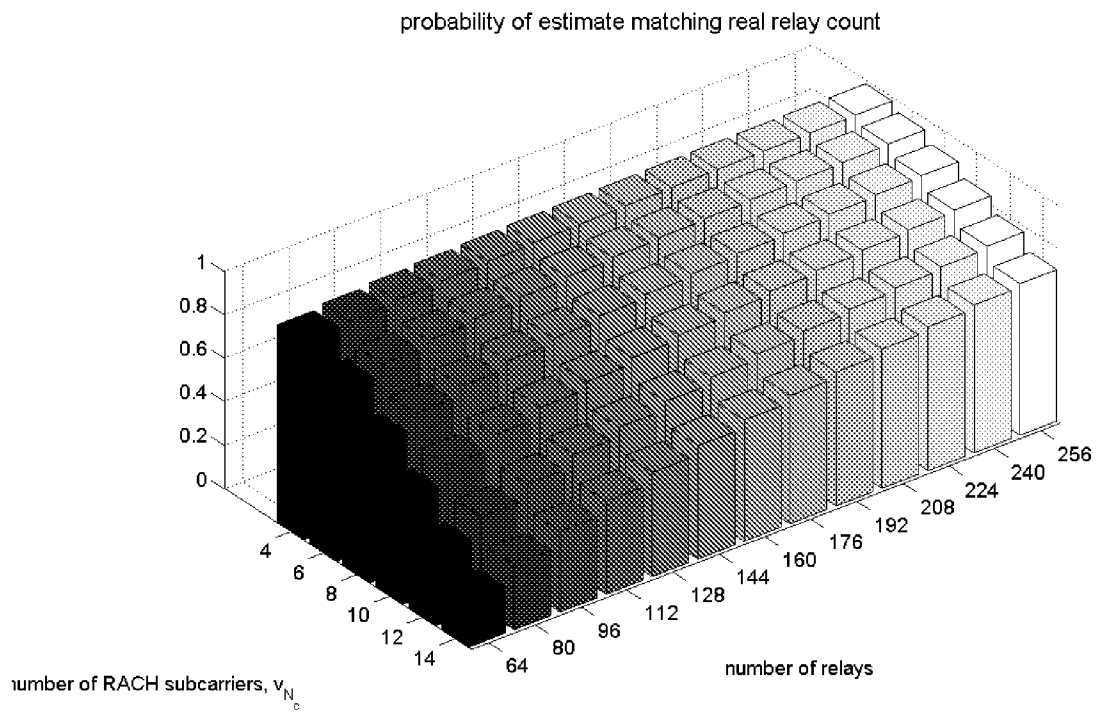


FIG. 2

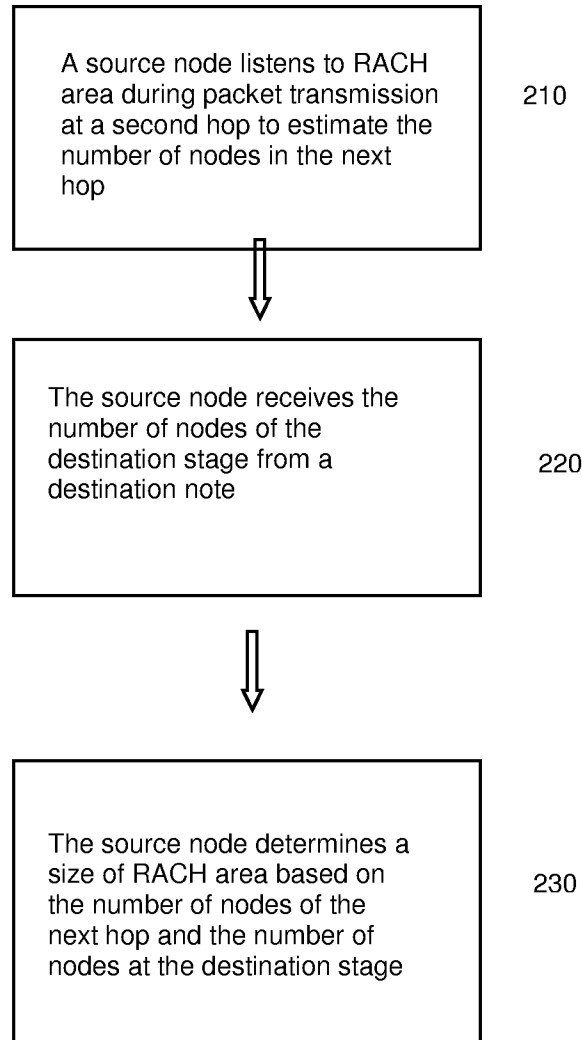
**3/4**

FIG. 3

4/4

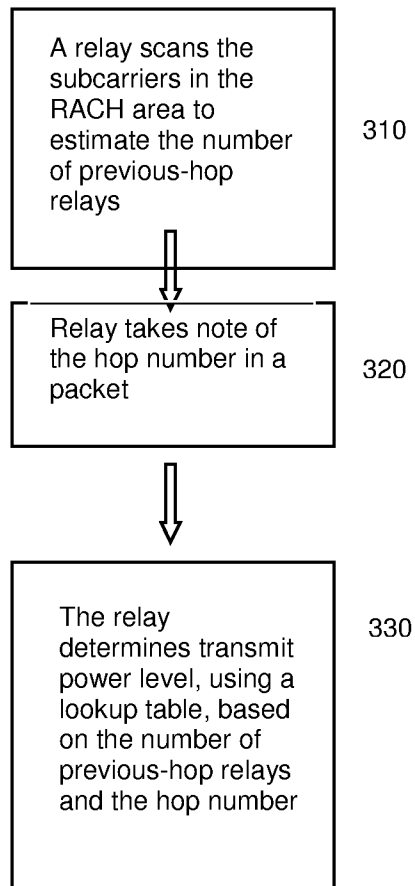


FIG. 4