(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
24 August 2017 (24.08.2017)

WIPO | PCT

(10) International Publication Number
WO 2017/143320 A1

(51) International Patent Classification:
H04L 12/28 (2006.01) *H04B 1/713* (2011.01)

(21) International Application Number:
PCT/US2017/018591

(22) International Filing Date:
20 February 2017 (20.02.2017)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
15/048,843 19 February 2016 (19.02.2016) US

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[Continued on next page]

(54) Title: WIDEBAND BEACON CHANNEL FOR FREQUENCY HOPPING SYSTEMS

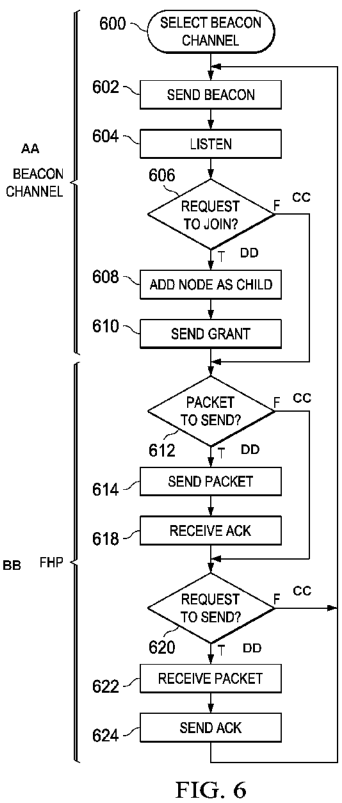


FIG. 6

(57) Abstract: In described examples of a method of operating a network on a plurality of frequency hopping channels, the method includes transmitting a beacon (602) on a beacon channel different from the frequency hopping channels, and receiving a request from a node to join the network (606) in response to the beacon. The method further includes adding the node to the network (608) in response to the step of receiving, and communicating with the node on the plurality of frequency hopping channels (612-624) after the step of adding.

WO 2017/143320 A1

(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, DJ, 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, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, 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, ST, 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).

Declarations under Rule 4.17:

— *as to the identity of the inventor (Rule 4.17(i))*

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

— *with international search report (Art. 21(3))*

WIDEBAND BEACON CHANNEL FOR FREQUENCY HOPPING SYSTEMS

[0001] This relates to wireless mesh communication systems, and more particularly to a network with wideband beacon channels for frequency hopping systems.

BACKGROUND

[0002] In a wireless mesh network type of wireless communication system, at least one wireless transceiver receives and processes its own data, and it also serves as a relay for other wireless transceivers in the network. This may be accomplished by a wireless routing protocol where a data frame is propagated within the network by hopping from transceiver to transceiver to transmit the data frame from a source node to a destination node. A wireless node may be a wireless access point such as a wireless router, a mobile phone, or a computer capable of accessing the internet. In other applications, the wireless node may be an external security monitor, a room monitor, a fire or smoke detector, a weather station, or any number of other network applications for home or business environments.

[0003] FIG. 1 shows a conventional wireless network as disclosed in version 0v79 of the 2013 Wi-SUN Alliance Field Area Network Working Group, which is incorporated by reference herein in its entirety. The network includes an internet access circuit 150. The network also includes Personal Area Network (PAN) circuits A through C. Each of PAN communicates with circuit 150 through respective Master nodes MA 100, MB 120, and MC 130.

[0004] PAN A is an example network that may be similar to PANs B and C. PAN A communicates with circuit 150 through Master node MA 100. MA 100 communicates directly with relay node (RN) 102 and with leaf node (LN) 114. Thus, MA 100 is a parent node of RN 102 and LN 114. RN 102 is a parent of RN 104 and communicates indirectly with LN 106 via RN 104. RN 102 also communicates directly with RN 108 and indirectly with RN 110 via RN 108. RN 108 also communicates directly with LN 112. RN 108 is a parent of both RN 110 and LN 112. Frequency Hopping Protocol (FHP) is often used within the network to reduce interference and provide frequency diversity.

[0005] Frequency hopping is used for many narrowband communication systems in the United

States because the FCC regulations (15.247) allow higher transmit power for narrowband frequency hopping systems in the bands 902–928 MHz, 2400–2483.5 MHz, and 5725–5850 MHz. For the 902-928 MHz band if at least 50 hopping channels are used with 20 dB bandwidth less than 250 kHz, then 1 watt of transmit power can be used. For a 20 dB bandwidth between 250 kHz and 500 kHz then at least 25 hopping channels are needed. If frequency hopping is not used for these narrowband systems then they would fall under regulation 15.249, where the transmit power would be limited to -1.25 dBm or 0.75 mW. This is over 1000 times lower transmit power than the frequency hopping system. For wider bandwidth systems using digital modulation techniques, 1 watt of transmit power can be used if the 6 dB bandwidth is at least 500 kHz.

[0006] IEEE 802.15.4g defines frequency hopping systems for smart utility networks (SUN) using one of three physical layers: frequency shift keying (FSK), orthogonal frequency division multiplexing (OFDM), or direct sequence spread spectrum (DSSS). DSSS may also be referred to as offset quadrature phase shift keying (OQPSK). The 902-928 MHz band has 129 channels with a 200 kHz channel spacing or 64 channels with a 400 kHz channel spacing (FIG. 2). Both of these definitions meet the number of hopping channels required by 15.247, so 1 watt of transmit power can be used. One challenge with SUN frequency hopping systems is that the join procedure for a new node may take a long time.

[0007] When the network uses a star configuration having a central hub, the central hub can transmit a beacon that other nodes can use to learn the hopping sequence, so that they can join the network. However, a mesh network has no central hub. In a mesh network, each node can transmit to a neighboring node until the message reaches a data concentrator or network master which would be connected to a backbone to transmit data to the utility. For the reverse direction messages can hop from node to node to reach a leaf node. For a new node to join a mesh network, it would need to either camp on one channel and wait until a neighboring node transmits a beacon message, or it would need to be able to scan many channels sequentially to find a beacon.

[0008] This problem is illustrated with reference to FIG. 3. When powered up the slave nodes must perform an acquisition to find out where in the sequence of frequencies the master resides. A new acquisition may also have to be performed if synchronization is lost, such as due to noise or being temporarily moved out of radio range. In the latter case, the slave has an idea of which frequency the master is transmitting on, and this information is exploited to achieve faster acquisition. When performing acquisition, the slave must always listen for one full period at each frequency that is being examined to be sure of picking up the beacon. It starts at the frequency that it believes to be most likely and then moves on to the most nearby frequencies in the pseudo-random sequence. This is typically a random selection when the slave is powered up. At time 0 (first row), if the first master frequency guess is 0 (second row), the closest frequencies are 0, 1, -1, 2, -2, 3, -3, and so forth. However, because the master is also stepping through the frequencies, this sequence must be shifted by the sequence 0, 1, 2, 3, 4, 5, 6, etc. The actual frequencies examined, therefore, are 0, 2, 1, 5, 2, 8, 3 (third row). If all frequencies are examined without result, the acquisition sequence must start over again. Assuming the failure is due to the slave being out of radio range, the application may choose to have a delay between each acquisition to reduce power consumption.

[0009] For conventional networks, when the slave is powered up and does not know where the master is hopping, it chooses a random frequency and listens. A long time can be necessary until it finds a beacon from the master. For example, if 50 hopping frequencies exist, then the slave may need to listen through 50 beacon cycles to find a beacon in absence of fading or interference. If beacons are missed due to fading or interference, a much longer can be necessary to find a beacon. A typical beacon packet format is illustrated at FIG. 4 together with a data packet and acknowledge/negative acknowledge (ACK/NACK) packets. Each packet includes a preamble, packet length, and cyclic redundancy check (CRC) field. The beacon and ACK/NACK packets also include a source identification (ID) field. The beacon packet also includes control information which specifies the network frequency hopping protocol (FHP) and other network information to the slave.

SUMMARY

[0010] In a first embodiment of a method of operating a network on a plurality of frequency hopping channels, the method includes transmitting a beacon on a beacon channel different from the frequency hopping channels and receiving a request from a node to join the network in response to the beacon. The method further includes adding the node to the network in response to the step of receiving and communicating with the node on the plurality of frequency hopping channels after the step of adding.

[0011] In a second embodiment of a method of operating a network on a plurality of frequency hopping channels, the method includes receiving a beacon on a beacon channel different from the frequency hopping channels and transmitting a request to a parent node to join the network in response to the beacon. The method further includes receiving a grant to join in response to the step of transmitting and communicating with the parent node on the plurality of frequency hopping

channels after the step of receiving the grant to join.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG. 1 is a diagram showing a conventional wireless network.

[0013] FIG. 2 is a diagram showing example channel hopping channels for the wireless network of FIG. 1.

[0014] FIG. 3 is a diagram showing a problem that may arise during network acquisition in a wireless network operating under frequency hopping protocol (FHP).

[0015] FIG. 4 is an example diagram showing packet formats for beacon, data, and acknowledge/negative acknowledge (ACK/NACK) packets.

[0016] FIG. 5 is a diagram showing network frequency hopping channels and dedicated beacon channels according to example embodiments.

[0017] FIG. 6 is a flow diagram showing network master operation when receiving a request to join during network acquisition.

[0018] FIG. 7 is a flow diagram showing slave operation when requesting to join a network.

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS

[0019] Although conventional network proposals provide steady improvements in wireless network communications, further improvements in mesh network protocol are possible.

[0020] FIG. 5 shows network frequency hopping channels and dedicated beacon channels according to example embodiments. The diagram is the same as FIG. 2, except that channels 5-6, 30-31 and 55-56 are replaced by three dedicated beacon channels. Therefore, the diagram of FIG. 5 has fifty-eight (58) 400 kHz frequency hopping channels and three (3) 800 kHz dedicated beacon channels. The three wideband channels are used for dedicated beacon channels during network acquisition, while the fifty-eight narrowband channels are used for frequency hopping during normal network communication. If the 6 dB bandwidth of a channel is greater than 500 kHz, then frequency hopping is not needed. The three beacon channels, therefore, are advantageously used to provide frequency diversity in case one or more of the beacon frequencies are in a fade. Because only three dedicated beacon channels are in the 902-928 MHz frequency band, a node wishing to join the network is not required to listen to all 64 channels with the added complexity of frequency hopping.

[0021] In an alternative embodiment, the 902-928 MHz band may be divided into one hundred twenty-nine (129) 200 kHz channels. Nine narrowband channels may be removed from the frequency hopping sequence and used for three (3) 600 kHz dedicated beacon channels. If a beacon channel occupies 600 kHz, this would remove 9 narrowband channels from the frequency hopping channel list leaving 120 channels with a bandwidth 200 kHz.

[0022] FIG. 6 is a flow diagram of network master operation when receiving a node request to join during network acquisition. The network master selects a dedicated beacon channel at step 600 and transmits a beacon packet 602 periodically. The beacon packet may be similar to the beacon packet of FIG. 2 and includes control information to enable a node attempting to join the network to adapt to network frequency hopping protocol (FHP). The control information may also include other network operating information such as power modes, synchronization, time slot information, and other relevant control information to enable the node to join the network. The network master sends the beacon periodically followed by a listening period at step 604. If no request to join is received during the listening period 604, operation proceeds to test 612. If the network master does receive a request to join 606 during the listening period 604, it adds the requesting node as a child or slave 608 and becomes its network parent. At step 610 the network master sends the node a grant to join and proceeds to test 612. If the network master determines a packet is to be sent 612, it sends the packet to the appropriate network recipient 614 and receives an ACK (or NACK) 618 as determined by the packet cyclic redundancy check (CRC). The network master further determines if one or more of the network nodes has transmitted a request to send at test 620. If so, the network master receives the packet 622 and sends an ACK (or NACK) 624 as determined by the CRC. The network master then returns to step 602 and transmits another beacon on the dedicated beacon channel. The network master steps through a pseudo-random sequence of frequencies known to network slaves at each step 602. Each beacon includes unique network information (ID), so network slaves do not respond to the wrong network master. In example embodiments, a dedicated beacon channel is used for network acquisition in steps 600 through 610. Transmissions on the dedicated beacon channel have a greater bandwidth than normal frequency hopping channels, and corresponding beacons are transmitted with about the same transmit power as the normal frequency hopping channels. This advantageously improves reception and reduces acquisition time during network acquisition. An alternative embodiment is to have two distinct systems where one uses wideband channels such as in wireless LAN systems, and the joining of the network is done through that system. The frequency hopping system is a distinct system such as Bluetooth, and the frequency hopping information is passed from the wideband system to make it easier to join the frequency hopping system.

[0023] FIG. 7 is a flow diagram of node operation when requesting to join a network. A node attempting to join a network selects a beacon channel 700 to monitor. If the signal-to-noise ratio (SNR) of the selected beacon is unsuitable, the node may select a different beacon channel to monitor. If no beacon is received, the node continues to monitor the selected beacon channel. If a beacon is received on the dedicated beacon channel 702, the node transmits a request to join 704. The request to join is granted at step 708. The node then enters the network and operates according to network frequency hopping protocol (FHP) as specified by the beacon control information (FIG. 4). When the node enters the network, it becomes a slave to the network master and determines if a packet is to be received 710. If so, the slave receives the packet and sends an ACK (or NACK) 712 as determined by the CRC. The slave then proceeds to step 714 and determines if it has a packet to send. If so, the slave initiates a request to send and sends the packet 716 at the proper time. At step 718, the slave receives an ACK (or NACK) as determined by the CRC and returns to step 710. Example embodiments advantageously provide several dedicated beacon channels that are not subject to frequency hopping to facilitate network acquisition. A node attempting to join the network may select a beacon channel with the best SNR. The beacon is transmitted at a higher transmit power to further improve the SNR without interfering with the normal frequency hopping channels.

[0024] Modifications are possible in the described embodiments, and other embodiments are possible, within the scope of the claims.

CLAIMS

What is claimed is:

1. A method of operating a network on a plurality of frequency hopping channels, the method comprising:

transmitting a beacon on a beacon channel different from the frequency hopping channels;

receiving a request from a node to join the network in response to the beacon;

adding the node to the network in response to the step of receiving; and

communicating with the node on the plurality of frequency hopping channels after the step of adding.

2. The method of claim 1, wherein the beacon channel has a different bandwidth from each of the frequency hopping channels.

3. The method of claim 1, wherein the beacon is transmitted on a separate network from the network of the frequency hopping channels.

4. The method of claim 1, wherein beacon comprises control information to control network operation.

5. The method of claim 1, wherein beacon comprises frequency hopping protocol (FHP) information.

6. The method of claim 1, wherein beacon comprises a periodic sequence of frequencies.

7. The method of claim 1, wherein beacon channel comprises a plurality of dedicated beacon channels.

8. A method of operating a network on a plurality of frequency hopping channels, the method comprising:

receiving a beacon on a beacon channel different from the frequency hopping channels;

transmitting a request to a parent node to join the network in response to the beacon;

receiving a grant to join in response to the step of transmitting; and

communicating with the parent node on the plurality of frequency hopping channels after the step of receiving the grant to join.

9. The method of claim 8, wherein the beacon is received on a separate network from the network of the frequency hopping channels.

10. The method of claim 8, wherein transmit power of the beacon is greater than transmit power on the frequency hopping channels.

11. The method of claim 8, wherein beacon comprises control information to control network operation.

12. The method of claim 8, wherein the beacon comprises frequency hopping protocol (FHP) information.

13. The method of claim 8, wherein beacon channel comprises a plurality of dedicated beacon channels.

14. The method of claim 8, comprising monitoring the beacon channel for at least a duration of the beacon channel.

15. A method of operating a mesh network, the method comprising:

selecting a beacon channel;

selecting a plurality of frequency hopping channels different from the beacon channel;

transmitting a network beacon on the beacon channel; and

communicating data signals with a plurality of nodes in the mesh network over the plurality of frequency hopping channels.

16. The method of claim 15, comprising selecting the beacon channel from a plurality of dedicated beacon channels.

17. The method of claim 15, wherein the beacon channel has a different bandwidth from each of the frequency hopping channels.

18. The method of claim 15, wherein transmit power of the network beacon is greater than transmit power on the frequency hopping channels.

19. The method of claim 15, wherein network beacon comprises control information to control network operation.

20. The method of claim 15, wherein the network beacon comprises frequency hopping protocol (FHP) information.

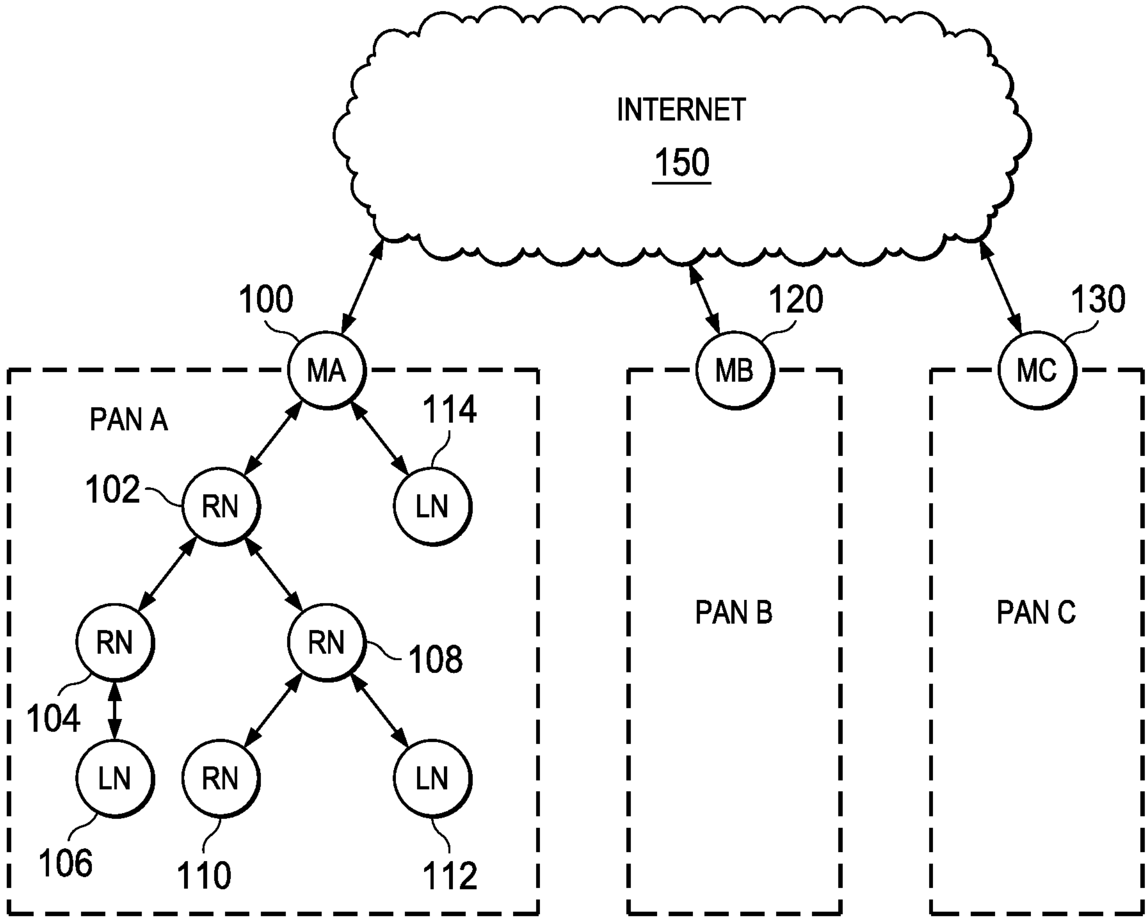


FIG. 1
(PRIOR ART)

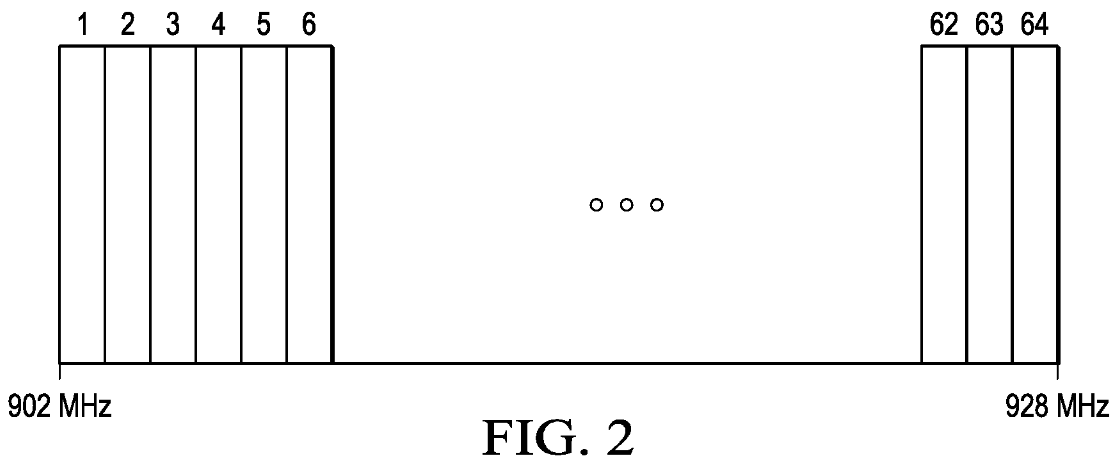


FIG. 2
(PRIOR ART)

TIME	0	1	2	3	4	5	6
GUESSED MASTER	0	1	2	3	4	5	6
SLAVE	0	2	1	5	2	8	3

FIG. 3
(PRIOR ART)

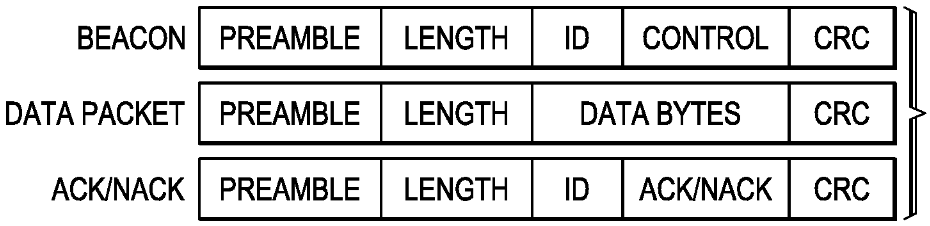


FIG. 4
(PRIOR ART)

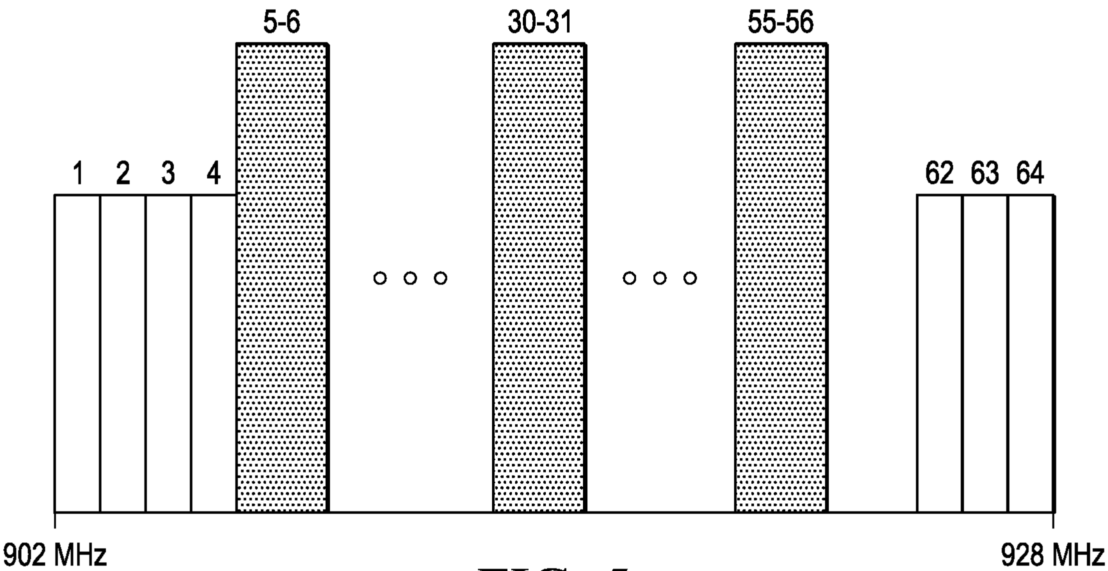


FIG. 5

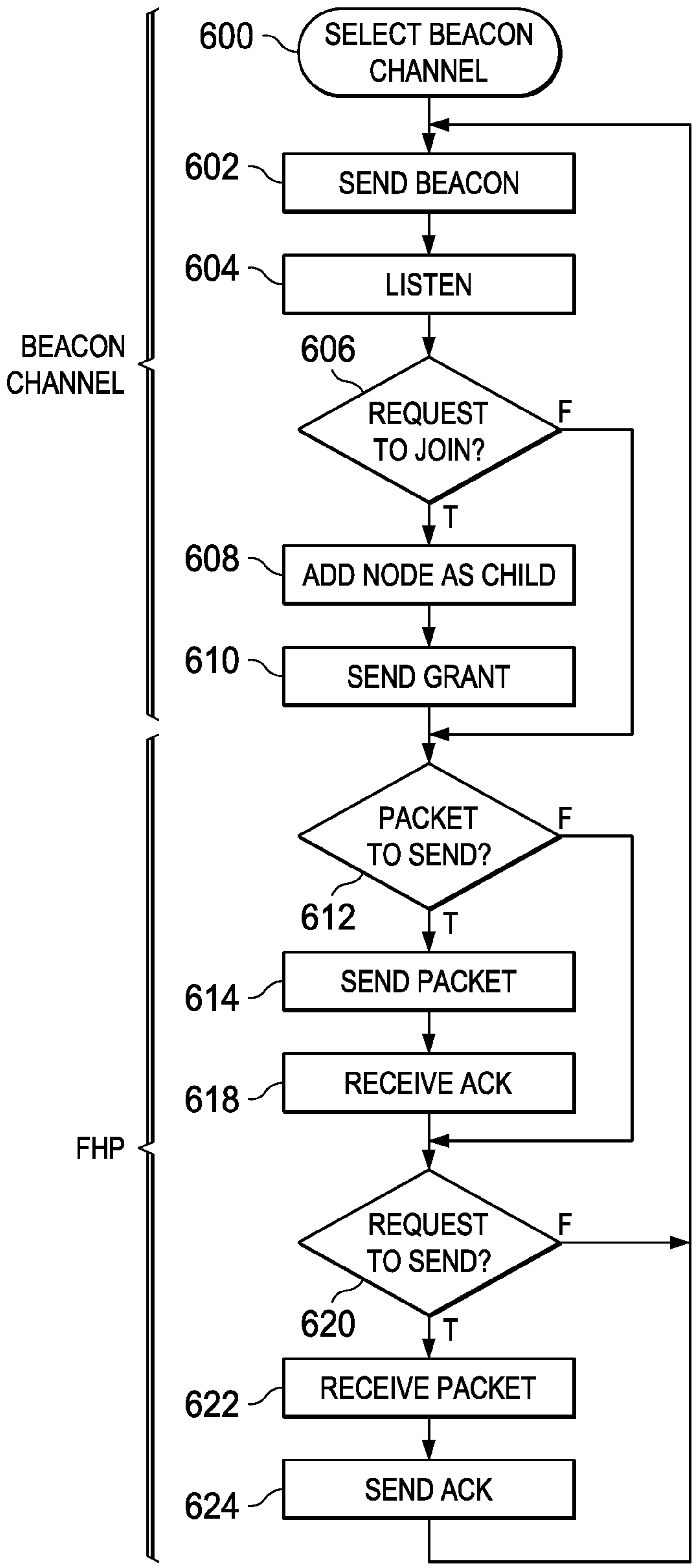
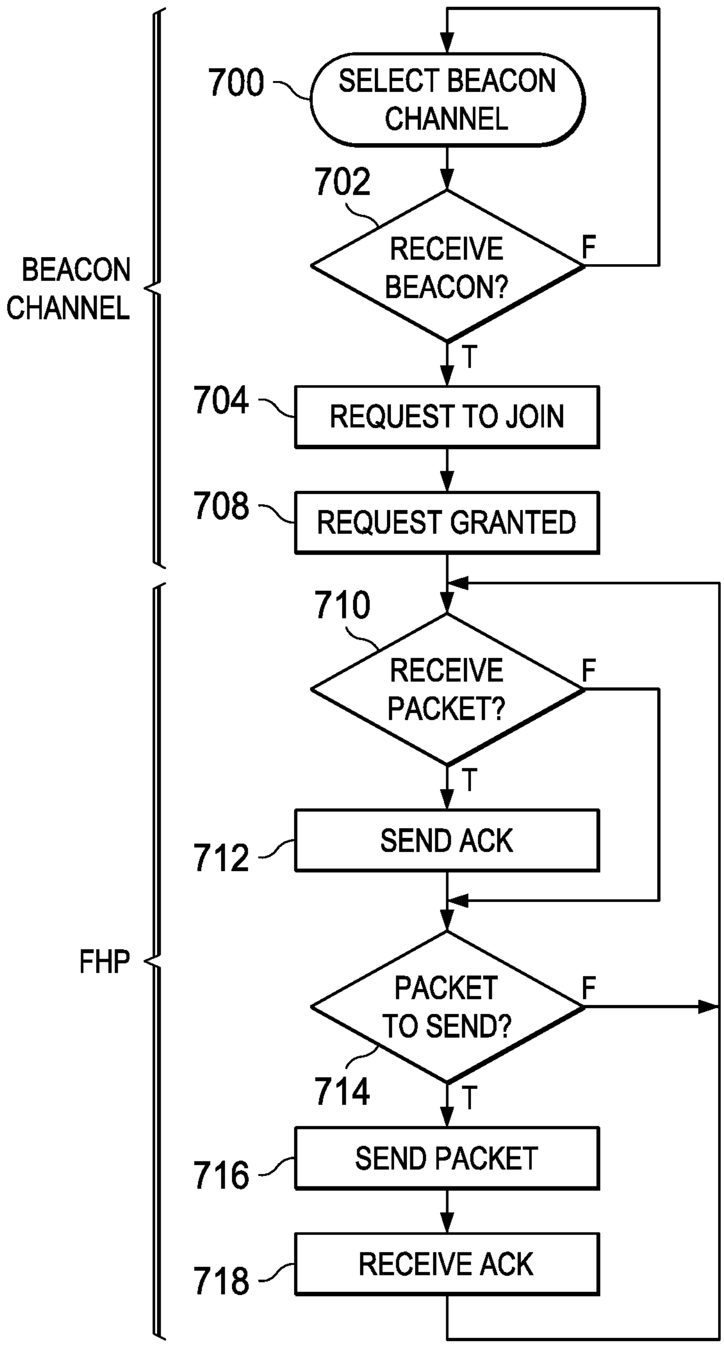

600
SELECT BEACON CHANNEL
602
SEND BEACON
604
LISTEN
606
REQUEST TO JOIN?
F
T
BEACON CHANNEL
608
ADD NODE AS CHILD
610
SEND GRANT
PACKET TO SEND?
F
612
T
614
SEND PACKET
618
RECEIVE ACK
FHP
REQUEST TO SEND?
F
620
T
622
RECEIVE PACKET
624
SEND ACK

FIG. 6



700
SELECT BEACON CHANNEL
702
RECEIVE BEACON?
F
T
BEACON CHANNEL
704
REQUEST TO JOIN
708
REQUEST GRANTED
710
RECEIVE PACKET?
F
T
712
SEND ACK
FHP
PACKET TO SEND?
F
714
T
716
SEND PACKET
718
RECEIVE ACK

FIG. 7

INTERNATIONAL SEARCH REPORT	International application No. PCT/US 2017/018591

A. CLASSIFICATION OF SUBJECT MATTER

H04L12/28 *(2006.01)*
H04B1/713 *(2011.01)*

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04L12/00, 12/02, 12/26, 12/28, 12/54, 12/66, H04B1/00, 1/69, 1/713, H04W 40/00, 40/02, 40/12, 40/22, 48/00, 48/16, 72/00, 72/02, 74/00, 74/02

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PatSearch (RUPTO internal), USPTO, PAJ, Esp@cenet, DWPI, EAPATIS, PATENTSCOPE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 2006264168 A1 (BLAISE L. CORBETT et al) 23.11.2006, abstract, [0020], [0038-039], [0045], [0050], [0052], [0067], [0074], [0077-0078]	1, 4, 8, 11 2-3, 5-7, 9-10, 12-20
Y	US 7505426 B2 (TROPOS NETWORKS) 17.03.2009, col.2, lines 7-9, 46-58, col.3, line 56 .4, line 45, col.6, line 45 .7, line 8, col.7, line 13 .8, line 15	15-20
Y	WO 2002/05448 A1 (TELEFONAKTIEBOLAGET L M ERICSSON) 17.01.2002, p.2, lines 11-15, p.9, line 5 –p.10, line 15	2, 17
Y	US 8897277 B2 (KYOCERA CORPORATION) 25.11.2014, col.21, lines 13-27	3, 9

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier document but published on or after the international filing date		
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed	"&"	document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
05 May 2017 (05.05.2017)	18 May 2017 (18.05.2017)
Name and mailing address of the ISA/RU: Federal Institute of Industrial Property, Berezhkovskaya nab., 30-1, Moscow, G-59, GSP-3, Russia, 125993 Facsimile No: (8-495) 531-63-18, (8-499) 243-33-37	Authorized officer T. Vlasenko Telephone No. 8 499 240 25 91

INTERNATIONAL SEARCH REPORT	International application No. PCT/US 2017/018591

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	US 7995527 B2 (QUALCOMM INCORPORATED) 09.08.2011, abstract	10, 18
A	CN 101978761 (MITSUBISHI ELECTRIC CORP) 16.02.2011	1-20