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(54) **WIRELESS NETWORK CIRCUITS, SYSTEMS, AND METHODS FOR FREQUENCY HOPPING WITH REDUCED PACKET INTERFERENCE**

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Related U.S. Application Data

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(51) **Int. Cl.**[7] **H04Q 7/00**
(52) **U.S. Cl.** **370/330**; 370/344
(58) **Field of Search** 370/330, 480, 370/342, 441, 442, 241, 252, 254, 389, 392, 465, 394, 344, 345; 375/130, 131, 132–134; 380/49, 9, 48, 59; 455/422, 436

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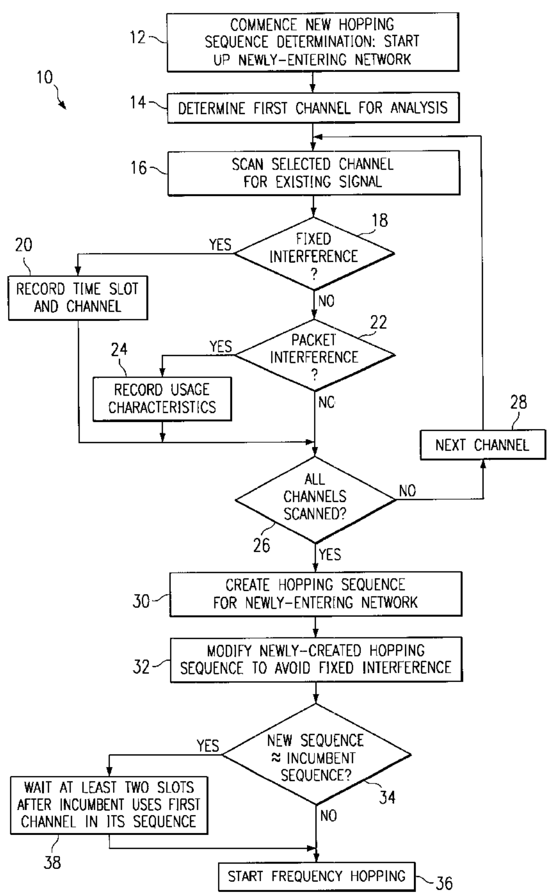
(57) **ABSTRACT**

A method **(10)** for determining a frequency hopping sequence for a newly-entering network. The method comprises the step of scanning **(16)** a plurality of frequency channels. For each of the plurality of frequency channels, the scanning step comprises detecting whether a signal **(18, 22)** exists on the channel and recording information **(20, 24)** corresponding to each channel on which a signal is detected. Finally, and responsive to the recorded information, the method forms **(30)** the frequency hopping sequence.

25 Claims, 2 Drawing Sheets



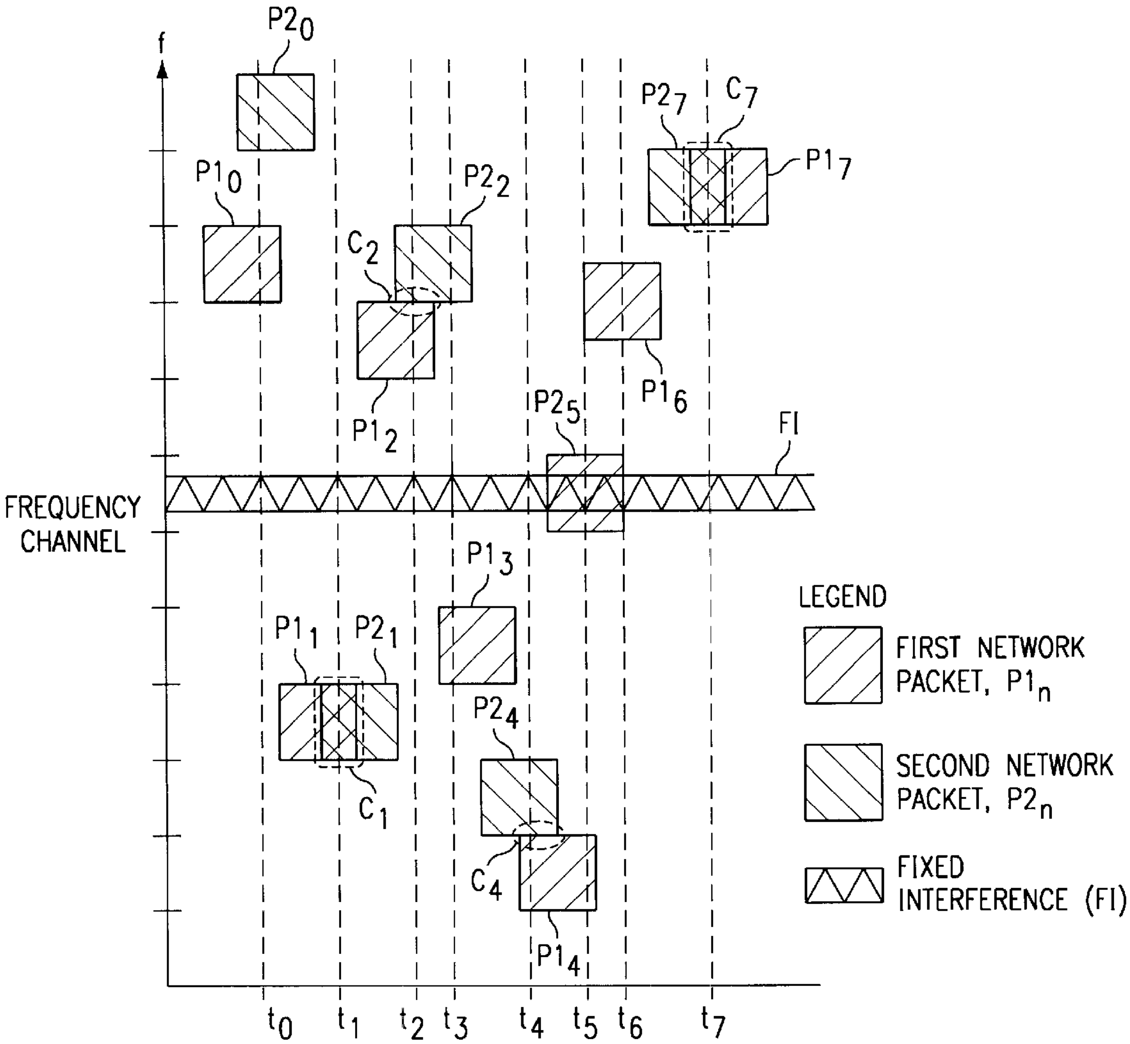

f
P2 0
P1 0
P2 2
C 2
P1 2
P2 7
C 7
P1 7
P1 6
P2 5
FI
FREQUENCY
CHANNEL
P1 3
P1 1
P2 1
C 1
P2 4
C 4
P1 4
t0 t1 t2 t3 t4 t5 t6 t7
LEGEND
FIRST NETWORK
PACKET, P1n
SECOND NETWORK
PACKET, P2n
FIXED
INTERFERENCE (FI)

FIG. 1

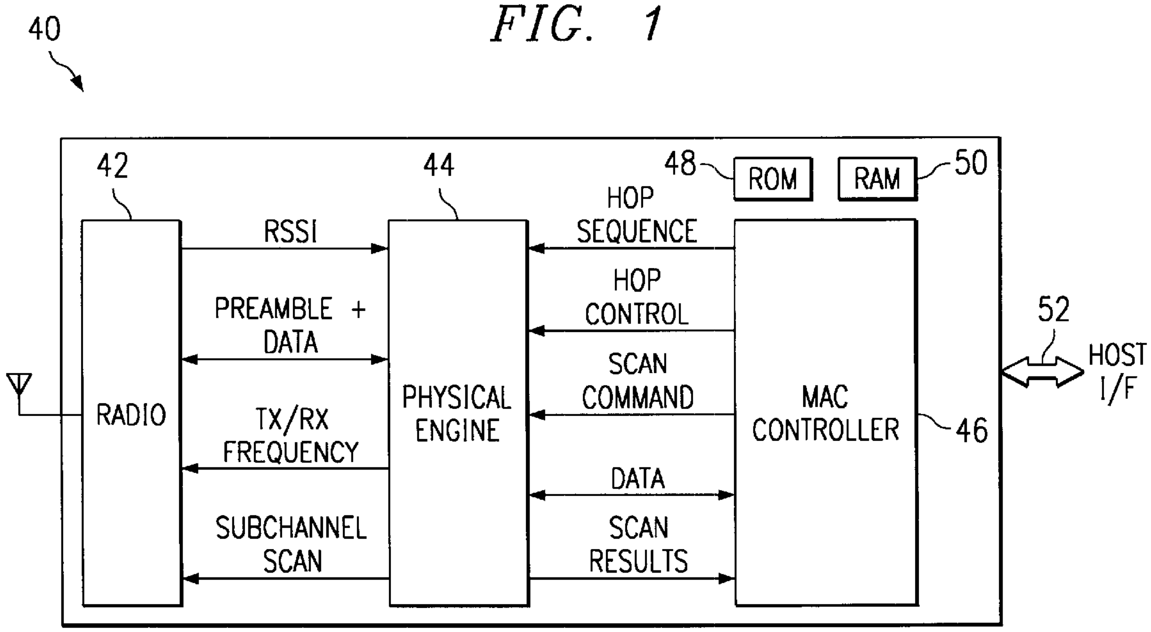
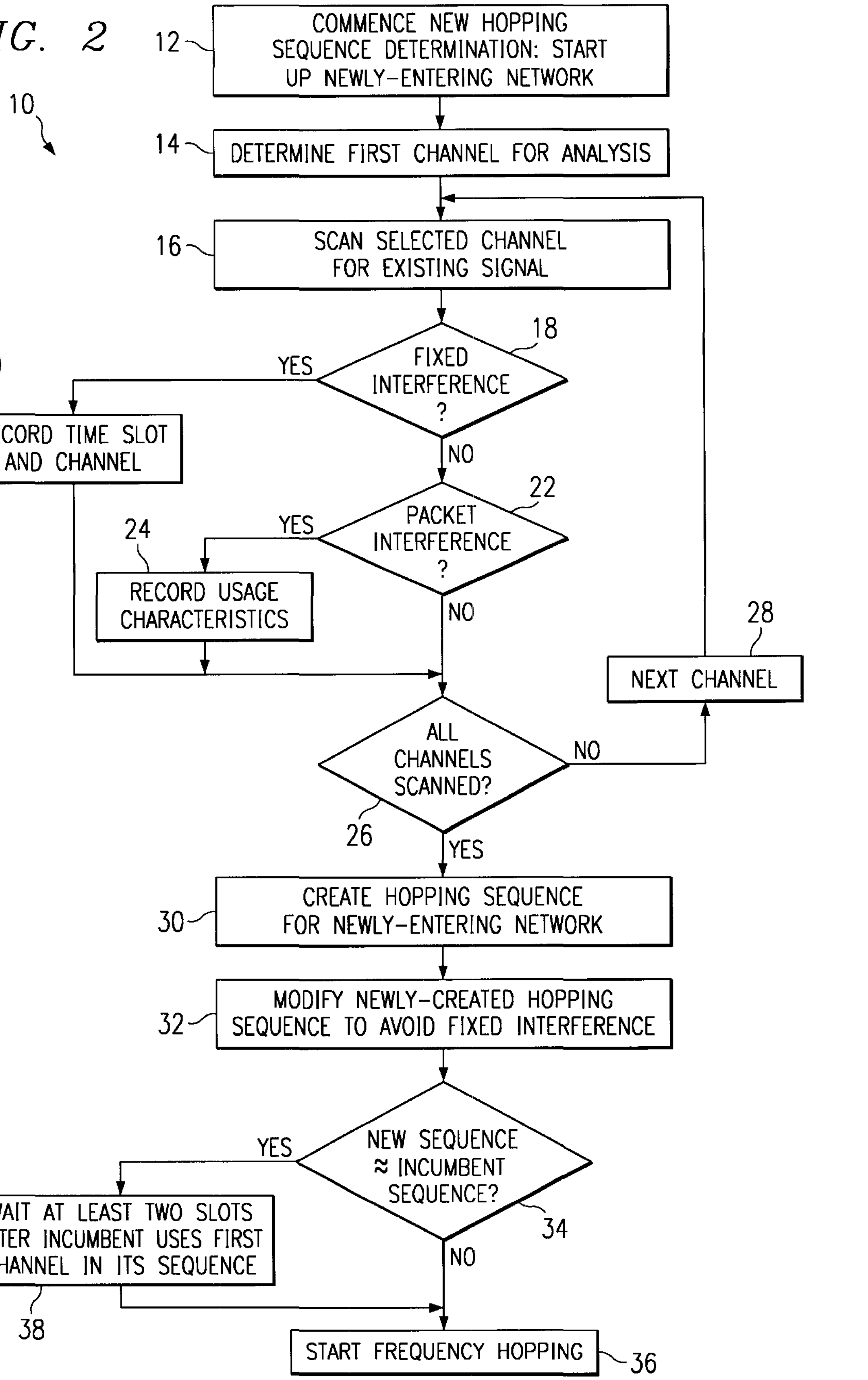

40
42
44
48
ROM
RAM
50
RSSI
HOP
SEQUENCE
PREAMBLE +
DATA
HOP
CONTROL
SCAN
COMMAND
RADIO
PHYSICAL
ENGINE
MAC
CONTROLLER
46
52
HOST
I/F
TX/RX
FREQUENCY
DATA
SUBCHANNEL
SCAN
SCAN
RESULTS

FIG. 3

FIG. 2


10
12
COMMENCE NEW HOPPING SEQUENCE DETERMINATION: START UP NEWLY-ENTERING NETWORK
14
DETERMINE FIRST CHANNEL FOR ANALYSIS
16
SCAN SELECTED CHANNEL FOR EXISTING SIGNAL
18
FIXED INTERFERENCE ?
YES
NO
20
RECORD TIME SLOT AND CHANNEL
22
PACKET INTERFERENCE ?
YES
NO
24
RECORD USAGE CHARACTERISTICS
28
NEXT CHANNEL
ALL CHANNELS SCANNED?
NO
26
YES
30
CREATE HOPPING SEQUENCE FOR NEWLY-ENTERING NETWORK
32
MODIFY NEWLY-CREATED HOPPING SEQUENCE TO AVOID FIXED INTERFERENCE
NEW SEQUENCE ≈ INCUMBENT SEQUENCE?
YES
34
NO
WAIT AT LEAST TWO SLOTS AFTER INCUMBENT USES FIRST CHANNEL IN ITS SEQUENCE
38
START FREQUENCY HOPPING
36

WIRELESS NETWORK CIRCUITS, SYSTEMS, AND METHODS FOR FREQUENCY HOPPING WITH REDUCED PACKET INTERFERENCE

This application claims the benefit of Provisional Application Ser. No. 60/125,573 filed Mar. 23, 1999.

CROSS-REFERENCES TO RELATED APPLICATIONS

Not Applicable.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not Applicable.

BACKGROUND OF THE INVENTION

The present embodiments relate to wireless communication systems, and are more particularly directed to such systems using frequency hopping.

Wireless networks are becoming increasingly popular, and in this regard there has been improvement in many aspects of such networks. Some improvements relate to configurations that permit simultaneously operation of different networks where there is minimal or no interference between communications belonging to each of the networks. In this respect, the term network is used, and is further used in the same manner for the remainder of this document, to describe a system consisting of an organized group of intercommunicating devices. Further in this respect, the different networks may be labeled according to a first network that is already transmitting in time followed by a second network in time seeking to transmit and thereby possibly communicating and causing interference due to a communication overlapping the pre-existing communication of the first network. Accordingly, to facilitate the remaining discussion, such a first network is referred to as an incumbent network, while the network which seeks to communicate, or in fact does communicate, after the incumbent network is referred to as the newly-entering network. Given this terminology, the present background and embodiments discussed below are directed to reducing interference between incumbent network communications and newly-entering network communications.

One approach to reducing the above-introduced interference is known in the art as spread spectrum frequency hopping and is sometimes referred to more simply as frequency hopping. In frequency hopping, a newly-entering network transmitter transmits packets of information at different frequencies in an effort to reduce the chance that the packet will interfere or "collide" with a packet transmitted at a frequency by a transmitter in an incumbent network. The change between frequencies, that is, from one frequency to another, is said to be a "hop" between the frequencies. Moreover, the goal is such that each packet from a newly-entering network is transmitted at a frequency which neither overlaps nor is near enough to a frequency at which an incumbent network is transmitting. Further in this regard, some systems (e.g., using Bluetooth protocol) transmit each successive packet at a different frequency, that is, the transmitter is "hopping" to a different frequency for each packet. Alternatively, others systems (e.g., IEEE 802.11) transmit a first set of packets at a first frequency, and then hop to a second frequency to transmit a second set of packets, and so forth for numerous different sets of packets at numerous

different respective frequencies. Note further that if interference or a collision does occur, it typically corrupts the data of both packets, that is, the data transmitted by both the newly-entering network and the incumbent network. As a result, both networks are then required to re-transmit the packets an additional time so as to replace the corrupted data resulting from the collision.

In an effort to achieve minimal packet collision using frequency hopping, two prior art methods have arisen for determining the different frequencies to which a network will hop. In a first method, a frequency hopping network uses a pre-ordained hopping sequence. This first approach is used by way of example under the IEEE 802.11 standard. In a second method, a seed is provided to a pseudo-random generator which produces a corresponding pseudo-random series of frequencies along which the network hops. This second approach is used by way of example under the fairly recently developed Bluetooth protocol. Both of these approaches have achieved some level of success in reducing the amount of inter-network packet collision. Nevertheless, the present inventors have empirically determined that by locating two or more different networks in the same vicinity such that transmissions from each different network effectively compete for airtime, there still arises a considerable amount of packet collisions, thereby reducing the effective transmission rate for each network.

Frequency hopping as described thus far reduces the chances of interference between a packet from newly-entering network and a packet from an incumbent network. Further in this regard and by way of additional background, FIG. **1** illustrates communications of such packets and, as detailed below, it also illustrates instances where packet collisions occur. Looking to FIG. **1** in greater detail, its horizontal axis illustrates time (or time slots), and its vertical axis indicates frequency. Additionally, FIG. **1** illustrates a number of blocks, where each block is intended to depict a packet as transmitted by either an incumbent network or a newly-entering network. Further in this regard, note that the term "packet" is used in this document to define a block of information sent in a finite period of time, where subsequent such packets are sent at other times. This block of information may take on various forms, and sometimes includes different information types such as a preamble or other type of control information, followed by user information which is sometimes also referred to as user data. Further, the overall packet also may be referred to in the art by other names, such as a frame, and thus these other information blocks are also intended as included within the term "packet" for purposes of defining the present inventive scope. In any event, returning to FIG. **1**, for the sake of reference, each packet illustrated in FIG. **1** is labeled with an identifier using the letter "P" (i.e., for packet) and following after that letter is a number corresponding to the network which transmitted the packet. More particularly, packets transmitted by the first network (i.e., the incumbent network) are labeled with an identifier P**1** while packets transmitted by the second network (i.e., the newly-entering network) are labeled with an identifier P**2**. Further, the subscript for each packet identifies a time period encompassed by the duration of the packet. For example, during a time to, the first network transmits a packet $\mathbf{P1}_0$ while also during time t_0 the second network transmits a packet $\mathbf{P2}_0$. Further in this regard, in the prior art transmissions by the first network are asynchronous with respect to transmissions of the second network, both in start time and periodicity. Thus, time t_0 is only meant as a relative indication for the first packet from each network, and it is not intended to suggest that the packets from both networks begin and end at the same time.

With respect to all packets in FIG. **1**, the preceding demonstrates that each packet begins at a certain time, ends at a later time, and fills a certain frequency range (where the range is referred to as a channel). As a result and as described below, interference may occur if the area in FIG. **1** defined by a packet overlaps or is within a certain distance of a packet from another wireless link. Indeed and as discussed below, such interference may occur in one of four different ways.

Time t_1 in FIG. **1** illustrates a first type of packet interference, where it may be seen that the first network transmits a packet **P1**$_1$ After packet **P1**$_1$ commences but also during time t_1 the second network transmits a packet **P2**$_1$. The overlap of packets **P1**$_1$ and **P2**$_1$ is shown as a first collision C_1. Note that the horizontal alignment of packets **P1**$_1$ and **P2**$_1$ graphically indicates that in the example of collision C_1, both packets occupy the same frequency channel. Thus, collision C_1 represents an example where two different networks attempt to transmit packets during an overlapping time period and along the same channel.

Before proceeding with other types of packet collisions, an additional discussion is noteworthy with respect to a methodology which has been used to further reduce the likelihood and impact of packet collisions such as collision C_1. More particularly, this additional methodology is referred to in the art as listen-before-talk ("LBT"). In an LBT system, the system uses the hopping sequence described above, but prior to transmitting along a channel in the sequence the system monitors (or "listens") at the channel to determine if there is another packet already occupying that channel during the current time. Returning to packet **P1**$_1$ by way of example, if the second network employed LBT, then it would listen at the desired channel at which it intended to transmit **P2**$_1$ and would therefore detect the presence of packet **P1**$_1$. As a result, the second network would avoid collision C**1** by not transmitting packet **P2**$_1$ at the desired frequency, but instead it would delay a random period and then proceed to the next designated channel of its hopping sequence. Next, the second network would listen at that next designated channel to again determine if that channel was occupied by a packet from another network, and if no packet was detected then the second network would transmit its packet; however, if this next designated channel also was occupied, then the second network would continue to examine additional channels in this same manner until a channel was detected without being occupied by a packet from another network, at which time the second network would transmit its packet along the now unoccupied channel. Given this process, however, note that a delay arises in LBT systems, where the amount of delay depends on the number of times that the LBT network is forced to listen, detect, and advance from an occupied channel, and then delay an additional random period to listen, detect, and transmit along an unoccupied channel.

While LBT as shown above reduces the possibility of collisions, it also has drawbacks. For example, LBT delays transmission by the network which was prepared to transmit along a channel but was prevented from doing so due to an already-transmitted packet in the desired channel. As another example, it adds an element of delay to each packet due to its listening aspect. Also, all the devices in an environment must utilize LBT to gain the most benefit (fairness) of the scheme. As still another example, some protocols (e.g., Bluetooth) utilized in the unlicensed bands do not support LBT, while such protocols may nonetheless provide other beneficial aspects and, thus, the choice to use such a protocol is a tradeoff in that other aspects are obtained without the availability of LBT.

Time t_2 in FIG. **1** illustrates a second type of packet interference in connection with a collision C_2 occurring between a first network packet **P1**$_2$ and a second network packet **P2**$_2$. For collision C_2, the incumbent first network transmits packet **P1**$_2$ during a period including time t_2 and at a first channel, and thereafter the second network transmits packet **P2**$_2$ also during a period including time t_2 (i.e., the periods of the packets overlap). Packet **P2**$_2$ is transmitted at a second channel which, while different than the channel of packet **P1**$_2$, it is immediately adjacent the channel occupied by packet **P1**$_2$. Further in this regard, it is known in the art that while packets occupy a certain channel as shown by the vertical displacement of a packet in FIG. **1**, there is an additional tendency for a packet to provide slight interference or "splatter" into adjacent frequency channels. As a result of this effect, even though packets **P1**$_2$ and **P2**$_2$ occupy different channels, they are still in adjacent channels and, thus, they are close enough to one another in frequency such that the splatter effect causes a collision between the packets. Indeed, in some networks the filters used are relatively inexpensive and, as a result, the concept illustrated with packets **P1**$_2$ and **P2**$_2$ may also apply to next-adjacent channels, that is, to the channels that are one more channel away from the channels adjacent to the channel in which a packet is transmitted. Thus, collision C_2 represents an example where two different networks attempt to transmit packets during an overlapping time period and along adjacent (or next-adjacent) frequency channels. Here, if neither network uses LBT, then both packets **P1**$_2$ and **P2**$_2$ will require retransmission due to the collision. If, however, the network that intended to transmit the second packet of the two uses LBT, then note first that LBT mechanisms are less likely to correctly discern an adjacent channel collision. However, if the LBT mechanism does recognize the potential adjacent channel collision, then the second packet is not transmitted along the channel represented by **P2**$_2$ and instead that packet is delayed. This delay, while diminishing the effective transmission of the second network, avoids any disturbance to the first already-existing packet. In the example of time t_2, therefore, if the second network uses LBT, then packet **P1**$_2$ will not be disturbed because the second network will move the transmission of packet **P2**$_2$ to a different channel.

Time t_4 in FIG. **1** illustrates a third type of packet interference in connection with a collision C_4, which is comparable to collision C_2 except that for collision C_4 the networks transmit in opposite order. More particularly, for collision C_4, the second network first transmits a packet **P2**$_4$ and, thereafter, the first network transmits a packet **P1**$_4$. The duration of both of these packets overlaps time t_4, and again their channels are adjacent to one another rather than being the same channel. Nonetheless, the splatter effect again causes sufficient reach of each packet into the adjacent channel such that a collision occurs. Here, if neither network uses LBT, then both packets **P2**$_4$ and **P1**$_4$ require re-transmission due to the collision; if, however, the network transmitting the second packet in time (i.e., **P1**$_4$) of the two which would otherwise collide uses LBT, then only that packet is delayed and the first already-existing packet (i.e., **P2**$_4$) is not disturbed.

Time t_7 in FIG. **1** illustrates a fourth type of packet interference in connection with a collision C_7, which is comparable to collision C_1 except that for collision C_7 the networks transmit in opposite order. More particularly, for

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