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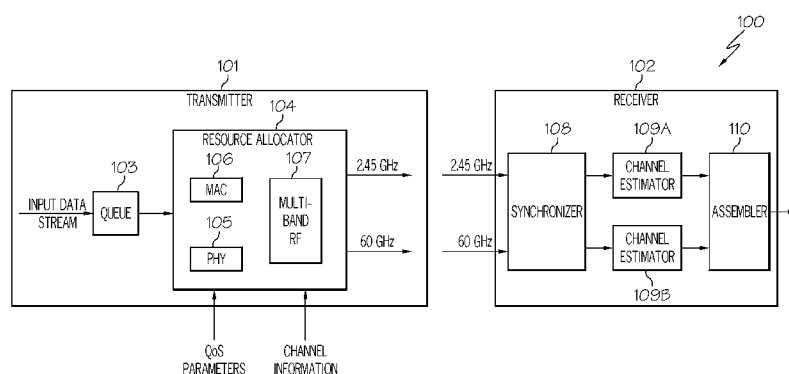


FIG. 1

(57) Abstract: A method and system for improving the throughput of a wireless communication system. A resource allocator in a transmitter is configured to implement the functionality of the physical layer and the media access control layer across multiple frequency bands. The resource allocator is configured to split the control information and the data information in the received data stream among multiple frequency bands. Information that requires high throughput is to be allocated to the higher frequency band; whereas, information that requires high reliability is to be allocated to the lower frequency band. As a result, particular functions, such as synchronization and frequency offset are to be performed at the lower frequency band. By reducing the amount of information that needs to be transmitted on the higher frequency band, the throughput is improved as well as the reliability of the symbol rate.

IMPLEMENTING PHYSICAL LAYER AND MEDIA ACCESS CONTROL LAYER
FUNCTIONALITY ACROSS FREQUENCY BANDS JOINTLY

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is related to the following commonly owned co-pending U.S. Patent Application:

[0002] Provisional Patent Application Serial No. 61/113,283, "Implementing Physical Layer and Media Access Control Layer Functionality Across Frequency Bands Jointly," filed November 11, 2008, and claims the benefit of its earlier filing date under 35 U.S.C. §119(e).

TECHNICAL FIELD

[0003] The present invention relates to wireless communication, and more particularly to implementing physical layer and media access control layer functionality across multiple frequency bands jointly.

BACKGROUND OF THE INVENTION

[0004] Wireless communication is the transfer of information over a distance without the use of electrical conductors or wires. One such wireless communication system is referred to as a multiple-input and multiple-output ("MIMO") system. A MIMO system involves the use of multiple antennas at both the transmitter and receiver to improve communication performance. It has recently attracted much attention since it offers significant increases in data throughput and link range without additional bandwidth or transmit power. It achieves this by higher spectral efficiency (more bits per second per hertz of bandwidth) and link reliability or diversity (reduced fading).

[0005] However, there is a limit in the amount of increase in the data throughput and link range as there is a limit in the number of additional antennas to be used by the transmitter and receiver due to the increase in power consumption and cost. Further, there is a limit as to how much additional gain can be achieved through the use of additional antennas.

[0006] As a result, there has been an attempt to improve the data throughput through using multiple frequency bands, such as the additional use of an unlicensed higher frequency band (e.g., 60 GHz) that operates in the same coverage area as the frequency band (e.g., 2.45 GHz) currently being used by the wireless communication system. However, different bands

display different transmission characteristics, including path loss (range), bandwidth, Doppler (how quickly the wireless channel fluctuates), and hardware power consumption. For example, as the carrier frequency of transmission increases, the transmission range generally decreases. Hence, if the receiver and transmitter are beyond the range of communicating on the higher frequency band, then this frequency band may only be used through the use of repeaters. The physical layer and the media access control layer are currently being designed separately for each frequency band (e.g., 2.45 GHz and 60 GHz). As a result, it is difficult to coordinate the interactions between the repeaters. That is, it is difficult to coordinate the interactions between the multiple hops from the transmitter to the receiver, which as a result, reduce throughput and increase latency in the wireless communication system.

[0007] If, however, the multiple distinct frequency bands (e.g., 2.45 GHz, 60 GHz) to be used by the transmitter and receiver could be coordinated with the same protocol (e.g., physical layer and media access control layer), then the transmission characteristics of each band may be considered for protocol design, and hence, throughput may be improved and latency may be reduced thereby improving the overall performance of the wireless communication system.

BRIEF SUMMARY OF THE INVENTION

[0008] In one embodiment of the present invention, a method for improving the throughput of a wireless communication system comprises receiving an input data stream, where the input data stream comprises control and data information. The method further comprises determining how the data information is to be split among multiple frequency bands. Furthermore, the method comprises determining how the control information is to be split among the multiple frequency bands. Additionally, the method comprises splitting the data information and the control information among the multiple frequency bands. Further, the method comprises transmitting the data information and the control information split among the multiple frequency bands.

[0009] In another embodiment of the present invention, a wireless communication system comprises a transmitter, where the transmitter comprises a queue configured to store a received input data stream, where the input data stream comprises control and data information. The transmitter further comprises a resource allocator coupled to the queue, where the resource allocator is configured to determine how the data information is to be split among multiple frequency bands. Further, the resource allocator is configured to determine how the control information is to be split among the multiple frequency bands. Additionally, the resource allocator is configured to split the data information and the control information among the multiple frequency bands. Further, the resource allocator is configured to transmit the data information and the control information split among the multiple frequency bands.

[00010] The foregoing has outlined rather generally the features and technical advantages of one or more embodiments of the present invention in order that the detailed description of the present invention that follows may be better understood. Additional features and advantages of the present invention will be described hereinafter which may form the subject of the claims of the present invention.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

[00011] A better understanding of the present invention can be obtained when the following detailed description is considered in conjunction with the following drawings, in which:

[00012] Figure 1 illustrates an embodiment of the present invention of a wireless communication system;

[00013] Figure 2 illustrates splitting control and data information received from a data stream among multiple frequency bands in accordance with an embodiment of the present invention;

[00014] Figure 3 is another illustration of splitting control and data information received from a data stream among multiple frequency bands in accordance with an embodiment of the present invention;

[00015] Figure 4 is a further illustration of splitting control and data information received from a data stream among multiple frequency bands in accordance with an embodiment of the present invention;

[00016] Figure 5 is a flowchart of a method for improving the throughput of a wireless communication system using the functionality of the transmitter of the present invention in accordance with an embodiment of the present invention; and

[00017] Figure 6 is a flowchart of a method for improving the throughput of a wireless communication system using the functionality of the receiver of the present invention in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[00018] In the following description, numerous specific details are set forth to provide a thorough understanding of the present invention. However, it will be apparent to those skilled in the art that the present invention may be practiced without such specific details. For instance, certain components of a transmitter and receiver (e.g., modulators, demodulators) were not depicted or described in order to not obscure the principles of the present invention as well as for ease of understanding. However, one of ordinary skill in the art would know that such components exist and would be capable of implementing these components in connection with the embodiments disclosed herein. In other instances, well-known circuits have been shown in block diagram form in order not to obscure the present invention in unnecessary detail. For the most part, details considering timing considerations and the like have been omitted inasmuch as such details are not necessary to obtain a complete understanding of the present invention and are within the skills of persons of ordinary skill in the relevant art.

[00019] As discussed in the Background section, there have been attempts to improve the data throughput through using multiple frequency bands, such as the additional use of an unlicensed higher frequency band (e.g., 60 GHz) that operates in the same coverage area as the frequency band (e.g., 2.45 GHz) currently being used by the wireless communication system. However, as the frequency rate increases, the transmission range decreases. Hence, if the receiver and transmitter are beyond the range of communicating on the higher frequency band, then this frequency band may only be used through the use of repeaters. The physical layer and the media access control layer are currently being designed separately for each frequency band (e.g., 2.45 GHz and 60 GHz). As a result, it is difficult to coordinate the interactions between the repeaters. That is, it is difficult to coordinate the interactions between the multiple hops from the transmitter to the receiver, which as a result, reduce throughput and increase latency in the wireless communication system. If, however, the multiple distinct frequency bands (e.g., 2.45 GHz, 60 GHz) to be used by the transmitter and receiver could be coordinated with the same protocol (e.g., physical layer and media access control layer), then throughput may be improved and latency may be reduced thereby improving the overall performance of the wireless communication system.

[00020] The wireless communication system of the present invention uses a physical layer and a media access control layer that is coordinated across multiple frequency bands thereby

improving throughput and reducing latency. A description of such a wireless communication system is discussed below in connection with Figure 1.

[00021] Figure 1 illustrates an embodiment of the present invention of a wireless communication system 100. Referring to Figure 1, wireless communication system 100 includes a transmitter 101 configured to transmit a received data stream across multiple frequency bands to a receiver 102. It is noted that Figure 1 does not depict several components (e.g., antennas, modulators, demodulators) that are standard in transmitters and receivers in order to not obscure the principles of the present invention as well as for ease of understanding. A person of ordinary skill in the art would know these standard components and would be capable of implementing these standard components in connection with the transmitters and receivers depicted in Figure 1.

[00022] Transmitter 101 includes one or more queues 103 configured to store the input data stream, which includes both control information and data information. Control information may include information such as the short training field and the long training field used in connection with the IEEE 802.11a standard. Data information may include data, such as voice, audio, computer files, etc.

[00023] Transmitter 101 may further include a resource allocator 104 configured to perform the functionality of the physical layer and the media access layer across multiple frequency bands. Resource allocator 104 may include a component 105 (indicated as "PHY" in Figure 1) configured to perform the physical layer functionality across multiple frequency bands. Physical layer functionality involves splitting the "control information" among multiple frequency bands as discussed herein. Further, resource allocator 104 may include a component 106 (indicated as "MAC" in Figure 1) configured to perform the media access control layer functionality across multiple frequency bands. Media access control functionally involves splitting the "data information" among multiple frequency bands as discussed herein. In one embodiment, PHY 105 and MAC 106 are designed jointly.

[00024] Additionally, resource allocator 104 is configured to split the control and data information in the received data stream (i.e., split the received data and control information) across multiple bands in a radio frequency spectrum 107 using the received quality of service (indicated as "QoS" in Figure 1) parameters and channel information for each frequency band to be used in radio frequency spectrum 107.

[00025] For instance, suppose that the input data stream included physical layer control information, such as the short training field, the long training field and the signaling field used in connection with the IEEE 802.11a standard. The short training field may be used for signal detection, automatic gain control, synchronization and/or generating an initial frequency-offset estimate. The long training field may be used to estimate the channel characteristics and/or to fine tune the initial frequency-offset estimate. The signaling field may be used to define data rate and the frame length. Further, suppose that the input data stream included data, such as data from a computer file.

[00026] Resource allocator 104 may be configured to split the control and data information among multiple frequency bands (e.g., 2.45 GHz and 60 GHz), such as illustrated in Figure 2. Figure 2 illustrates splitting the control and data information received from a data stream among multiple frequency bands (e.g., 2.45 GHz and 60 GHz) in accordance with an embodiment of the present invention. Referring to Figure 2, the control information, such as the short training field (indicated as "STF" in Figure 2), the long training field (indicated as "LTF" in Figure 2) and the signaling field (indicated as "SIG" in Figure 2) may be transmitted on the lower frequency band (e.g., 2.45 GHz). However, only the long training field associated with the higher frequency band (e.g., 60 GHz) as well as the received data (e.g., computer file) (indicated as "DATA" in Figure 2) may be transmitted on the higher frequency band (e.g., 60 GHz).

[00027] By performing such functions, such as synchronization and frequency offset at the lower frequency band, the performance at the higher frequency band is improved by reducing the amount of information to be transmitted thereby improving the throughput as well as improving the reliability of the symbol rate.

[00028] Furthermore, resource allocator 104 (Figure 1) uses the quality of service parameters to determine what, if any data information, should be transmitted on the different frequency bands based on the type of data to be transmitted. For instance, if the data to be transmitted requires high throughput, such as a computer file, then such data may be transmitted on bands with larger spectral width (i.e., bandwidth). Since higher frequency bands often have more bandwidth available, it is often desirable to use the higher frequency bands for high throughput. While the higher frequency band may be used for high throughput data, the higher frequency band has less reliability for a fixed range. The opposite is true for the lower frequency band. Hence, one may only be interested in transmitting information that requires high reliability, such as low throughput Internet traffic, on the low frequency band. However,

one may be interested in transmitting information that requires high throughput but does not require high reliability, such as video information, on the higher frequency band.

[00029] An illustration of transmitting different types of data across multiple frequency bands is provided in Figure 3. Figure 3 illustrates splitting data information received from a data stream among multiple frequency bands (e.g., 2.45 GHz and 60 GHz) in accordance with an embodiment of the present invention. Referring to Figure 3, data that requires high reliability and low latency, such as voice over Internet Protocol data, may be transmitted on the lower frequency band (e.g., 2.45 GHz). However, data that requires high throughput, such as a compute file, may be transmitted on the higher frequency band (e.g., 60 GHz).

[00030] Furthermore, resource allocator 104 (Figure 1) divides media access control functionality across multiple frequency bands (e.g., 2.45 GHz and 60 GHz) as illustrated in Figure 4. Figure 4 illustrates dividing media access control functionality across multiple frequency bands (e.g., 2.45 GHz and 60 GHz) in accordance with an embodiment of the present invention. As illustrated in Figure 4, the acknowledgement signal (indicated as "ACK" in Figure 4) to acknowledge receipt of a message may be transmitted on the lower frequency band (e.g., 2.45 GHz). However, data that requires high throughput, such as a computer file, may be transmitted on the higher frequency band (e.g., 60 GHz).

[00031] Returning to Figure 1, wireless communication system 100 includes receiver 102 which receives the control and data information split among multiple frequency bands. Receiver 102 may include a synchronizer 108 configured to synchronize the data information and the control information split among the multiple frequency bands (e.g., 2.45 GHz and 60 GHz). Synchronization may take place by using a same clock signal for all the frequency bands. Synchronizer 108 is configured to perform various functions in connection with synchronizing, such as detecting a packet in a random access network, determining a fine timing of symbols and correcting frequency offsets.

[00032] Receiver 102 may further include channel estimators 109A-B for estimating a channel impulse response for a frequency band. Channel estimators 109A-B may collectively or individually be referred to as channel estimators 109 or channel estimator 109, respectively. In one embodiment, each channel estimator 109 is associated with a particular frequency band. For example, channel estimator 109A is associated with the lower frequency band (e.g., 2.45 GHz) and channel estimator 109B is associated with the higher frequency band (e.g., 60 GHz). Channel estimator 109A would then be configured to estimate a

channel impulse response for the lower frequency band (e.g., 2.45 GHz) and channel estimator 109B would then be configured to estimate a channel impulse response for the higher frequency band (e.g., 60 GHz).

[00033] Receiver 102 may additionally include an assembler 110 configured to recombine the data information and the control information split among the multiple frequency bands using the estimated channel impulse response for each frequency band (e.g., 2.45 GHz, 60 GHz) after the data information and the control information that was split among the frequency bands has been synchronized by synchronizer 108. Assembler 110 may have functionality similar to a detector, which assembles bits from the symbols.

[00034] A flowchart of a method for improving the throughput of a wireless communication system 100 (Figure 1) using the functionality of transmitter 101 (Figure 1) is discussed below in connection with Figure 5. Figure 5 is a flowchart of a method 500 for improving the throughput of wireless communication system 100 (Figure 1) using the functionality of transmitter 101 (Figure 1) in accordance with the principles of the present invention.

[00035] Referring to Figure 5, in conjunction with Figures 1-4, in step 501, transmitter 101 receives an input data stream to be stored in one or more queues 103. The input data stream may include both control and data information.

[00036] In step 502, resource allocator 104 determines how the data information is to be split among the multiple frequency bands (e.g., 2.45 GHz and 60 GHz). As discussed above, resource allocator 104 may distribute the data information based on the quality of service parameters and channel information. Resource allocator 104 may transmit high reliability data on the lower frequency band (e.g., 2.45 GHz); whereas, resource allocator 104 may transmit high throughput data on the higher frequency band (e.g., 60 GHz). It is noted that resource allocator 104 may transmit all of the data information on one of the multiple frequency bands or may transmit a portion of the data information on each of the multiple frequency bands. The statement of resource allocator 104 determining how to split the data information among the multiple frequency bands is to include these scenarios.

[00037] In step 503, resource allocator 104 determines how the control information is to be split among the multiple frequency bands (e.g., 2.45 GHz and 60 GHz). As discussed above, resource allocator 104 may distribute the control information based on the quality of service parameters and channel information. For example, resource allocator 104 may transmit control information, such as the short training field and the signaling field, on the lower

frequency band as well as the long training field associated with the low frequency band. In another example, resource allocator 104 may transmit the long training field associated with the higher frequency band on the higher frequency band.

[00038] In step 504, resource allocator 104 splits the data information and the control information among the multiple frequency bands in accordance with the determinations made in steps 502 and 503.

[00039] In step 505, transmitter 101 transmits the data information and the control information split among the multiple frequency bands to receiver 102.

[00040] Method 500 may include other and/or additional steps that, for clarity, are not depicted. Further, method 500 may be executed in a different order presented and that the order presented in the discussion of Figure 5 is illustrative. Additionally, certain steps in method 500 may be executed in a substantially simultaneous manner or may be omitted.

[00041] A flowchart of a method for improving the throughput of a wireless communication system 100 (Figure 1) using the functionality of receiver 102 (Figure 1) is discussed below in connection with Figure 6. Figure 6 is a flowchart of a method 600 for improving the throughput of wireless communication system 100 using the functionality of receiver 102 (Figure 1) in accordance with the principles of the present invention.

[00042] Referring to Figure 6, in conjunction with Figures 1-4, in step 601, receiver 102 receives the data information and the control information split among the multiple frequency bands (e.g., 2.45 GHz and 60 GHz).

[00043] In step 602, synchronizer 108 synchronizes the data information and the control information split among the multiple frequency bands. Synchronizing may involve various functions, such as detecting a packet in a random access network, determining a fine timing of symbols and correcting frequency offsets.

[00044] In step 603, channel estimators 109 estimate a channel impulse response for each associated frequency band.

[00045] In step 604, assembler 110 recombines the data and control information split among the multiple frequency bands using the estimated channel response for each frequency band after the data information and the control information split among the multiple frequency bands has been synchronized by synchronizer 108.

[00046] Method 600 may include other and/or additional steps that, for clarity, are not depicted. Further, method 600 may be executed in a different order presented and that the order presented in the discussion of Figure 6 is illustrative. Additionally, certain steps in method 600 may be executed in a substantially simultaneous manner or may be omitted.

[00047] Although the method and system are described in connection with several embodiments, it is not intended to be limited to the specific forms set forth herein, but on the contrary, it is intended to cover such alternatives, modifications and equivalents, as can be reasonably included within the spirit and scope of the invention as defined by the appended claims. It is noted that the headings are used only for organizational purposes and not meant to limit the scope of the description or claims.

CLAIMS:

1. A method for improving a throughput of a wireless communication system, the method comprising:
 - receiving an input data stream, wherein said input data stream comprises control and data information;
 - determining how said data information is to be split among multiple frequency bands;
 - determining how said control information is to be split among said multiple frequency bands;
 - splitting said data information and said control information among said multiple frequency bands; and
 - transmitting said data information and said control information split among said multiple frequency bands.
2. The method as recited in claim 1, wherein said input data stream is stored in a queue of said transmitter.
3. The method as recited in claim 1, wherein a media access control layer determines how said data information is to be split among said multiple frequency bands.
4. The method as recited in claim 1, wherein a physical layer determines how said control information is to be split among said multiple frequency bands.
5. The method as recited in claim 1 further comprising:
 - receiving said data information and said control information split among said multiple frequency bands; and
 - synchronizing said data information and said control information split among said multiple frequency bands.
6. The method as recited in claim 5, wherein said synchronizing comprises:
 - detecting a packet in a random access network;
 - determining a fine timing of symbols; and
 - correcting frequency offsets.
7. The method as recited in claim 5 further comprising:
 - estimating a channel impulse response for each of said multiple frequency bands.

8. The method as recited in claim 7 further comprising:

recombining said data information and said control information split among said multiple frequency bands using said estimated channel impulse response for each of said multiple frequency bands after said data information and said control information split among said multiple frequency bands has been synchronized.

9. A wireless communication system comprising:

a transmitter, wherein said transmitter comprises:

a queue configured to store a received input data stream, wherein said input data stream comprises control and data information;

a resource allocator coupled to said queue, wherein said resource allocator is configured to perform the following:

determining how said data information is to be split among multiple frequency bands;

determining how said control information is to be split among said multiple frequency bands;

splitting said data information and said control information among said multiple frequency bands; and

transmitting said data information and said control information split among said multiple frequency bands.

10. The wireless communication system as recited in claim 9, wherein said resource allocator comprises:

circuitry for performing a functionality of a media access control layer for determining how said data information is to be split among said multiple frequency bands.

11. The wireless communication system as recited in claim 9, wherein said resource allocator comprises:

circuitry for performing a functionality of a physical layer for determining how said control information is to be split among said multiple frequency bands.

12. The wireless communication system as recited in claim 9 further comprises:

a receiver wirelessly connected to said transmitter, wherein said receiver comprises:

a synchronizer configured to synchronize said data information and said control information split among said multiple frequency bands.

13. The wireless communication system as recited in claim 12, wherein said synchronizer is configured to perform the following:

- detecting a packet in a random access network;
- determining a fine timing of symbols; and
- correcting frequency offsets.

14. The wireless communication system as recited in claim 12, wherein said receiver further comprises:

- a plurality of channel estimators coupled to said synchronizer, wherein said plurality of channel estimators are configured to estimate a channel impulse response for each of said multiple frequency bands.

15. The wireless communication system as recited in claim 14, wherein said receiver further comprises:

- an assembler coupled to said plurality of channel estimators, wherein said assembler is configured to recombine said data information and said control information split among said multiple frequency bands using said estimated channel impulse response for each of said multiple frequency bands after said data information and said control information split among said multiple frequency bands has been synchronized.

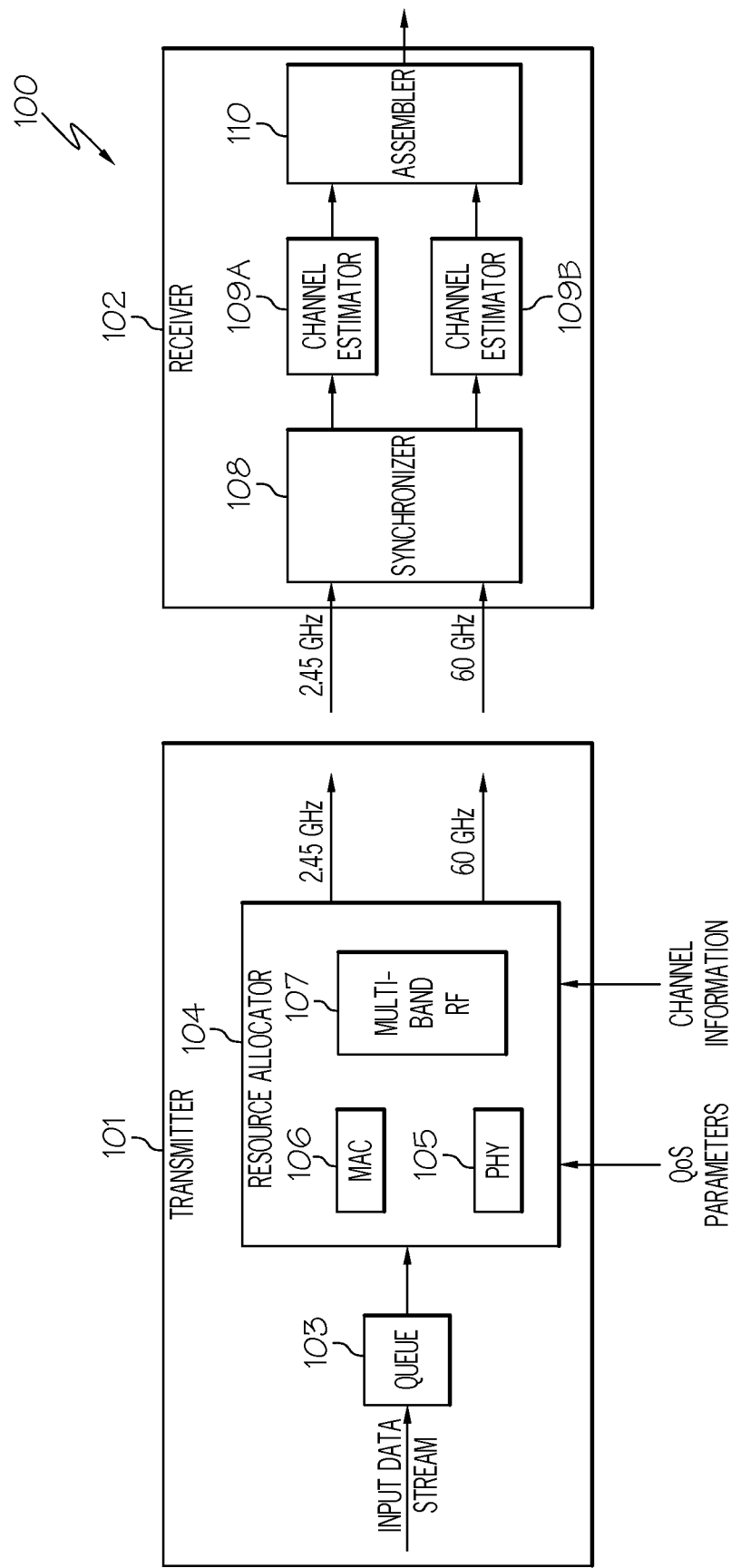


FIG. 1

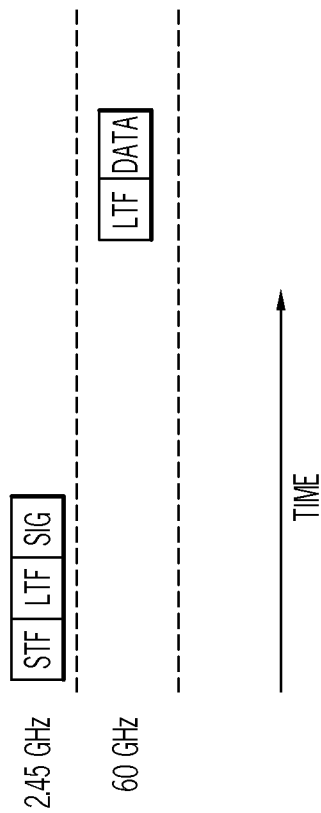


FIG. 2

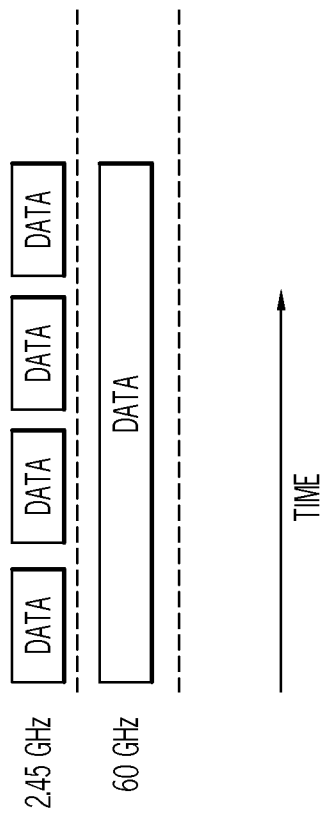


FIG. 3

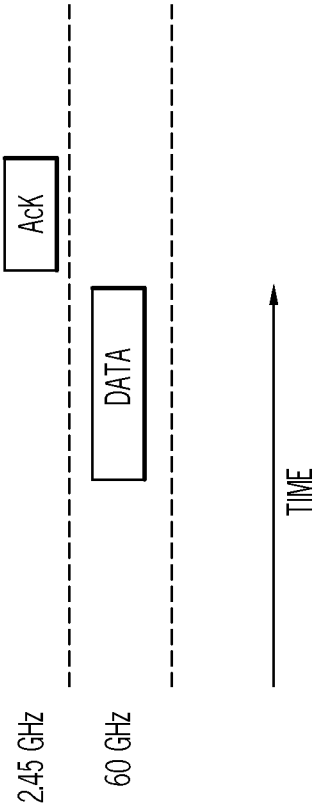


FIG. 4

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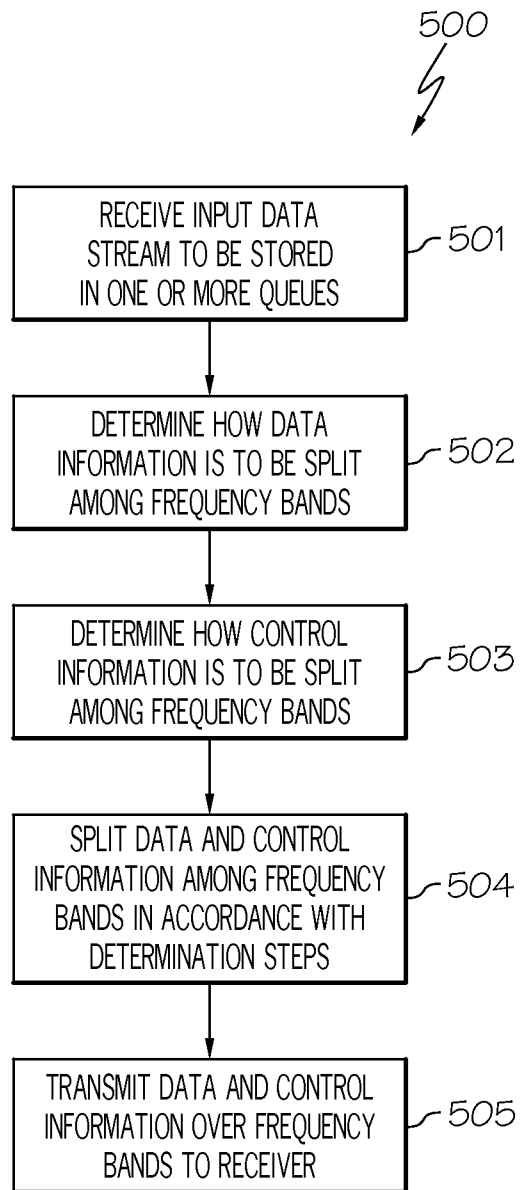


FIG. 5

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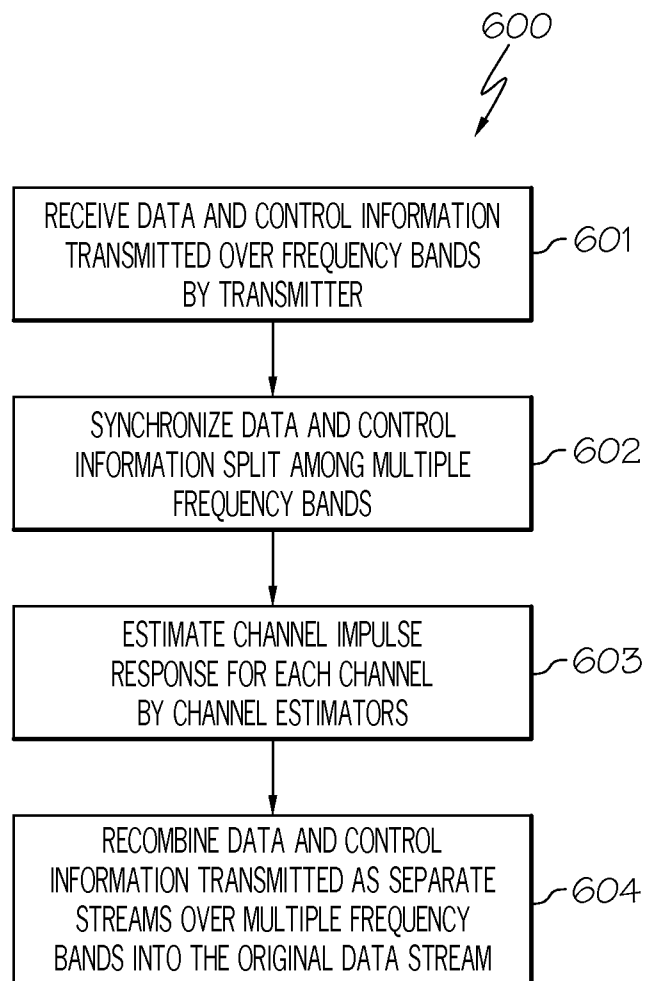


FIG. 6