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(54) **SYSTEMS AND METHODS FOR OUT-OF-BAND FULL DUPLEX COMMUNICATIONS**

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H04L 5/00	(2006.01)
H04L 5/14	(2006.01)
H04W 72/04	(2009.01)

(52) **U.S. Cl.**

CPC ***H04W 74/0808*** (2013.01); ***H04L 5/0055*** (2013.01); ***H04L 5/14*** (2013.01); ***H04W 72/0446*** (2013.01)

(58) **Field of Classification Search**

CPC H04W 74/0808; H04W 72/0446; H04L 5/0055; H04L 5/14

See application file for complete search history.

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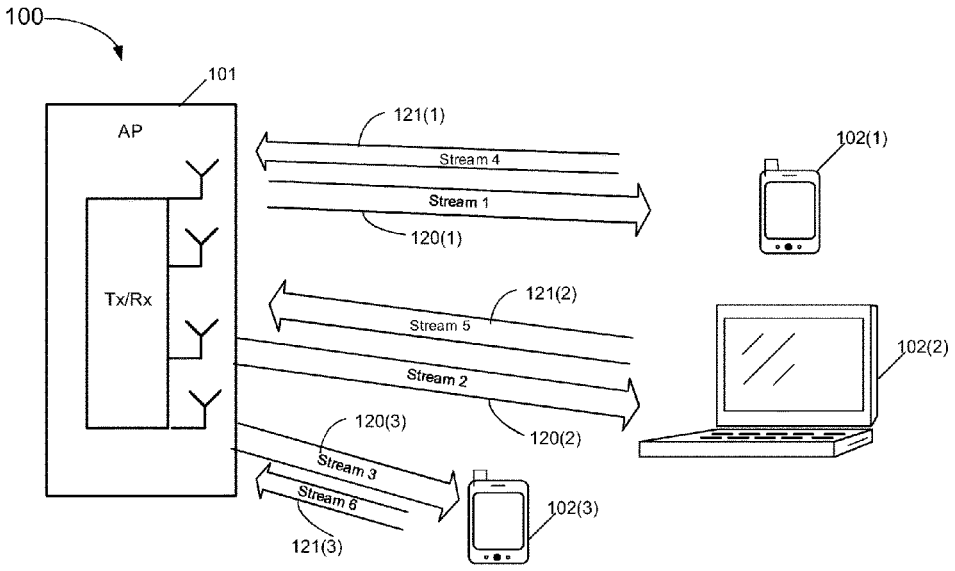
(57) **ABSTRACT**

Systems and methods for emulating Full Duplex (FD) transmissions between two or more devices by way of out-of-band Full Duplex communication, also known as Frequency Division Duplexing-Full Duplex (FDD-FD) communication. FD communication refers to a wireless communication device being able to transmit and receive communications at the same time. In out-of-band FD communication, a first communication channel is used for transmitting a first communication in one direction and a second communication channel is used for simultaneously transmitting a second communication in the reverse direction. Examples relate to management frames for managing channel availability and channel selection for implementing the out-of-band FD communication. An example wi-fi management frame includes an identification of both the first channel for the wireless communication device to transmit on, and the second channel for the wireless communication device to simultaneously receive on.

26 Claims, 13 Drawing Sheets



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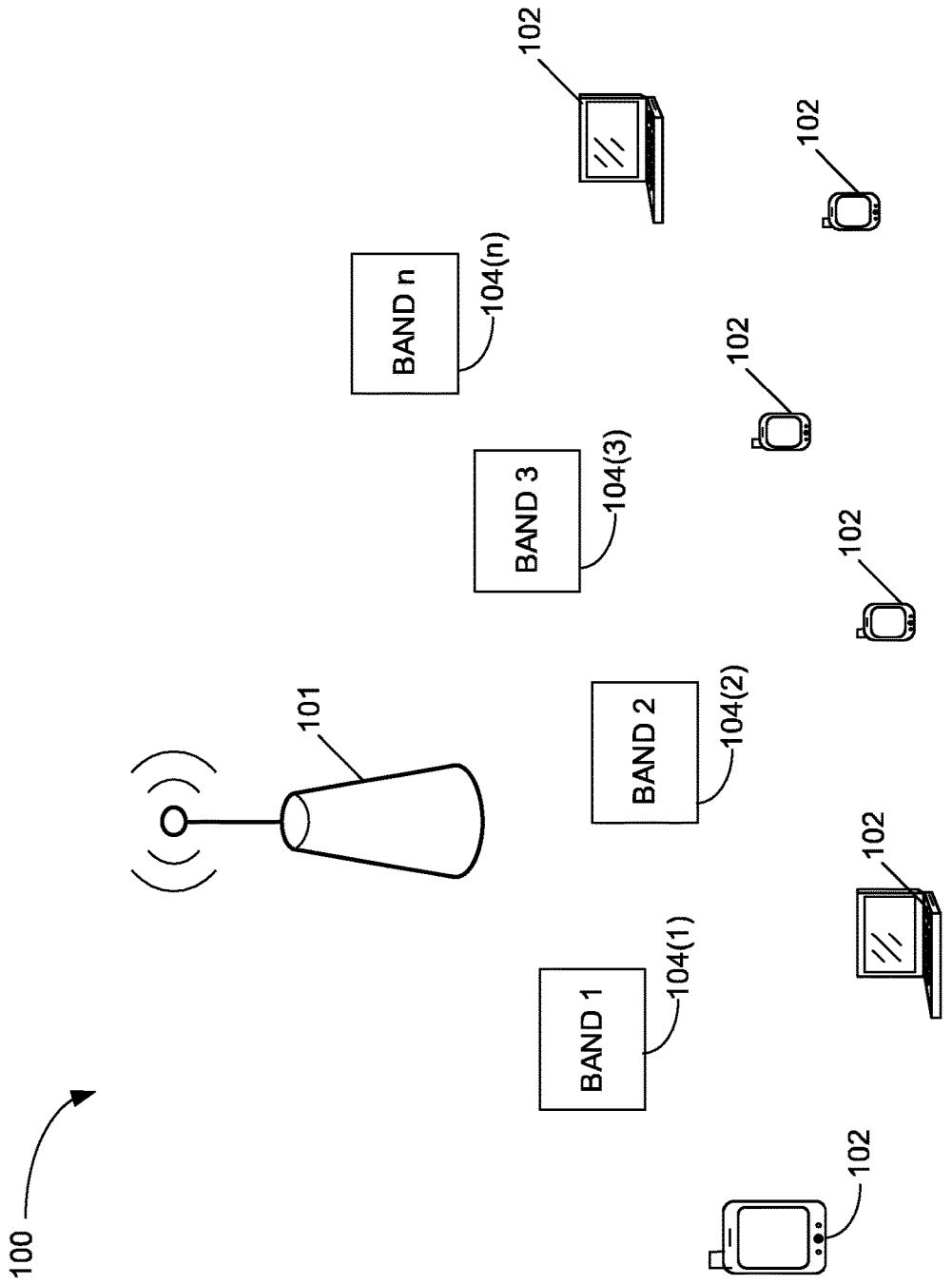
100
101
BAND 1
104(1)
BAND 2
104(2)
BAND 3
104(3)
BAND n
104(n)
102
102
102
102
102
102

FIG. 1A

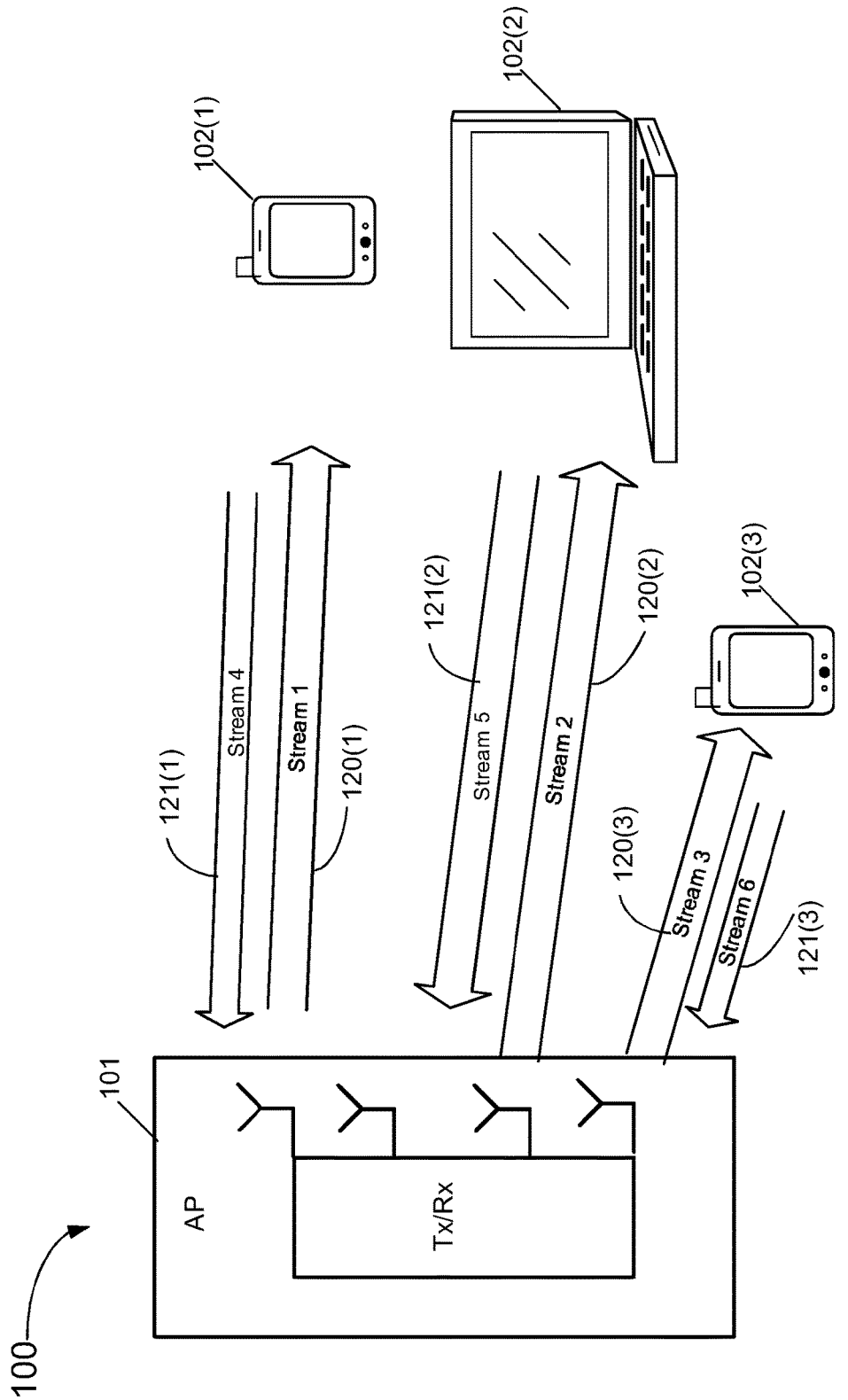
100
101
AP
Tx/Rx
102(1)
102(2)
102(3)
Stream 4
Stream 1
Stream 5
Stream 2
Stream 3
Stream 6
121(1)
120(1)
121(2)
120(2)
120(3)
121(3)

FIG. 1B

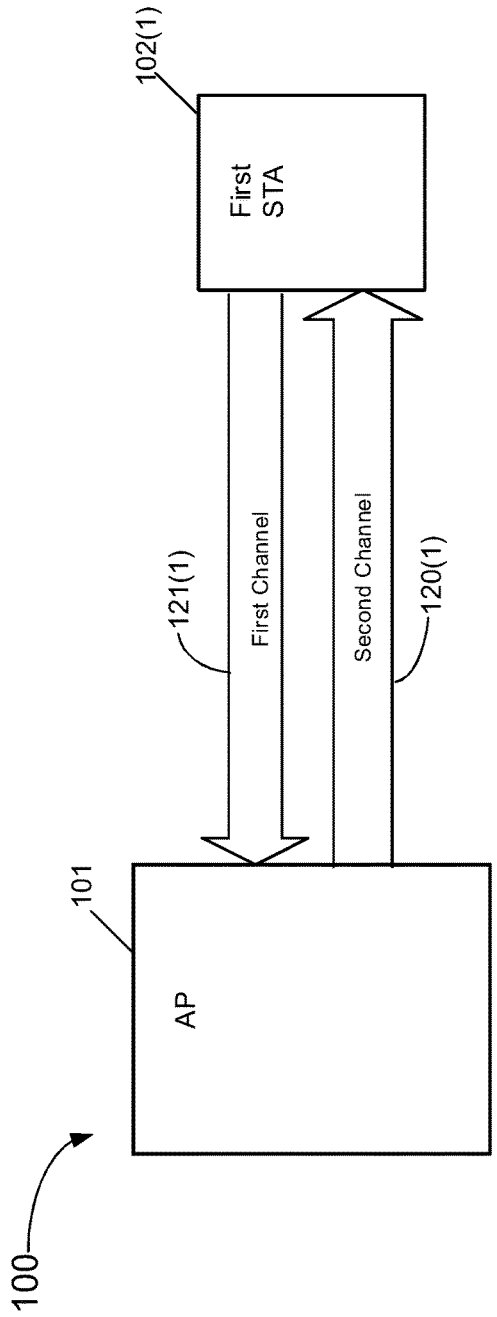
102(1)
First STA
121(1)
First Channel
Second Channel
120(1)
101
AP
100

FIG. 1C

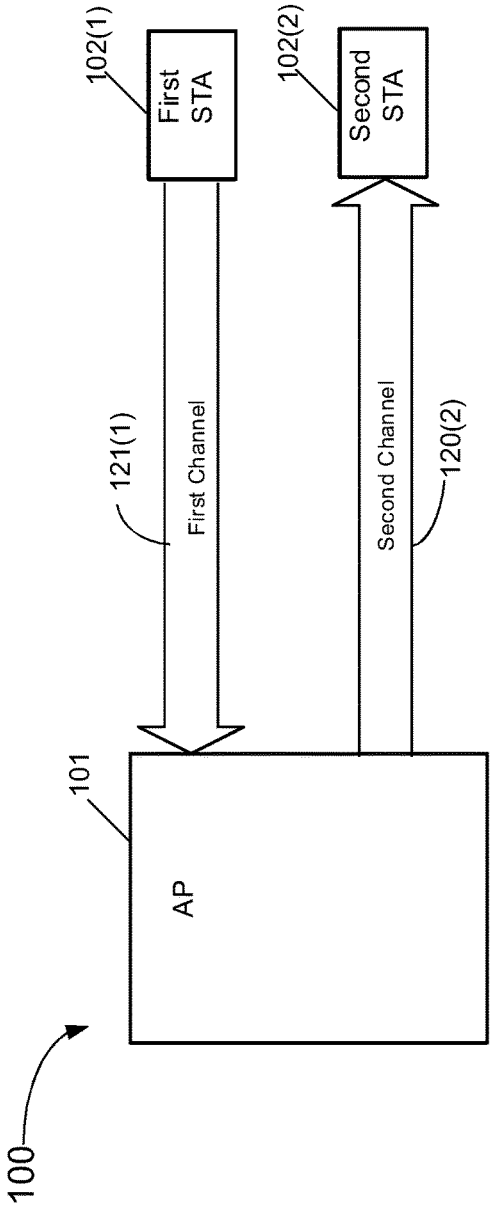
102(1)
First STA
102(2)
Second STA
121(1)
First Channel
Second Channel
120(2)
101
AP
100

FIG. 1D

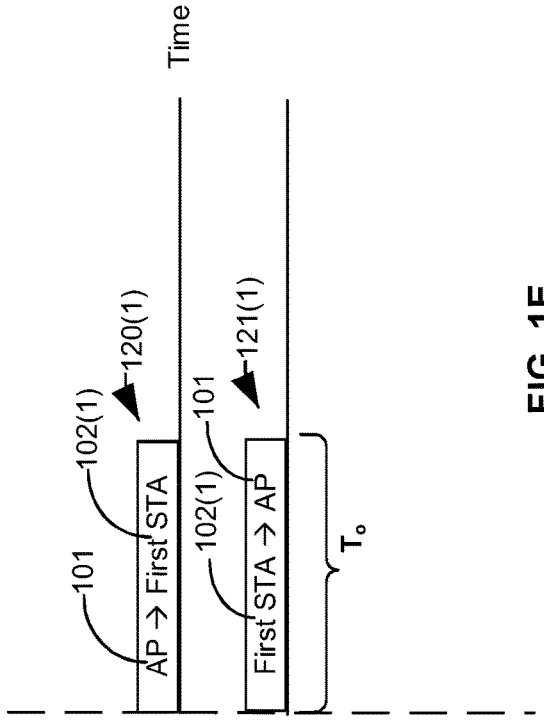
Time
101
102(1)
120(1)
AP → First STA
101
102(1)
121(1)
First STA → AP
T_o

FIG. 1E

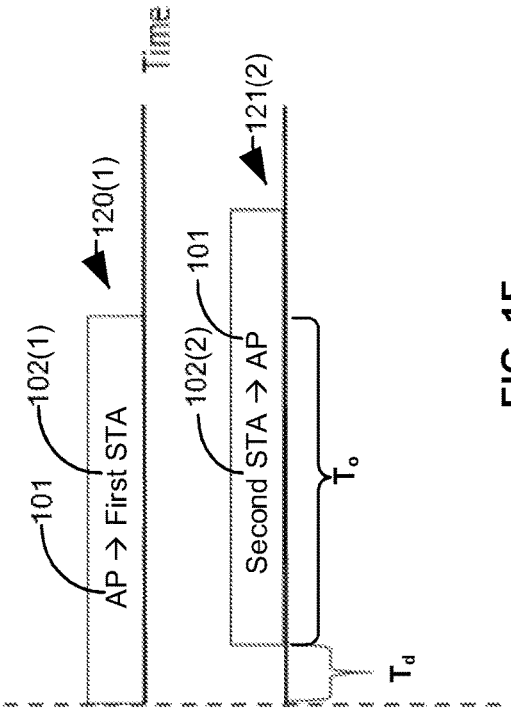
Time
101
102(1)
120(1)
AP → First STA
102(2)
101
121(2)
Second STA → AP
T_o
T_d

FIG. 1F

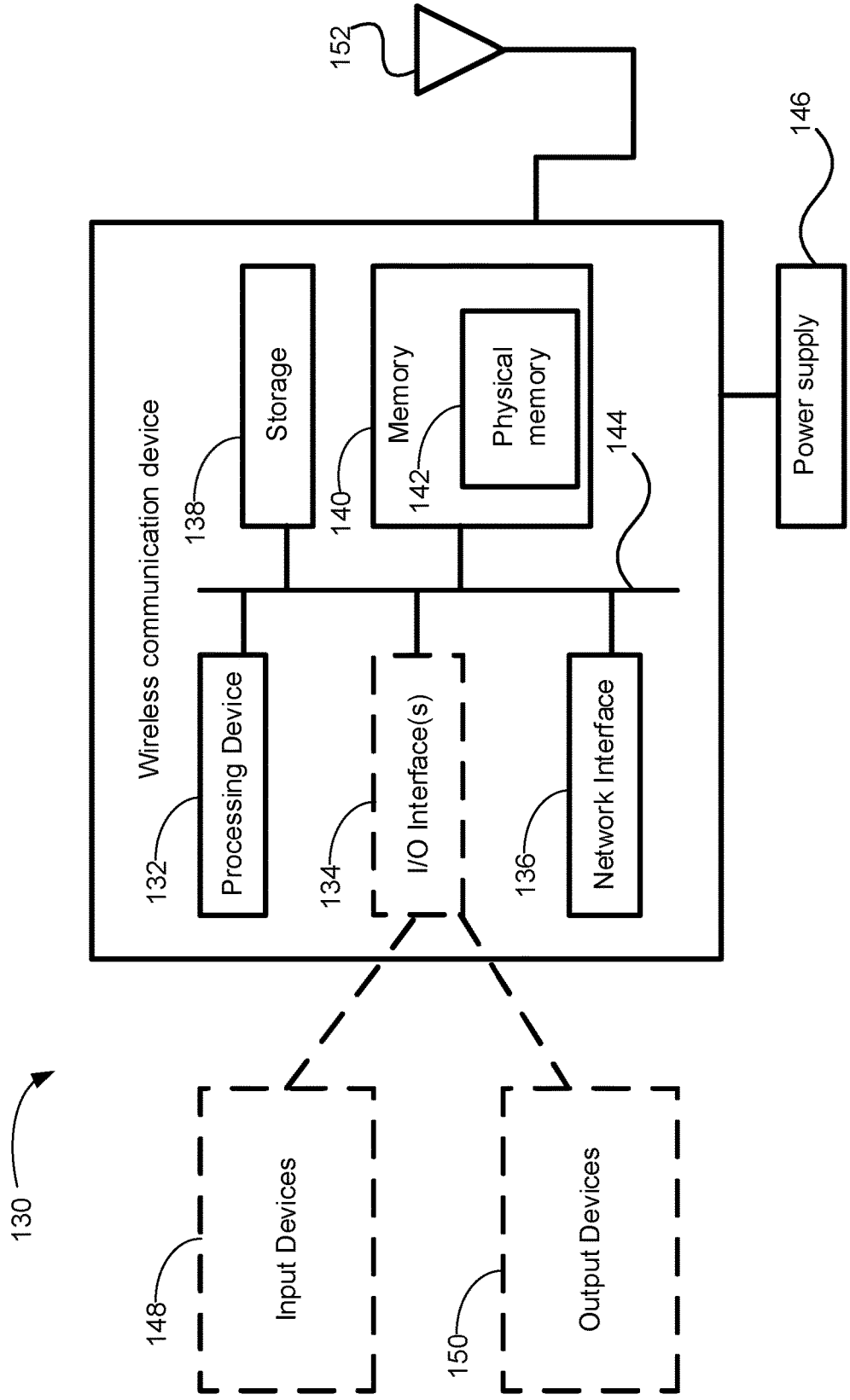
152
146
Wireless communication device
Storage
138
Memory
140
Physical memory
142
144
Power supply
Processing Device
132
I/O Interface(s)
134
Network Interface
136
130
Input Devices
148
Output Devices
150

FIG. 2

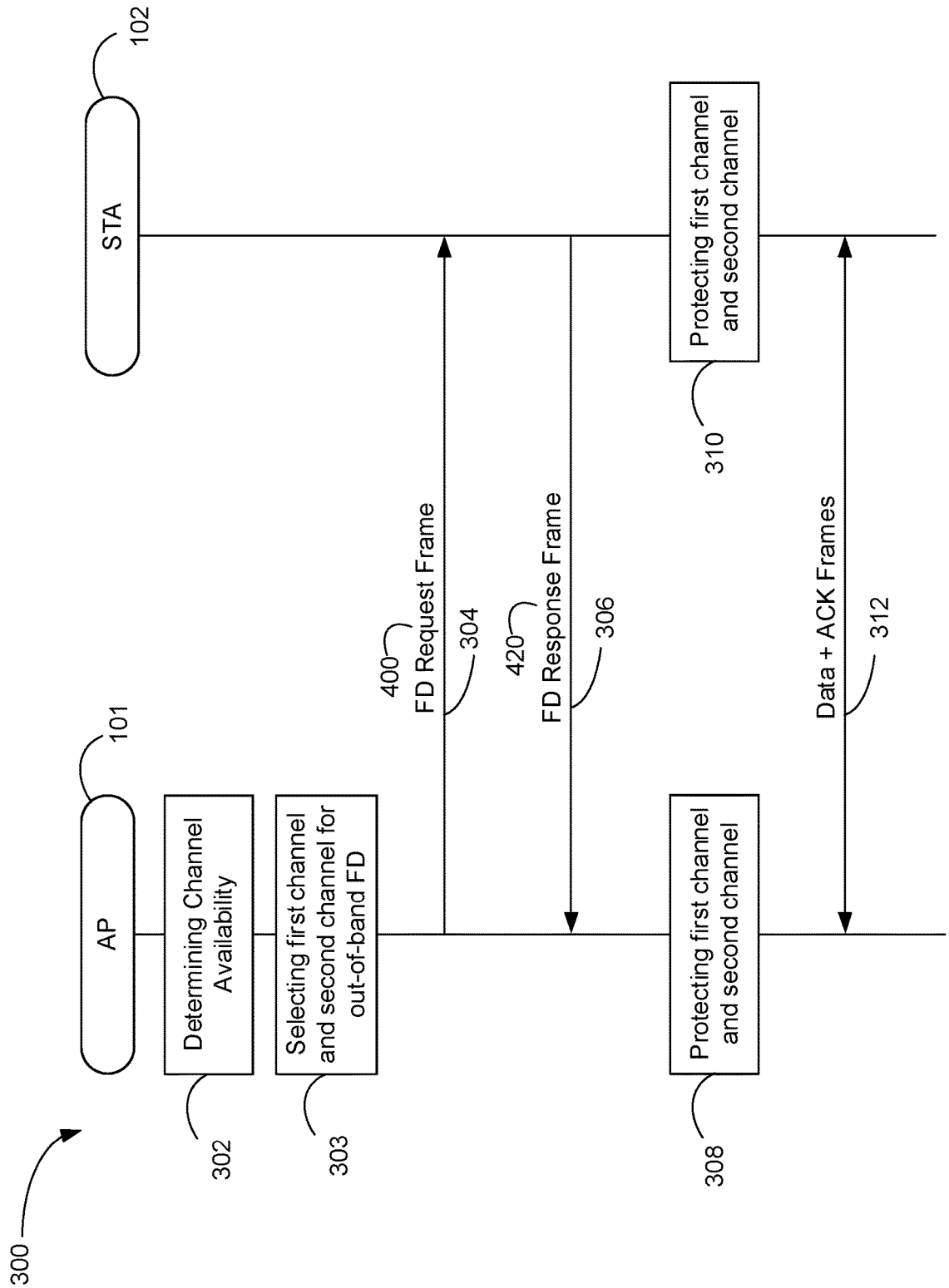
300
AP
101
STA
102
Determining Channel Availability
302
Selecting first channel and second channel for out-of-band FD
303
400
FD Request Frame
304
420
FD Response Frame
306
Protecting first channel and second channel
308
Protecting first channel and second channel
310
Data + ACK Frames
312

FIG. 3

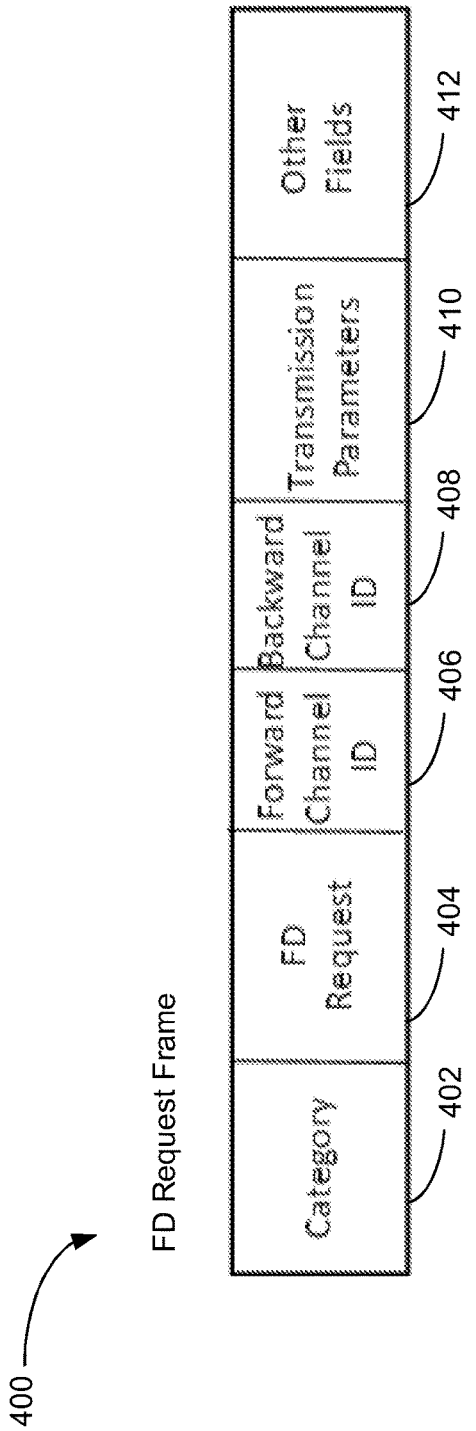
400
FD Request Frame
Category
FD Request
Forward Channel ID
Backward Channel ID
Transmission Parameters
Other Fields
402
404
406
408
410
412

FIG. 4A

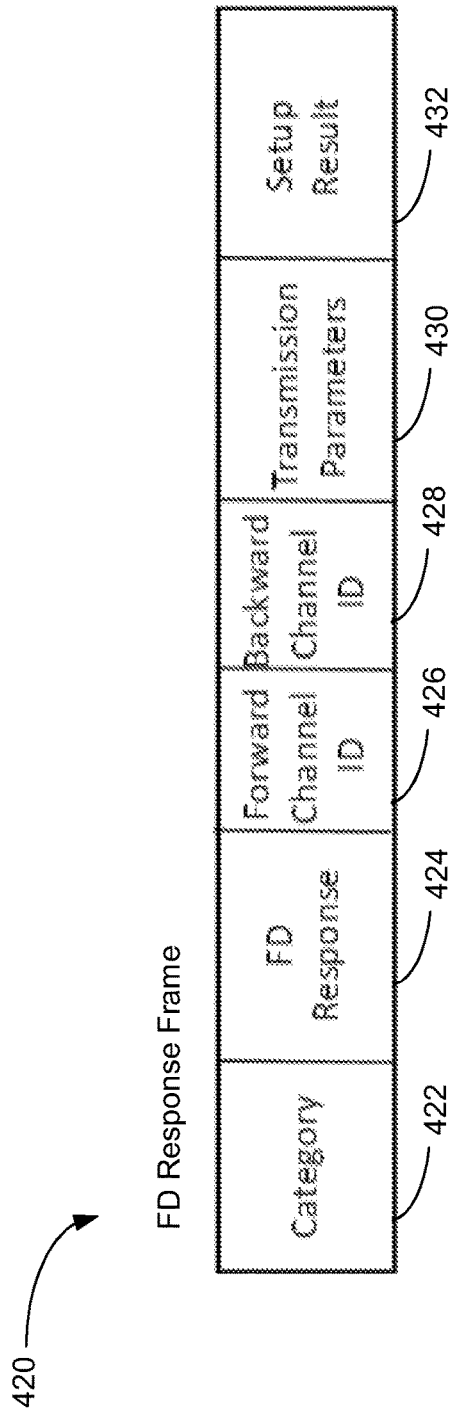
420
FD Response Frame
Category
FD Response
Forward Channel ID
Backward Channel ID
Transmission Parameters
Setup Result
422
424
426
428
430
432

FIG. 4B

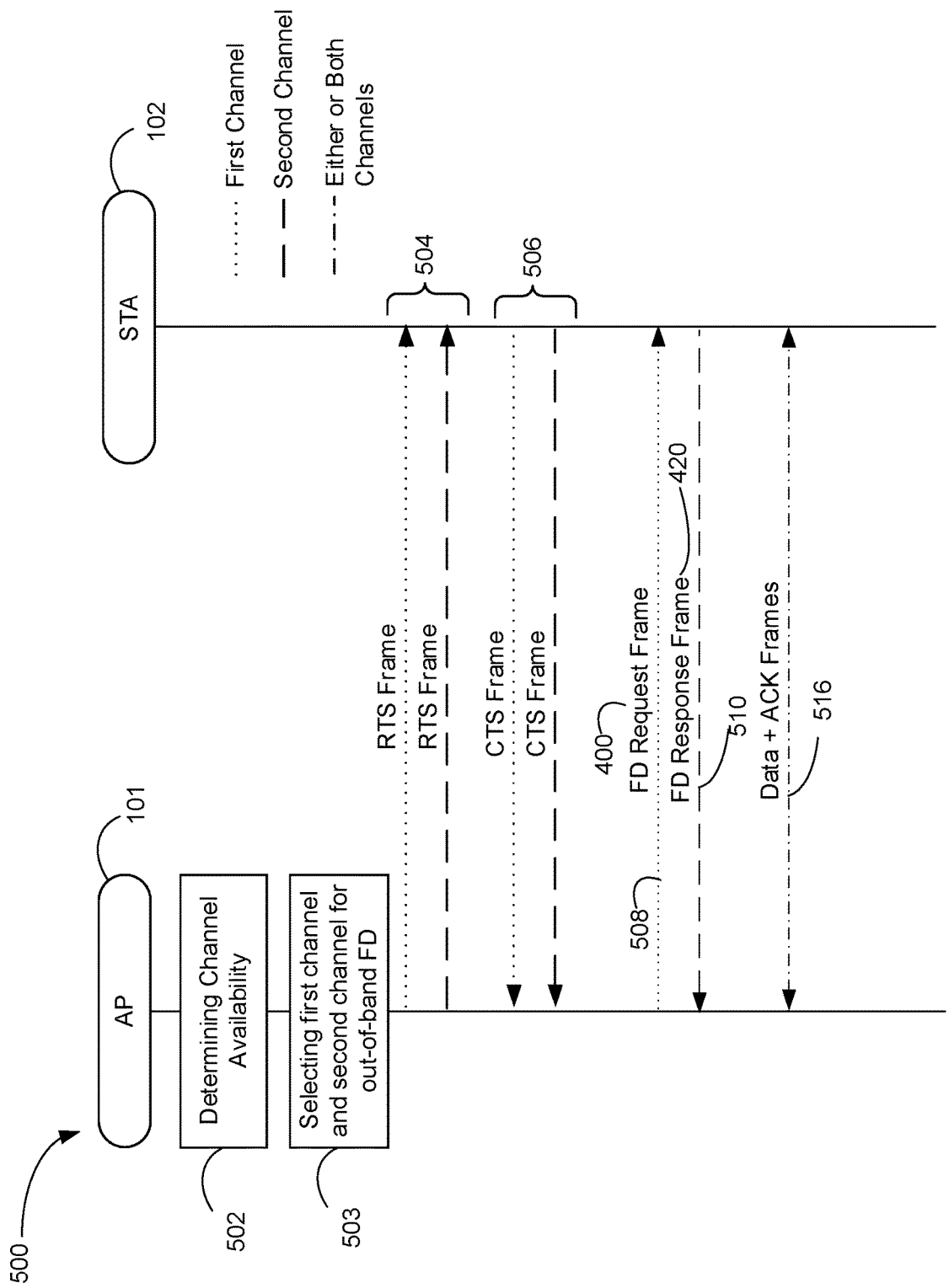
500
AP
101
STA
102
First Channel
Second Channel
Either or Both Channels
Determining Channel Availability
502
Selecting first channel and second channel for out-of-band FD
503
504
506
RTS Frame
RTS Frame
CTS Frame
CTS Frame
400
FD Request Frame
508
FD Response Frame
420
510
Data + ACK Frames
516

FIG. 5

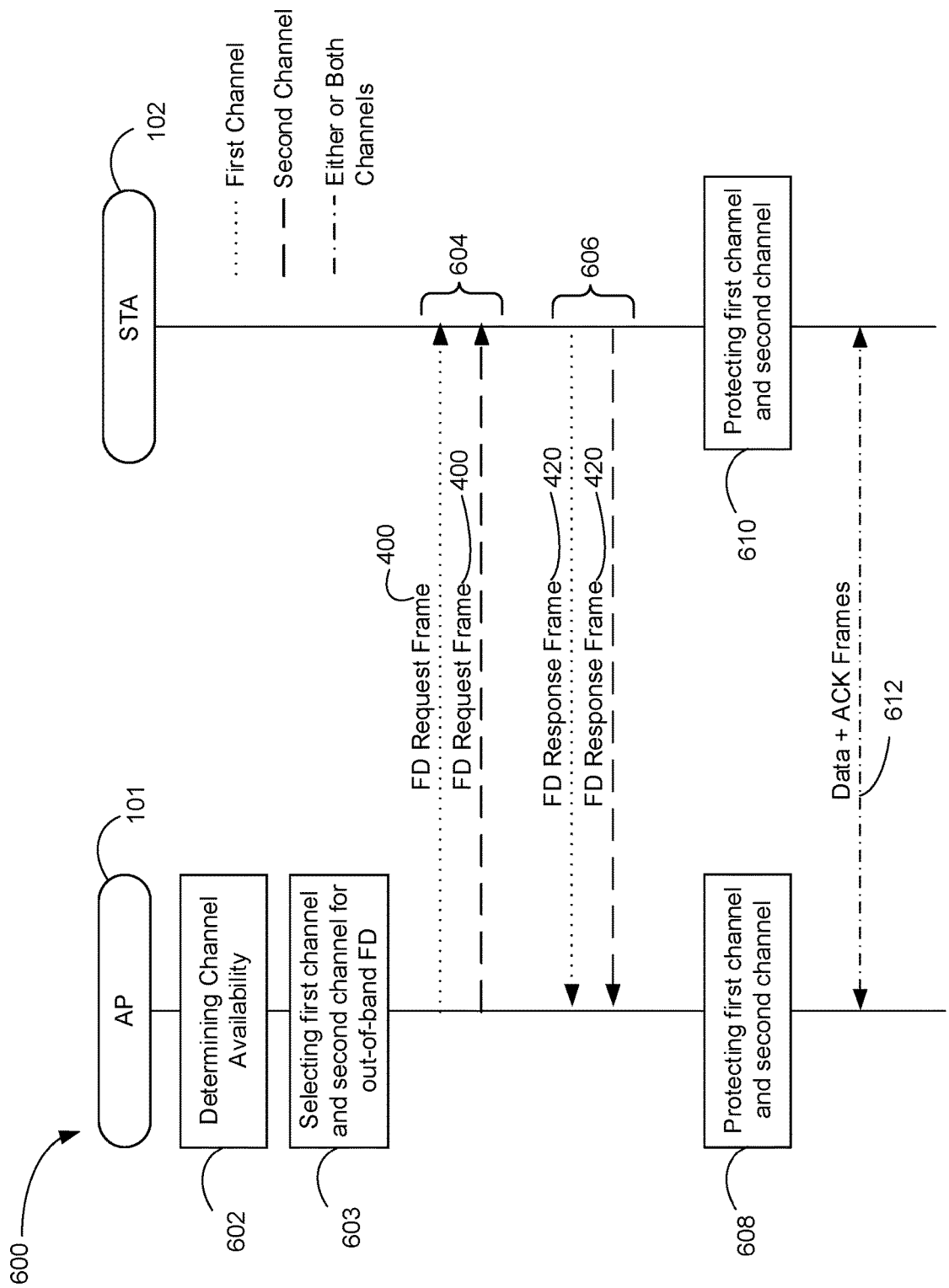
First Channel
Second Channel
Either or Both Channels
STA
102
AP
101
600
602
603
604
606
608
610
612
Determining Channel Availability
Selecting first channel and second channel for out-of-band FD
FD Request Frame
FD Request Frame
FD Response Frame
FD Response Frame
400
400
420
420
Protecting first channel and second channel
Protecting first channel and second channel
Data + ACK Frames

FIG. 6

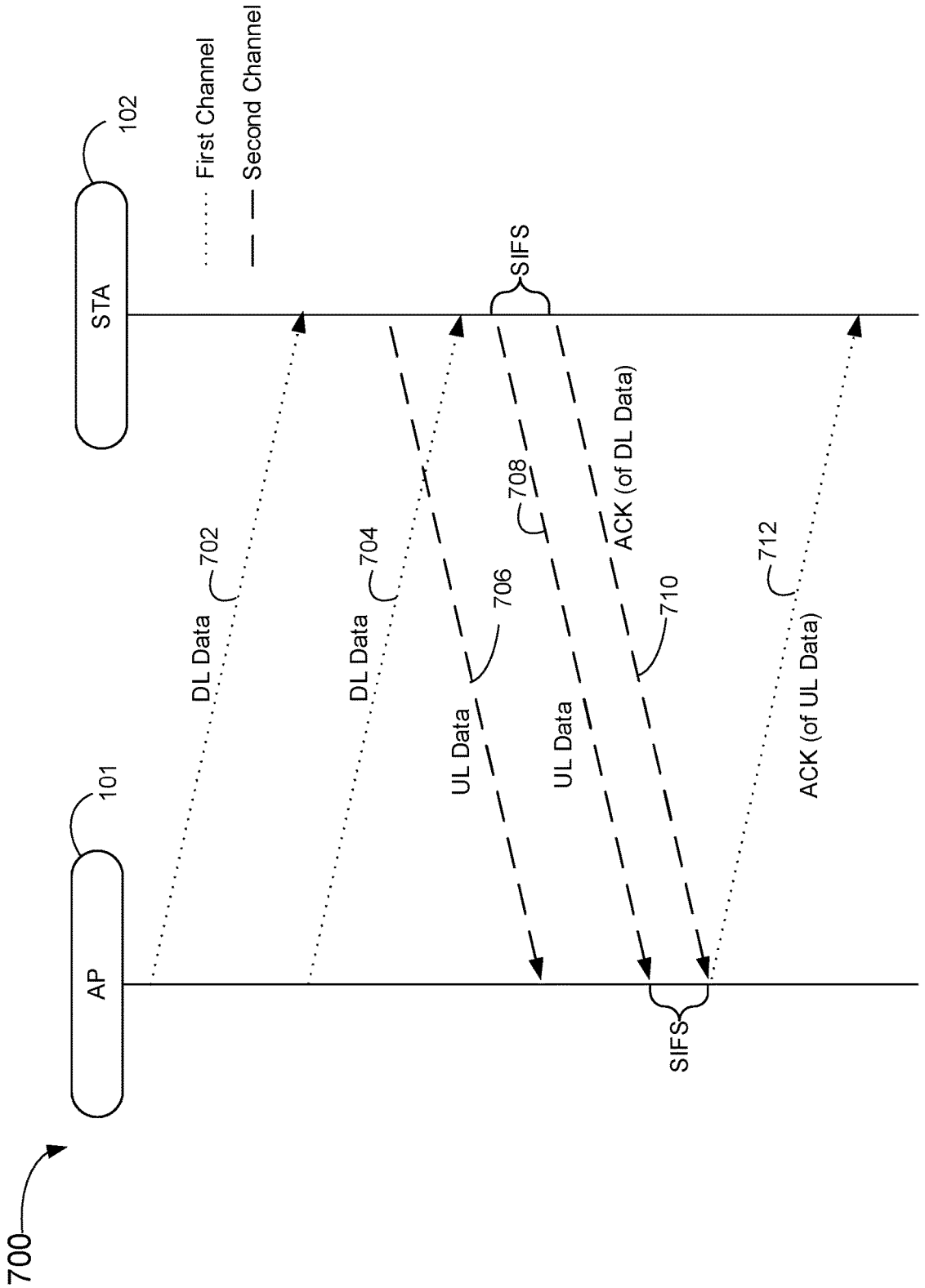
700
AP
101
STA
102
First Channel
Second Channel
DL Data
702
DL Data
704
UL Data
706
SIFS
708
UL Data
ACK (of DL Data)
710
SIFS
712
ACK (of UL Data)

FIG. 7

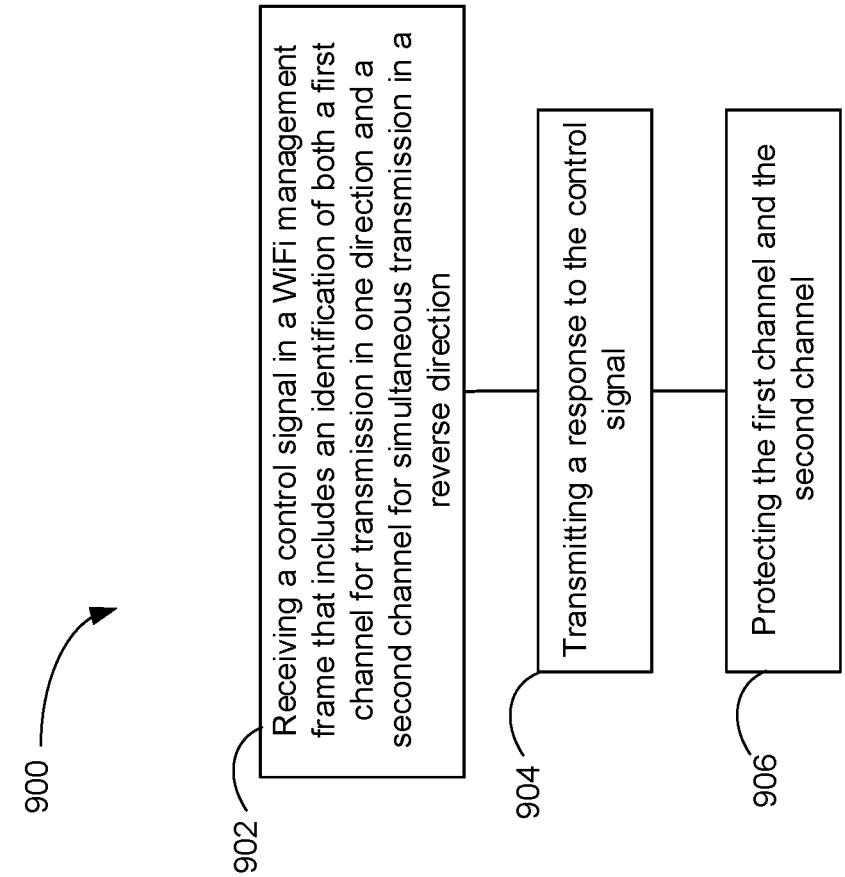
900
902
Receiving a control signal in a WiFi management frame that includes an identification of both a first channel for transmission in one direction and a second channel for simultaneous transmission in a reverse direction
904
Transmitting a response to the control signal
906
Protecting the first channel and the second channel

FIG. 9

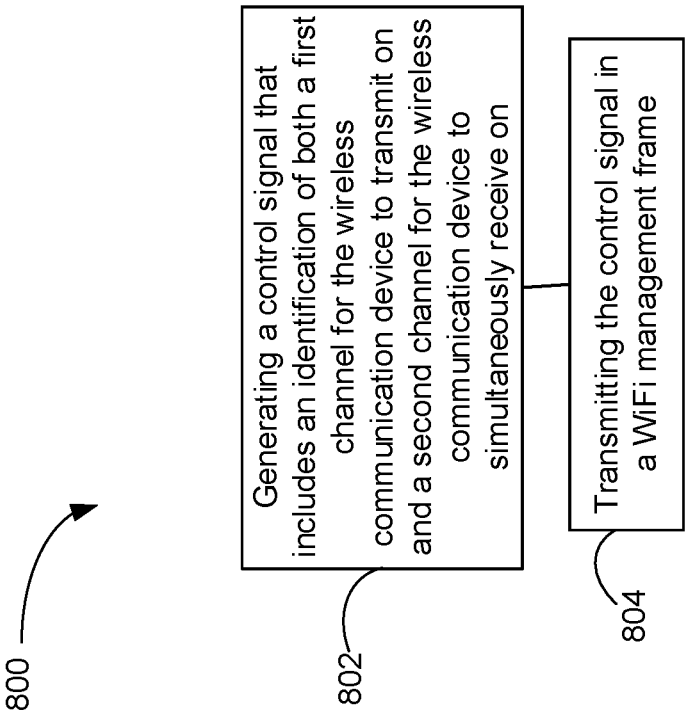
800
802
Generating a control signal that includes an identification of both a first channel for the wireless communication device to transmit on and a second channel for the wireless communication device to simultaneously receive on
804
Transmitting the control signal in a WiFi management frame

FIG. 8

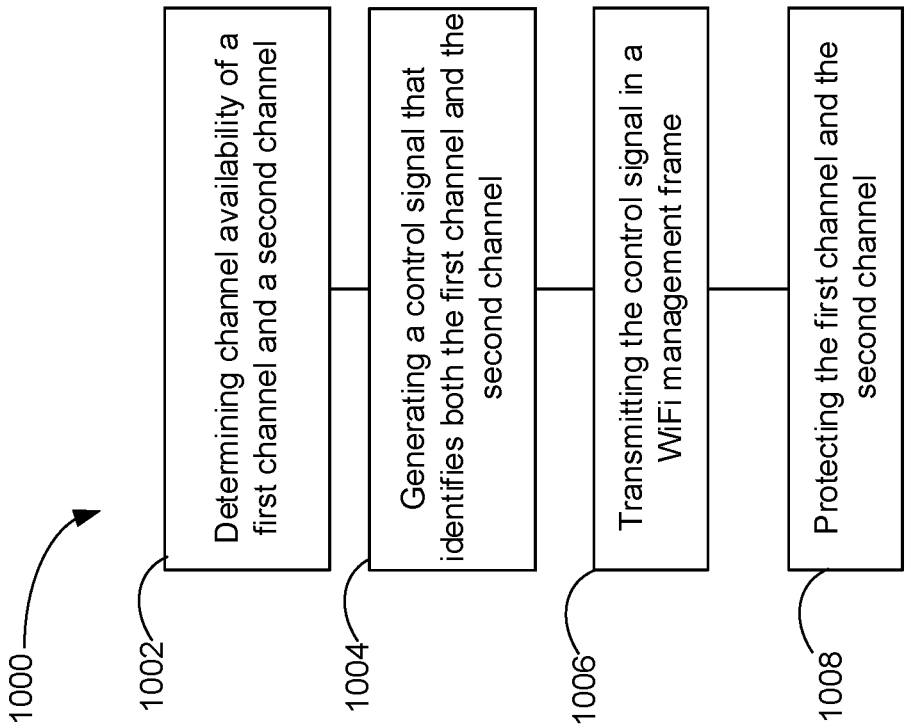
1000
1002
Determining channel availability of a first channel and a second channel
1004
Generating a control signal that identifies both the first channel and the second channel
1006
Transmitting the control signal in a WiFi management frame
1008
Protecting the first channel and the second channel

FIG. 10

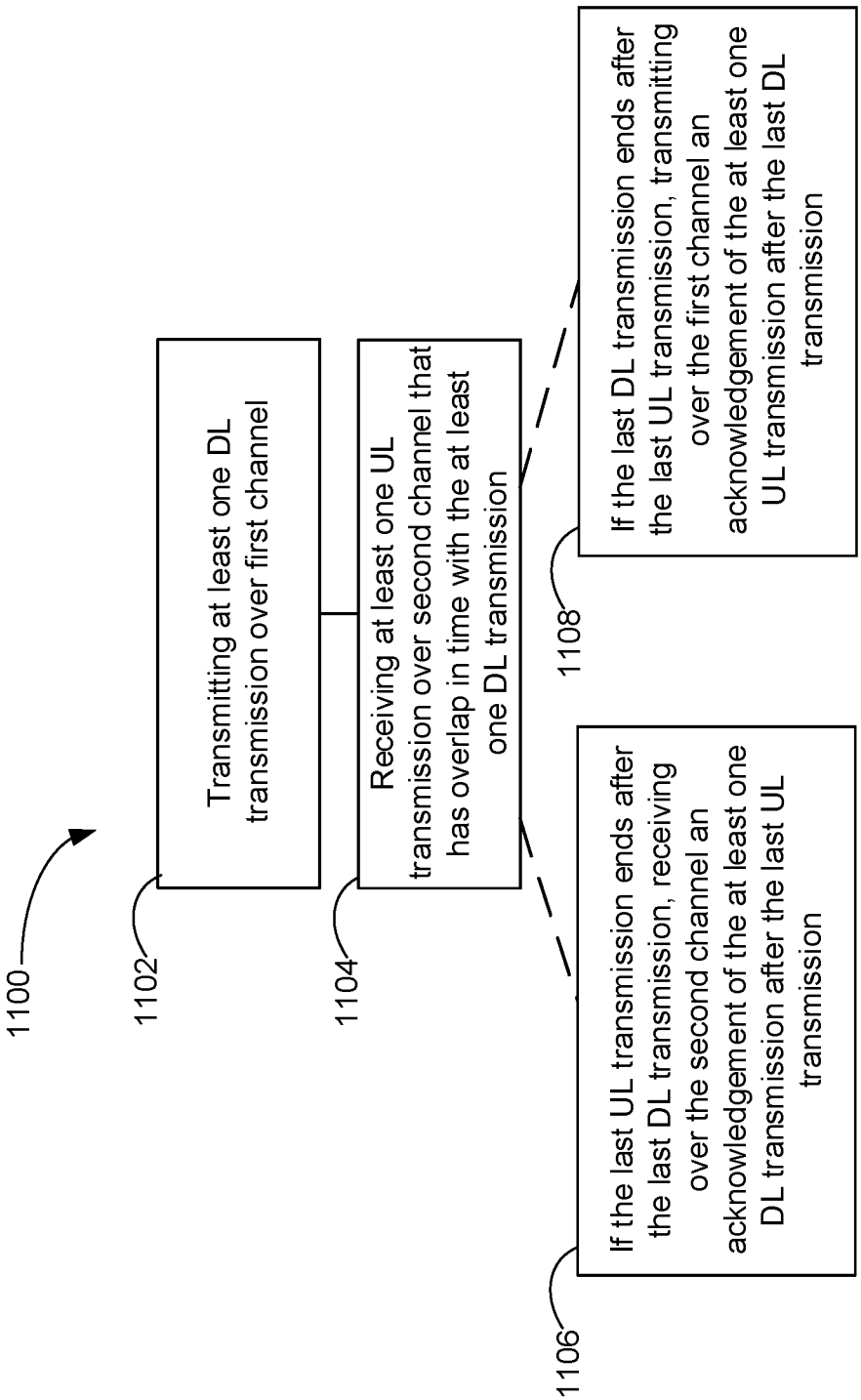
1100
1102
Transmitting at least one DL transmission over first channel
1104
Receiving at least one UL transmission over second channel that has overlap in time with the at least one DL transmission
1106
If the last UL transmission ends after the last DL transmission, receiving over the second channel an acknowledgement of the at least one DL transmission after the last UL transmission
1108
If the last DL transmission ends after the last UL transmission, transmitting over the first channel an acknowledgement of the at least one UL transmission after the last DL transmission

FIG. 11

SYSTEMS AND METHODS FOR OUT-OF-BAND FULL DUPLEX COMMUNICATIONS

TECHNICAL FIELD

Example embodiments relate to wireless communications, in particular systems and methods for out-of-band full duplex communications.

BACKGROUND

The Institute of Electrical and Electronics Engineers (IEEE) sets standards for wireless communication technologies, including wireless local area network (WLAN) communication technologies. The IEEE 802.11 family of standards relate to WLANs and their quality of service (QoS), access point protocol, security enhancement, wireless management, etc.

Full Duplex (FD) communications refers to a wireless communication device transmitting and receiving communications at the same time. Half Duplex refers to transmitting and receiving being performed by a wireless communication device, in only one direction at a time. When two-way FD communications is performed over the same communication channel, there exists self-interference between the transmitted and the received signals at the same frequency, which is generally undesired and needs to be cancelled.

Accordingly, it would be desirable to provide a solution that emulates FD communications, and does not cause self-interference within a single communications channel.

SUMMARY

Example embodiments relate to emulating Full Duplex (FD) communications between two or more wireless communication devices by way of out-of-band Full Duplex, also known as Frequency Division Duplexing-Full Duplex (FDD-FD). In out-of-band FD communications, one communication channel is used for transmitting a first communication in one direction and a second (different) communication channel is used for simultaneously transmitting in the reverse direction. Example embodiments relate to management frames and control signals for managing channel availability and channel selection for the out-of-band FD communications between wireless communication devices. The out-of-band FD communications may reduce any self-interference when compared to FD communications that only use a single communications channel. An example management frame includes an identification of both the first channel for the wireless communication device to transmit on, and the second channel for the wireless communication device to simultaneously receive on.

An example embodiment is a method implemented by a wireless communication device capable of simultaneously transmitting and receiving wireless signals, the method includes: generating a control signal that includes an identification of a first channel for the wireless communication device to transmit on, and a second channel for the wireless communication device to simultaneously receive on; and transmitting the control signal in a WiFi management frame.

In an example embodiment of any of the above-described methods, the method further includes determining channel availability for the first channel and the second channel.

In an example embodiment of any of the above-described methods, the determining includes performing a Clear Channel Assessment (CCA) on the first channel and the second channel.

In an example embodiment of any of the above-described methods, the determining includes: generating a Request-To-Send (RTS) Frame and transmitting the RTS Frame over the first channel and the second channel; receiving a Clear to Send (CTS) Frame over the first channel and the second channel; and determining that the first channel and the second channel are available based on receiving the CTS Frame over the first channel and the second channel.

In an example embodiment of any of the above-described methods, the CTS Frame protects the first channel and the second channel.

In an example embodiment of any of the above-described methods, the determining includes: transmitting the control signal over the first channel; receiving a response to the control signal over the second channel; and determining that the first channel and the second channel are available based on receiving the response over the first channel and the second channel.

In an example embodiment of any of the above-described methods, one or both of the first channel and the second channel is a primary channel.

In an example embodiment of any of the above-described methods, the first channel and the second channel are each a primary channel in different bands.

In an example embodiment of any of the above-described methods, the method further includes: receiving a response to the control signal; and protecting, in response to the receiving, the first channel and the second channel.

In an example embodiment of any of the above-described methods, the method further includes: transmitting at least one first transmission over the first channel; and receiving at least one second transmission over the second channel, wherein the at least one second transmission has overlap in time with the at least one first transmission.

In an example embodiment of any of the above-described methods, the transmitting includes transmitting the at least one first transmission to a first station (STA), and the receiving includes receiving the at least one second transmission from a second STA.

In an example embodiment of any of the above-described methods, the method further includes, when a last transmission of the at least one first transmission ends after a last transmission of the at least one second transmission, transmitting an acknowledgment frame over the first channel in response to the at least one second transmission and after time unit Short InterFrame Space (SIFS) from the last transmission of the at least one transmission.

In an example embodiment of any of the above-described methods, the method further includes, when a last transmission of the at least one second transmission ends after a last transmission of the at least one first transmission, receiving an acknowledgement frame over the second channel in response to the at least one first transmission and after time unit Short InterFrame Space (SIFS) from the last transmission of the at least one second transmission.

In an example embodiment of any of the above-described methods, the transmitting of the control signal includes broadcasting the control signal or transmitting a beacon frame that includes the control signal.

In an example embodiment of any of the above-described methods, the wireless communication device is a Station (STA), an access point (AP), or a personal basic service set (PBSS) control point (PCP).

Another example embodiment is a method implemented by a wireless communication device, the method including: receiving a control signal in a WiFi management frame that includes an identification of both a first channel for transmission in one direction and a second channel for simultaneous transmission in a reverse direction; transmitting a response to the control signal; and protecting the first channel and the second channel.

In an example embodiment of any of the above-described methods, the receiving includes receiving the control signal from a second wireless communication device, wherein the protecting includes protecting the first channel and the second channel for communication between the wireless communication device and the second wireless communication device.

In an example embodiment of any of the above-described methods, the protecting excludes use of the first channel and the second channel by devices other than the wireless communication device and the second wireless communication device.

In an example embodiment of any of the above-described methods, the first channel and the second channel is protected for any wireless communication devices that responds to the control signal.

In an example embodiment of any of the above-described methods, the method further includes receiving a Request-To-Send (RTS) Frame over the first channel and the second channel, wherein the protecting includes transmitting a Clear to Send (CTS) Frame over the first channel and the second channel.

In an example embodiment of any of the above-described methods, the receiving includes receiving the control signal over the first channel and the second channel, and the transmitting includes transmitting the response over the first channel and the second channel.

In an example embodiment of any of the above-described methods, the method further includes: receiving at least one first transmission over the first channel; and transmitting at least one second transmission over the second channel, wherein the at least one second transmission has overlap in time with the at least one first transmission.

In an example embodiment of any of the above-described methods, the method further includes, when a last transmission of the at least one second transmission ends after a last transmission of the at least one first transmission, transmitting an acknowledgement frame over the second channel in response to the at least one first transmission and after time unit Short InterFrame Space (SIFS) from the last transmission of the at least one second transmission.

In an example embodiment of any of the above-described methods, the method further includes, when a last transmission of the at least one first transmission ends after a last transmission of the at least one second transmission, receiving an acknowledgement frame over the first channel in response to the at least one second transmission and after time unit Short InterFrame Space (SIFS) from the last transmission of the at least one first transmission.

An example embodiment is a wireless communication device, comprising an antenna; a processing device; a memory associated with the processing device for storing instructions that when executed by the processing device causes the processing device to perform any of the described methods, processes or functions.

An example embodiment is a non-transitory computer-readable medium which stores instructions that when executed by a processing device causes the processing device to perform any of the described methods, processes or functions.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present example embodiments, and the advantages thereof, reference is now made to the following description taken in conjunction with the accompanying drawings, in which:

FIG. **1**A is a schematic diagram illustrating a wireless communication system in which example embodiments may be implemented, according to an example embodiment;

FIG. **1**B is a schematic diagram of uplink (UL) and downlink (DL) transmissions of the wireless communication system, according to an example embodiment;

FIG. **1**C is a schematic diagram of out-of-band Full Duplex (FD) communication between two wireless communication devices such as an Access Point (AP) and a Station (STA) of the wireless communication system, according to an example embodiment;

FIG. **1**D is a schematic diagram of asymmetric out-of-band FD communication between an AP and two different STAs of the wireless communication system, according to an example embodiment;

FIG. **1**E is an example timing diagram of the out-of-band FD communication of FIG. **1**C between the AP and the STA;

FIG. **1**F is an example timing diagram of the asymmetric out-of-band FD communication of FIG. **1**D between the AP and the two different STAs;

FIG. **2** is a schematic representation of an example wireless communication device according to an example embodiment;

FIG. **3** is an example method in the form of a messaging diagram between the AP and a STA for managing out-of-band FD communication, according to an example embodiment;

FIG. **4**A is an example management frame for requesting FD communication, according to an example embodiment;

FIG. **4**B is an example management frame for responding to the request for FD communication of FIG. **4**A, according to an example embodiment;

FIG. **5** is an example detailed implementation of the messaging diagram of FIG. **3** between the AP and the STA, according to an example embodiment;

FIG. **6** is another example detailed implementation of the messaging diagram of FIG. **3** between the AP and the STA, according to an example embodiment;

FIG. **7** is an example method in the form of a messaging diagram between the AP and a STA for performing out-of-band FD communication, according to an example embodiment;

FIG. **8** illustrates an example method implemented by a wireless communication device for managing out-of-band FD communication, in accordance with an example embodiment; and

FIG. **9** illustrates an example method implemented by a wireless communication device for managing out-of-band FD communication, in accordance with an example embodiment.

FIG. **10** illustrates an example method implemented by a wireless communication device for protecting channels, in accordance with an example embodiment.

FIG. **11** illustrates an example method implemented by a wireless communication device capable of out-of-band FD communication, in accordance with an example embodiment.

Similar reference numerals may have been used in different figures to denote similar components.

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS

Example embodiments relate to management of out-of-band Full Duplex (FD) communications between wireless communication devices. Example embodiments relate to management frames and control signals for managing channel availability and channel selection for the out-of-band FD communications between the wireless communication devices.

FIG. **1**A illustrates an example schematic diagram of a wireless communication system **100** in which example embodiments may be implemented. The wireless communication system **100** includes an access point **101** (AP, also known as an AP STA, a personal basic service set (PBSS) control point (PCP), or a network coordinator), and at least one station **102** (STA, also known as non-AP STA) in a wireless communication network, such as a wireless local area network (WLAN). The AP **101** is any entity that has STA functionality and provides access to the Internet or a distribution service for the associated STAs **102**. The AP **101** can be any component (or collection of components) configured to provide wireless access in a network, and can be an evolved NodeB (eNB), a macro-cell, a femtocell, distribution node, a WiFi AP, or other wirelessly enabled devices. The AP **101** may, for example, provide wireless access in accordance with one or more wireless communication protocols, e.g., Long Term Evolution (LTE), LTE advanced (LTE-A), High Speed Frame Access (HSPA), WiFi 802.11a/b/g/n/ac/ad/ax/ay, and other 802.11 protocols or future 802.11 protocols. The STAs **102** may be mobile communication devices enabled for wireless communications, including but not limited to User Equipment (UE), mobile phones, smart phones, laptops, tablet computers, machine-type communication devices, Internet of Things (IoT) devices, and wireless sensing and reporting devices. The AP **101** and the STAs **102** can each be configured to execute uplink (UL) transmission and downlink (DL) transmissions in the WLAN. An example detailed embodiment of the AP **101** and the STA **102** is a wireless communication device **130** as illustrated in FIG. **2**.

In the WLAN of FIG. **1**A, the AP **101** may provide access to the Internet or a distribution service for one or more STAs **102** that are wirelessly and communicatively associated with the AP **101**. The AP **101** can access the Internet or the distribution service by way of wired or wireless communication. Although only one single AP **101** is shown, this is only illustrative and is not intended to be limiting. In other examples, there may be more than one AP **101** within the wireless communication system **100**.

The AP **101** and the STAs **102** can communicate over one or more wireless bands, shown as Band **1** (**104**(**1**)), Band **2** (**104**(**2**)), Band **3** (**104**(**3**)), . . . , and Band n (**104**(*n*)) (generically referred to as band **104**). In some examples, each band **104** can be defined by a particular IEEE 802.11 standard, future IEEE 802.11 standards, unlicensed standards or bands, or one or more specified bands as agreed between the devices. In an example embodiment, Band 1 (**104**(**1**)) is the 2.4 GHz band, Band **2** (**104**(**2**)) is the 5 GHz band, and Band **3** (**104**(**3**)) is the 6 GHz band. Another example band is 60 GHz for IEEE 802.11ay enhanced directional multi-gigabit (EDMG).

In some example embodiments, each band **104** includes a plurality of channels, and each channel can include a plurality of sub-channels. Each channel has a channel bandwidth, for example the channels in Band **1** (**104**(**1**)) of 2.4 GHz band can have a defined bandwidth of 20 MHz or 40 MHz. For example, the channels in Band **2** (**104**(**2**)) of 5 GHz band or Band **3** (**104**(**3**)) of 6 GHz band can each have a defined bandwidth of 40 MHz, 80 MHz, or 160 MHz. In another example, for IEEE 802.11ay EDMG, the band **104** is 60 GHz and the defined channel bandwidth is 2.16 GHz. Some example embodiments have fixed defined bandwidths for each channel. Some example embodiments have variably-sized bandwidths for each channel, for example based on network requirements.

In some IEEE 802.11 standards, one of the channels in the respective band **104** is defined as the primary channel. The primary channel can be a designated channel used by the STAs **102** for listening of commands and control signals from the AP **101**. The primary channel may also be used as a default communication channel in some instances. The primary channel may be within one of the bands **104**. In some examples, subsequent command, control and payload can be transmitted on the primary channel of the respective band **104**, or other channels within the respective band **104**. In an example embodiment, there is more than one primary channel, one for each band. In an example embodiment, for out-of-band FD communication, the primary channel can be reserved or protected for one of UL or DL transmission, but not both, and a second channel (different from the primary) can be reserved or protected for the other of UL or DL transmission. In an example embodiment, the first channel and the second channel can be reserved or protected for use only by the AP **101** and one STA **102**, excluding use of the first channel and the second channel from all other devices.

Referring to FIG. **1**B, examples of the WLAN will be described in the context of wireless communications between an AP **101** and a plurality of STAs, including first STA **102**(**1**), second STA **102**(**2**), and third STA **102**(**3**). In some example embodiments, the wireless communication system **100** supports multi-user multiple input multiple output (MU-MIMO) transmissions. The AP **101** and at least one of the STAs **102** may be configured for single user (SU) communications in other examples. MU-MIMO based transmission, which can use multiple antennas with beam steering, allows simultaneous channel access by the STAs **102** for effective use of channels in the WLAN. The AP **101** can simultaneously transmit spatial-multiplexed data to the STAs **102**. Payload data can be simultaneously transmitted by the AP **101** to the STAs **102** using a plurality of respective streams (stream **1**, **2**, **3** shown in FIG. **1**B) in the DL direction, shown as DL transmissions **120**(**1**) to **120**(**3**) (generically referred to as DL transmission **120**). In the DL direction, payload data transmitted to each STA **102** may be different for each STA **102**. In the UL direction, payload data can be simultaneously transmitted to the AP **101** using a plurality of respective streams (stream **4**, **5**, **6** shown in FIG. **1**B), shown as UL transmissions **121**(**1**) to **121**(**3**) (generically referred to as UL transmission **121**). The DL transmissions **120** and the UL transmissions **121** are payload data transmissions. The DL transmissions **120** and the UL transmissions **121** may use Orthogonal Frequency Division Multiple Access (OFDMA), with MU-MIMO or without MU-MIMO.

In some examples, the streams of the DL transmissions **120** and the UL transmissions **121** are spatial streams that are directionally transmitted in space.

In some example embodiments, at least some of the streams of the DL transmissions **120** are DL Multi-User (MU) transmissions, and at least some of the streams of the

UL transmissions **121** are UL MU transmissions. In some example embodiments, at least some of the streams of the DL transmissions **120** are DL Single User (SU) transmissions, and at least some of the streams of the UL transmissions **121** are UL SU transmissions. In some example embodiments, the DL transmissions **120** and the UL transmissions **121** represent transmissions that are used to transmit non-payload information such as control frames, management frames (including WiFi management frames), control signals, broadcast frames, beacon frames, etc.

In some example embodiments, the AP **101** is configured to emulate FD communications, by way of out-of-band FD communications, so as to transmit and receive communications at the same time over two (or more) different communications channels. Example types of information transmitted in the out-of-band FD communications include Physical Layer Convergence Procedure (PLCP) Protocol Data Unit (PPDU) frames with payload data, Media Access Control (MAC) protocol data units (MPDU), aggregate MPDU (A-MPDU), management frames, trigger frames, broadcast frames, beacon frames, acknowledgement frames (ACK frames or BlockACK frames), control signals and other data. In some examples, at least one STA **102** can emulate FD communications by way of out-of-band FD communications and can transmit and receive communications at the same time over two (or more) different communications channels. In some examples, at least one STA **102** is only capable of Half Duplex wireless communication and can both transmit and receive communications, but not simultaneously.

In FIG. **1**B, in some example embodiments, for out-of-band FD communication, at least one stream of the DL transmissions **120** is transmitted simultaneously with at least one stream of the UL transmissions **121**. Such DL transmissions **120** are transmitted over one or more channels, and such UL transmissions **121** are transmitted over one or more different channels than those of the DL transmissions **120**, thereby implementing out-of-band FD communication.

FIG. **1**C is a schematic diagram of out-of-band FD communication between the AP **101** and the first STA **102**(**1**), according to an example embodiment. In the example of FIG. **1**C, the AP **101** and the first STA **102**(**1**) can both be capable of out-of-band FD communication. In FIG. **1**C, The AP **101** transmits a DL transmission **120**(**1**) to the first STA **102**(**1**), and the first STA **102**(**1**) simultaneously transmits an UL transmission **121**(**1**) to the AP **101**. The DL transmission **120**(**1**) is transmitted over a first (e.g. primary) channel, and the UL transmission **121**(**1**) is transmitted over a second channel, different from the primary channel. In an alternate example embodiment (not shown here), the UL transmission **121**(**1**) is transmitted over the primary channel, and the DL transmission **120**(**1**) is transmitted over a different channel.

FIG. **1**D is a schematic diagram of asymmetric out-of-band FD communication between the AP **101**, the first STA **102**(**1**), and the second STA **102**(**2**), according to an example embodiment. In the example of FIG. **1**D, the AP **101** can be capable of out-of-band FD communication. Each of the STAs first **102**(**1**) and the second STA **102**(**2**) can be capable of either out-of-band FD communication or only Half Duplex communication. In FIG. **1**D, The AP **101** transmits a DL transmission **120**(**2**) to the second STA **102**(**2**), and the first STA **102**(**1**) simultaneously transmits an UL transmission **121**(**1**) to the AP **101**. The DL transmission **120**(**2**) is transmitted over a first (e.g. primary) channel, and the UL transmission **121**(**1**) is transmitted over a second channel that is different than the first channel. In an alternate example embodiment (not shown here), the UL transmission **121**(**1**) is transmitted over the primary channel, and the DL transmission **120**(**1**) is transmitted over the second channel.

FIG. **1**E is an example timing diagram of the out-of-band FD communication of FIG. **1**C between the AP **101** and the first STA **102**(**1**). In FIG. **1**E, the DL transmission **120**(**1**) and the UL transmission **121**(**1**) between the AP **101** and the first STA **102**(**1**) overlap in time for an overlap time period of T_o. The DL transmission **120**(**1**) and the UL transmission **121**(**1**) occur at the same time.

FIG. **1**F is an example timing diagram of the asymmetric out-of-band FD communication of FIG. **1**D between the AP **101**, the first STA **102**(**1**) and the second STA **102**(**2**). During the asymmetric out-of-band FD communication, the AP **101** sends the DL transmission **120**(**1**) to the first STA **102**(**1**) over the first (primary) communication channel, and receives the UL transmission **102**(**2**) from the second STA **102**(**2**) over a second communication channel. In example embodiments the DL transmission **120**(**1**) and the UL transmission **121**(**2**) overlap for an overlap time period of T_o. As shown in FIG. **1**F, in some examples there is a time difference T_d that precedes the transmission of the UL transmission **102**(**2**) from the second STA **102**(**2**). In other example embodiments, there is no time difference T_d and the DL transmission **120**(**1**) and the UL transmission **102**(**2**) overlap in time.

In some examples, yet further STAs **102** can communicate asymmetric out-of-band FD communication with the AP **101**, having any combination of overlapping time periods, in one direction, using different channels or with the same respective channels that are used for the DL transmission **120**(**1**) and the UL transmission **121**(**2**). Any two transmissions over different channels that have any overlapping time period can be said to be communicated at the same time, or simultaneously, for the purposes of out-of-band FD communication.

FIG. **3** is an example method **300** in the form of a messaging diagram between two wireless communication devices **130**, e.g. the AP **101** and a STA **102**, for managing out-of-band FD communication. At step **302**, the AP **101** determines which channels are available. The AP **101** can determine availability of specific channels, or determine availability of all channels, or determine availability until a specific number of channels are available (e.g. two channels). At step **303**, the AP **101** selects, from the available channels determined at step **302**, a first channel and a second channel as candidate channels for out-of-band FD communication. At step **304**, the AP **101** transmits to the STA **102** a management frame that contains a request for out-of-band FD communication, denoted FD Request Frame **400**. The FD Request Frame **400** includes an identification of the first channel and the second channel. In an example, the first channel is designated for DL transmission for the out-of-band FD communication, and the second channel can be designated for UL transmission for the out-of-band FD communication. At step **306**, the STA **102** transmits to the AP **101** (and the AP **101** receives) a management frame that responds to the FD Request Frame **400**, denoted FD Response Frame **420**. The FD Response Frame **420** can positively respond to (affirm) the FD Request Frame **400**, or can negatively respond (reject) the FD Request Frame **400**. If no FD Response Frame **420** is received after a certain time period or frame interval, in some examples the AP **101** does not proceed with out-of-band FD communication. In an example, the AP **101** transmits the FD Request Frame **400** over both the first channel and the second channel, and if no response is received over both the first channel and the second channel, the AP **101** does not proceed with out-of-

band FD because the channels were not able to successfully carry the FD Request Frame **400** or the FD Response Frame **420**, or simply because the receiving STA **102** had ignored the request or was unable to handle the request. At step **306**, successful receipt of the FD Response Frame **420** over both the first channel and the second channel also means that the first channel and the second channel are available for out-of-band FD communications.

At step **308**, in response to receiving a positive response in the FD Response Frame **420**, the AP **101** protects the first channel and the second channel for purposes of out-of-band FD communication. At step **310**, the STA **102** also protects the first channel and the second channel for purposes of out-of-band FD communication. For steps **308** and **310**, for example, the first channel is protected for DL transmission, and the second channel is protected for UL transmission.

In some examples of step **308** and step **310**, the first channel and the second channel are protected by the AP **101** and the STA **102** for a protection period, e.g. specified number or amount of time, chips/slots, or time-to-live (TTL), or number of communications, etc. The protection period can be transmitted from the AP **101** to the STA **102** in some examples, and can be predetermined in other examples. In some examples, when the protection time expires or just before the protection time expires, the method **300** can be performed again to set up the out-of-band FD communication to provide continuity for the out-of-band FD communication.

At step **312**, out-of-band FD communication is performed between the AP **101** and the STA **102**, which can include further management frames, PPDU frames (which include payload data), MPDUs, and acknowledgement frames (ACK or BlockACK). The out-of-band FD communication at step **312** includes DL transmissions and UL transmissions that have overlap in time over the respective first channel and second channel. In an example, the first channel is protected for DL transmission from the AP **101** to the STA **102**, and any ACK or BlockACK frames or other confirmation messages from the STA **102** are transmitted over the second channel. Similarly, continuing the example, the second channel is protected for UL transmission from the STA **102** to the AP **101**, and any ACK frames, BlockACK frames or other confirmation messages from the AP **101** are transmitted over the first channel.

In some examples, the method **300** is performed between the AP **101** and one STA **102**. In some examples, the first channel and the second channel is protected only as between the AP **101** and the one STA **102** for the out-of-band FD communication, without being usable by other STAs **102**. In such examples, the AP **101** and the one STA **102** can exclusively perform two-way out-of-band FD communication in the manner of FIG. **1**C.

In other examples, the method **300** is performed between the AP **101** and a plurality of the STAs **102**. Each of the STAs **102** can confirm whether they are protecting (via step **310**) both the first channel and the second channel in the out-of-band FD communication. The AP **101** and the STAs **102** can perform asymmetric out-of-band FD communication as in FIG. **1**D in such examples. The AP **101** and the STAs **102** can also perform two-device out-of-band FD communication in the manner of FIG. **1**C in such examples. In other examples, the AP **101** and the plurality STAs **102** can perform OFDMA MU communications over out-of-band FD communication, for example with MU DL transmissions over the first channel and MU UL transmissions over the second channel. In some examples, a trigger frame is transmitted by the AP **101** to the STAs **102** over the first channel and the responsive OFDMA MU UL transmissions are received by the AP **101** from the STAs **102** over the second channel. As well, in some examples an acknowledgement frame (ACK or BlockACK) can be transmitted on the first channel or the second channel to acknowledge a transmission from the other of the first channel or the second channel.

In some examples, the method **300** is repeated by the AP **101** with each of the STAs using direct transmissions. In other examples, at step **304** the AP **101** transmits the FD Request Frame **400** in a broadcast or a beacon frame. Any of the STAs **102** can respond to the broadcast or the beacon frame to the AP **101** by way of the FD Response Frame **420** at step **306**.

In an alternate example, the steps of the method **300** performed by the AP **101** are instead performed by another wireless communication device, such as a STA **102**. In such a scenario, the STA **102** is the device that is initiating or requesting the out-of-band FD communication by transmitting the FD Request Frame **400**. In an example, the responding device that responds to the initiating STA **102** with the FD Response Frame **420** can be another STA **102**, thereby implementing peer-to-peer out-of-band FD communication. In another example, the responding device that responds to the initiating STA **102** with the FD Response Frame **420** can be the AP **101**, in which case the AP **101** performs step **306** and step **310**.

FIG. **4**A is an example of the FD Request Frame **400**, according to an example embodiment. FIG. **4**B is an example of the FD Response Frame **420**, according to an example embodiment. In some example embodiments, the FD Request Frame **400** and the FD Response Frame are in the format of an action frame. An action frame is a type of management frame. The FD Request Frame **400** includes Category Field **402**, FD Request Field **404**, Forward Channel ID Field **406**, Backward Channel ID Field **408**, Transmission Parameters Field **410**, and Other Fields **412**. The FD Response Frame **420** includes Category Field **422**, FD Response Field **424**, Forward Channel ID Field **426**, Backward Channel ID Field **428**, Transmission Parameters Field **430**, and Setup Result **432**. The FD Request Frame **400** and the FD Response Frame **420** are action frames, and the FD Request Field **404** and the FD Response Field **424** are the action codes for their respective action frames, for indicating the out-of-band FD request and out-of-band FD response, respectively.

The Forward Channel ID Field **406**, **426** and the Backward Channel ID Field **408**, **428** indicate the first channel and the second channel for the out-of-band FD communication. In an example, the Forward Channel ID Field **406**, **426** indicates the first channel for DL transmission, and the Backward Channel ID Field **408**, **428** indicates the second channel for UL transmission. In an example, the first channel indicated by the Forward Channel ID Field **406**, **426** is the primary channel for the particular band as defined by an IEEE standard or other definition. In an example, the second channel in the Backward Channel ID Field **408**, **428** is a second primary channel in the same band **104** as the primary channel, for IEEE standards or wireless communication systems that define two primary channels for a particular band **104**.

The Transmission Parameters Field **410** includes respective transmission parameters for the out-of-band FD communication. Example transmission parameters include Modulation and Coding Scheme (MCS), Space-Time Block Coding (STBC), Number of MU-MIMO Spatial Streams (NSS), bandwidth (BW), etc. In some examples, the Other

Fields **412** includes other subfields relating to the out-of-band FD communication, for example the duration of the protection period of the first channel and the second channel. The Other Fields **412** can also be reserved for future or alternative subfields.

In the FD Response Frame **420**, the Setup Result Field **432** indicates the response to the FD Request Frame **400**, which can be a positive response (affirmation) or a negative response (rejection) of the requested out-of-band FD communication for the first channel indicated in the Forward Channel ID Field **406** and the second channel indicated in the Backward Channel ID Field **408**.

In some examples, the Category Field **402**, **422** in each respective Frame **400**, **420** occupies one octet, and the size of the remaining fields of the Frames **400**, **420** is variable. In other examples the size of the remaining fields of the Frames **400**, **420** is fixed. More or fewer fields may be contained in the FD Request Frame **400** and the FD Response Frame **400** in some example embodiments.

In example embodiments, the control signals described in the fields of the FD Request Frame **400** and the FD Response Frame **400** can be contained in control frames, management frames (including WiFi management frames), action frames, broadcast frames, beacon frames, preambles, trigger frames, or other suitable transmission types.

Detailed examples of step **302** (FIG. **3**), in which the AP **101** determines channel availability for the out-of-band FD communication, will now be described in greater detail. In some example, the availability of each primary channel of each band **104** is simultaneously checked. In some examples, a primary and a secondary channel are simultaneously checked for availability. In some examples, once a first channel (e.g. for DL transmission) and a second channel (e.g. for UL transmission) are determined to be available, the AP **101** does not check any other channels and proceeds with next steps of the method **300**.

In an example of step **302**, the AP **101** performs a Clear Channel Assessment (CCA) to detect energy levels at select channels, as understood in the art. When the energy level is below a CCA threshold, then the channel is available (idle). For example, the AP **101** first senses the energy level of the primary channel(s) via the CCA, and then sense the secondary channel(s) before a backoff counter counts down to zero. The AP **101** can transmit on the particular channels that are available (idle). The AP **101** can transmit on the secondary channel(s) after the time unit PCF InterFrame Spacing (PIFS).

In some example embodiments, channel availability for out-of-band FD communication can be further determined by sending a request over one or more desired channels, and receiving a response over the same desired channels. For example, the request/response can be a Request-To-Send (RTS) Frame/Clear to Send (CTS) Frame, illustrated in greater detail in the method **500** FIG. **5**. For example, the request/response can be the Request Frame **400**/FD Response Frame **420** over the desired channels, illustrated in greater detail in the method **500** of FIG. **5** and the method **600** of FIG. **6**.

In some example embodiments, a particular channel can be determined as being available for the out-of-band FD communication as a default, unless the CCA or other specified criteria is determined by the AP **101** so as to conclude that the channel is non-available. In an example embodiment, a channel can be determined to be non-available when the AP **101** knows that channel is occupied by one STA **102**, or by a specified maximum number of STAs **102** (either currently or in just-past transmissions). In an example embodiment, a channel can be determined to be non-available in order to maintain a relatively equal distribution of STAs **102** in each channel, for load balancing, etc. In an example embodiment, a channel can be determined to be non-available when one STA **102** takes control of an available channel. Such a STA **102** may be reserving the channel for management, data content traffic, a different out-of-band FD communication with a different AP **101**, or for other purposes. In an example embodiment, a channel is non-available when the AP **101** is performing testing, calibrating, etc. In an alternate example embodiment, a particular channel can be determined as being non-available as a default, unless specified criteria is determined by the AP **101** so as to conclude the channel as available.

Additional details of step **302** and step **303** are now described in greater detail. In some examples of step **302**, the respective primary channel of each band **104** are each checked first (using CCA or other methods) to determine availability. Any available primary channels can be selected at step **303** as a potential first channel of the out-of-band FD communication. If there are two primary channels available, then a first primary channel of one band **104** is selected as the potential first channel, and a second primary channel of a different band **104** is selected as the potential second channel for the out-of-band FD. The use of different primary channels in different bands may reduce inter-channel interference or adjacent channel interference (ACI) for the simultaneous two-way communications over the first primary channel and the second primary channel for the out-of-band FD communication.

In some examples, when only one primary channel of one band **104** is available, further channels are then checked for availability in order of sequence within that one band **104**. In other examples, further channels are checked for availability in random order within the band **104** having the available primary channel. In some examples, further channels from any of the bands **104** outside of that one band **104** are checked for availability.

In some example implementations where a particular band **104** has two primary channels, the first potential channel for the out-of-band FD communication is the first primary channel in the particular band **104**, and the second channel for the out-of-band FD communication is the second primary channel in the same particular band **104**.

FIG. **5** illustrates an example method **500** which is an example detailed implementation of the method **300** of FIG. **3** between the AP **101** and the STA **102**, for managing out-of-band FD communication. At step **502**, the AP **101** determines which channels are available (e.g. as in step **302**, FIG. **3**). At step **503**, the AP **101** selects, from the available channels determined at step **502**, a first channel and a second channel as candidate channels for out-of-band FD communication (e.g. as in step **303**, FIG. **3**).

The AP **101** then transmits communications over the first and the second channels to protect those channels and set up the out-of-band FD communication. At step **504**, the AP **101** generates a Request-To-Send (RTS) Frame and transmits, to the STA **102**, the RTS frame over both the first channel and the second channel. At step **506**, the STA **102**, in response to receiving the RTS frame, generates a Clear to Send (CTS) Frame and transmits the CTS Frame back over the same channels which had contained the RTS Frame. In one example, if the STA **102** only receives the RTS on one channel, the STA **102** in response transmits to the AP **101** the CTS Frame back over the one channel. If the STA **102** receives the RTS over both the first channel and second channel, the STA **102** transmits to the AP **101** the CTS Frame

back over both the first channel and second channel. At step **506**, if the AP **101** only receives one CTS Frame over one channel, the setup for out-of-band FD communication is considered to have failed and the method **500** ends. At step **506**, if the AP **101** receives no CTS frame or receives no response after a specified time period, the setup for out-of-band FD communication is considered to have failed and the method **500** ends. The CTS frame at step **506** protects the first channel and the second channel for purposes of out-of-band FD communication exclusively between the AP **101** and the STA **102** (e.g. as in steps **308**, **310**, FIG. **3**). Other STAs **102** and wireless communication devices can determine from monitoring the RTS/CTS Frames that the AP **101** and the STA **102** intend to use the specified channels for a specified duration, and exclude use of the specified channels by the other STAs **102** and wireless communication devices.

The above description, in some examples, can use a bandwidth of 20 MHz for the forward and the backward channels. The method **500** is also applicable to the case where the bandwidth is greater than 20 MHz, e.g. 40 MHz, 80 MHz, or 160 MHz, for example using channel bonding or carrier aggregation. In an example, when the bandwidth is greater than 20 MHz, the RTS and CTS frames are transmitted on each component channel.

When the AP **101** receives the CTS Frame back over both the first channel and second channel, the AP **101** then initiates setup of the out-of-band FD communication. In an example, at step **508** the AP **101** generates the FD Request Frame **400** to the STA **102** and transmits over the first channel (identified in the Forward Channel ID Field **406**). At step **510**, in response, the STA **102** can positively respond to the FD Request Frame **400** (affirm) by generating the FD Response Frame **420** and transmitting to the AP **101** over the second channel (previously identified in the Backward Channel ID Field **408**). In another example, not shown, here, the STA **102** can positively respond to the FD Request Frame **400** (affirm) by generating the FD Response Frame **420** and transmitting to the AP **101** over both the first channel and the second channel.

At step **516**, out-of-band FD communication is performed between the AP **101** and the STA **102** (e.g. as in step **312**, FIG. **3**).

FIG. **6** is another example method **600** which is an example detailed implementation of the method **300** of FIG. **3** between the AP **101** and the STA **102**, for managing out-of-band FD communication. At step **602**, the AP **101** determines which channels are available (e.g. as in step **302**, FIG. **3**). At step **603**, the AP **101** selects, from the available channels determined at step **602**, a first channel and a second channel as candidate channels for out-of-band FD communication (e.g. as in step **303**, FIG. **3**).

The AP **101** then transmits communications over the first and the second channels to set up the out-of-band FD communication. At step **604**, the AP **101** generates the FD Request Frame **400** and transmits to the STA **102** over the first channel (identified in the Forward Channel ID Field **406**) and the second channel (identified in the Backward Channel ID Field **408**). At step **606**, in response, the STA **102** can positively respond to the FD Request Frame **400** (affirm) by generating the FD Response Frame **420** and transmitting to the AP **101** over the first channel (previously identified in the Forward Channel ID Field **406**) and the second channel (previously identified in the Backward Channel ID Field **408**). A successful receipt of the FD Response Frame **420** over both the second channel and the second channel also means that the first channel and the second channel are available. At step **606**, if the AP **101** only receives one FD Response Frame **420** over one channel, the setup for out-of-band FD is considered to have failed and the method **600** ends. At step **606**, if the AP **101** receives no FD Response Frame **420** or receives no response after a specified time period, the setup for out-of-band FD communication is considered to have failed and the method **600** ends.

At steps **608** and **610**, having cleared the first channel and the second channel, the AP **101** and the STA **102** protect the first channel and the second channel for purposes of out-of-band FD communication (e.g. as in steps **308**, **310**, FIG. **3**). At step **612**, out-of-band FD communication is performed between the AP **101** and the STA **102** (e.g. as in step **312**, FIG. **3**).

FIG. **7** is an example method **700** in the form of a messaging diagram between the AP **101** and a STA **102** for performing out-of-band FD communication, e.g., as in step **312** (FIG. **3**), **516** (FIG. **5**), **612** (FIG. **6**). The method **700** includes DL and UL transmissions that overlap in time and transmitted over the first channel and the second channel. In the method **700**, the AP **101** and the STA **102** have already established and protected the first channel and the second channel for the out-of-band FD communication. The method **700** can be used to communicate data and ACK frames using the out-of-band FD communication.

In some conventional systems, after receiving a PDU frame, the receiving device transmits an ACK frame (e.g., Normal ACK or BlockACK) after time unit Short Inter-Frame Space (SIFS). In some cases, a BlockACK frame is transmitted by the receiving device in response to a Block-ACK Request frame.

In the example method **700** of FIG. **7**, for out-of-band FD communication, the receiving wireless communication device **130** may be busy transmitting a frame in the reverse direction, and therefore may not able to send BlockACK at the typical time unit SIFS after receiving the forward frame. In the example method **700** of FIG. **7**, instead the receiving wireless communication device **130** is configured to send the ACK at time unit SIFS after finishing the backward frame transmission.

At step **702**, for example, the AP **101** transmits to the STA **102** a first DL PDU frame (e.g., MPDU or A-MPDU) that contains first DL data. The first DL PDU frame is transmitted over the first channel that was protected for out-of-band FD communication. At optional step **704**, the AP **101** transmits to the STA **102** a second DL PDU frame (e.g., MPDU or A-MPDU) that contains second DL data. The second DL PDU frame is also transmitted over the first channel.

At step **706**, overlapping with step **704**, the STA **102** transmits a first UL PDU frame (e.g., MPDU or A-MPDU) that contains first UL data. The first UL PDU frame is transmitted over the second channel that was protected for out-of-band FD communication. At optional step **708**, the STA **102** transmits a second UL PDU frame (e.g., MPDU or A-MPDU) that contains second UL data. The second UL PDU frame is also transmitted over the second channel.

Because the STA **102** is busy transmitting the second UL PDU frame at step **708**, the STA **102** is unable to transmit the ACK at the typical time unit SIFS after receiving the second DL PDU frame.

At step **710**, the second channel is now available for the STA **102** to transmit the ACK to acknowledge the first DL PDU frame and the second DL PDU frame. Accordingly, at time unit SIFS after step **708** (transmitting the second UL PDU frame), the STA **102** transmits an ACK to the AP **101**. Therefore, an ACK can be transmitted at the first opportunity when the second channel is idle, at time unit SIFS.

At step **712**, at time unit SIFS after receiving the second UL PDU frame at step **708**, the AP **101** transmits, over the first channel, an ACK to the STA **102**.

Referring generally to ACKs **710** and **712**, it should be understood that the AP **101** and the STA **102** transmits its ACK at the earliest opportunity after receipt of the last data frame in the FD communication. The first device to complete its one or more data transmissions (the AP **101** in this example) must therefore wait until all data transmissions **706**, **708** are received from the second device (the STA **102** in this example), and may then transmit its ACK **712** one SIFS after completing receipt of the data frames. The second device to complete its one or more data transmissions (the STA **102** in this example) cannot transmit an ACK while it is still transmitting data packets **706**, **708**, therefore the STA **102** must wait until one SIFS after completing its one or more transmissions before transmitting its ACK **710**.

In some examples, a BlockACK request is transmitted over the first channel by the transmitter device after transmitting a series of PDU frames over the first channel. A BlockACK response is transmitted by the receiver device over the second channel when the second channel is available (idle), or at the earliest opportunity after time unit SIFS of the last transmission in one or more of a series of transmissions from the receiver device.

In an alternate example of the method **700**, the steps or messages of the AP **101** are performed by the STA **102**, and vice versa. In an alternate example of the method **700**, the method **700** is performed between two different STAs **102** that have already established and protected between themselves the first channel and the second channel, for performing peer-to-peer out-of-band FD communication.

FIG. **8** illustrates an example method **800** implemented by a wireless communication device **130** configured to simultaneously transmit and receive wireless signals, such as the AP **101**. At step **802**, the wireless communication device **130** generates a control signal that includes and an identification of both a first channel for the wireless communication device **130** to transmit on and a second channel for the wireless communication device **130** to simultaneously receive on, for the out-of-band FD communication. At step **804**, the wireless communication device **130** transmits the control signal in a WiFi management frame.

FIG. **9** illustrates an example method **900** implemented by a wireless communication device **130**, such as the STA **102**. In some examples, the wireless communication device **130** is only capable of Half Duplex communications. In other examples, the wireless communication device **130** is configured to simultaneously transmit and receive communications over two different channels to perform out-of-band FD communication. At step **902**, the wireless communication device **130** receives a control signal in a WiFi management frame that includes a request for out-of-band FD communication and an identification of both a first channel for transmission in one direction (e.g. DL transmission) and a second channel for transmission in a reverse direction (e.g. UL transmission). At step **904**, the wireless communication device **130** transmits a response to the control signal that accepts the request for the out-of-band FD communication. At step **906**, the wireless communication device **130** protects the first channel and the second channel. In an example embodiment, the wireless communication device **130** may receive a Request-To-Send (RTS) Frame over the first channel and the second channel, and protect the first channel and the second channel by transmitting a Clear to Send (CTS) Frame over the first channel and the second channel.

FIG. **10** illustrates an example method **1000** implemented by a wireless communication device **130**. At step **1002**, the wireless communication device **130** determines channel availability of a first channel and a second channel. At step **1004**, the wireless communication device **130** generates a control signal that identifies both the first channel and the second channel. The control signal can identify the first channel for the wireless communication device **130** to transmit on, and the second channel for the wireless communication device **130** to simultaneously receive on. At step **1006**, the wireless communication device **130** transmits the control signal in a WiFi management frame. At step **1008**, the wireless communication device **130** protects the first channel for the wireless communication device **130** to transmit on and protects the second channel for the wireless communication device **130** to receive on. In an example embodiment, the wireless communication device **130** may transmit a Request-To-Send (RTS) Frame over the first channel and the second channel, and receiving a Clear to Send (CTS) Frame over the first channel and the second channel, thereby having the first channel and the second channel protected for out-of-band FD communication. In an example embodiment, the wireless communication device **130** is capable of out-of-band FD communication.

FIG. **11** illustrates an example method **1100** implemented by a wireless communication device **130** capable of out-of-band FD communication, in accordance with an example embodiment. In the method **700**, the wireless communication device **130** has already established and protected the first channel and the second channel for the out-of-band FD communication. At step **1102**, the wireless communication device **130** transmits at least one DL transmission over the first channel. At step **1104**, the wireless communication device **130** receives at least one UL transmission over the second channel. The at least one UL transmission has overlap in time with the at least one DL transmission. In an example, the wireless communication device **130** may be unable to transmit an ACK after time unit SIFS from the at least one DL transmission because the wireless communication device **130** is busy transmitting the at least one UL transmission. At step **1106**, if the last UL transmission ends after the last DL transmission, the wireless communication device **130** receives, over the second channel, an acknowledgement of the at least one DL transmission after the last UL transmission. In an example embodiment, the acknowledgement is received at time unit SIFS from the last UL transmission. Continuing the example, the wireless communication device **130** transmits, over the first channel, an acknowledgement of the at least one UL transmission at time unit SIFS from the last UL transmission.

In another example, at step **1108**, if the last DL transmission ends after the last UL transmission, the wireless communication device **130** transmits, over the first channel, an acknowledgement of the at least one UL transmission after the last DL transmission. In an example embodiment, the acknowledgement is received at time unit SIFS from the last DL transmission. Continuing the example, the wireless communication device **130** receives, over the second channel, an acknowledgement of the at least one DL transmission at time unit SIFS from the last DL transmission.

In some example embodiments of the method **1100**, the acknowledgment can be a Normal ACK or a BlockACK.

FIG. **2** is a schematic diagram of an example wireless communication device **130**, in accordance with example embodiments. For example, the wireless communication device **130** may be the AP **101** or the STA **102**. The wireless communication device **130** may be used for both Single

User (SU) and multiple access communications within the wireless communication network **100**. Although FIG. **2** shows a single instance of each component, there may be multiple instances of each component in the wireless communication device **130** and the wireless communication device **130** could be implemented using parallel and distributed architecture. Some of the components in FIG. **2** are optional in some examples.

The wireless communication device **130** may include one or more processing devices **132**, such as a processor, a microprocessor, an application-specific integrated circuit (ASIC), a field-programmable gate array (FPGA), a dedicated logic circuitry, or combinations thereof. The wireless communication device **130** may also include one or more optional input/output (I/O) interface(s) **134**, which may enable interfacing with one or more optional input devices **148** and output devices **150**. The wireless communication device **130** may include one or more network interfaces **136** for wired or wireless communication with a network (e.g., an intranet, the Internet, a Peer-to-Peer (P2P) network, a Wide Area Network (WAN), a wireless WAN (WWAN), a LAN, or a Radio Access Network (RAN)) or other node. Wireless networks may make use of wireless connections transmitted over an antenna **152**. The network interface(s) **136** may provide multiple access wireless communication via one or more transmitters or transmit antennas and one or more receivers or receive antennas, for example. In this example, one antenna **152** is shown, which may serve for multiple access transmission or single user transmission. However, in other examples there may be multiple antennas for transmitting and receiving. In some examples, an antenna array may be used. The wireless communication device **130** may also include one or more storage units **138**, which may include a mass storage unit such as a solid state drive, a hard disk drive, a magnetic disk drive or an optical disk drive.

In some example embodiments, the network interface(s) **136** and antenna **152** are collectively used to perform out-of-band FD communication and optionally FD communication, and transmit and receive communications simultaneously, either over two different channels in accordance with example embodiments, or optionally over the same channel.

The wireless communication device **130** may include one or more non-transitory memories **140** that can include physical memory **142**, which may include a volatile or non-volatile memory (e.g., a flash memory, a random access memory (RAM), or a read-only memory (ROM)). The memory **140** (as well as storage unit(s) **138**) may store instructions for execution by the processing device(s) **132**, such as to carry out processing such as those described in the present disclosure. The memory **140** may include other software instructions, such as for implementing an operating system (OS), and other applications/functions. In some examples, one or more data sets or modules may be provided by an external memory (e.g., an external drive in wired or wireless communication with the wireless communication device **130**) or may be provided by a transitory or non-transitory computer-readable medium. Examples of non-transitory computer readable media include a RAM, a ROM, an erasable programmable ROM (EPROM), an electrically erasable programmable ROM (EEPROM), a flash memory, a CD-ROM, or other portable memory storage.

In some examples, there may be a bus **144** providing communication among components of the wireless communication device **130**. The bus **144** may be any suitable bus architecture including, for example, a memory bus, a peripheral bus or a video bus. Optional input device(s) **148** (e.g., a keyboard, a mouse, a microphone, a touchscreen, or a keypad) and optional output device(s) **150** (e.g., a display, a speaker or a printer) are shown as external to the wireless communication device **130**, and connected to optional I/O interface(s) **134**. In other examples, one or more of the input device(s) **148** or the output device(s) **150** may be included as a component of the wireless communication device **130**.

A transmitter and a receiver may be included as one or more components of the wireless communication device **130**. For example, the transmitter and the receiver may be included as a single component for transmitting and receiving radio frequency (RF) analog signals. In other examples, the transmitter and the receiver may be included as two separate components for transmitting and receiving radio frequency (RF) analog signals respectively.

When the wireless communication device **130** is the AP **101**, communication with selected or associated STAs **102** can be performed using the antenna **152**. The processing device **132** may carry out the steps and functions described herein. When the wireless communication device **130** is a STA **102**, communications with the AP **101** can be performed via the antenna **152**.

The wireless communication device **130** also includes a power supply block **146** to supply power to the wireless communication device **130**. In some examples, the power supply block **146** can include a battery. In some examples, the power supply block **146** includes a power adapter (e.g., AC/DC or DC/DC) for connection to an external power source and can be used for charging the battery.

In at least some examples, instructions that cause the processing device **132** to carry out methods in accordance with example embodiments are stored in storage unit(s) **138** or memory **140** of the wireless communication device **130**. In some examples, the processing device **132** may be one or more controllers, which may comprise a modulator or a processor. Example systems and methods described herein, in accordance with examples, can be implemented by the one or more controllers. The one or more controllers can comprise hardware, software, or a combination of hardware and software, depending on the particular component and function. In some examples, the one or more controllers can include analog or digital components, and can include one or more processors, one or more non-transitory storage mediums such as memory storing instructions executable by the one or more processors, one or more transceivers (or separate transmitters and receivers), one or more signal processors (analog or digital), and one or more analog circuit components.

Example embodiments can applied to MU communication, single user (SU) communication, trigger based (TB) communication, or extended range (ER) TB communication.

An example embodiment is a method implemented by a wireless communication device capable of simultaneously transmitting and receiving wireless signals, the method includes: generating a control signal that includes an identification of a first channel for the wireless communication device to transmit on, and a second channel for the wireless communication device to simultaneously receive on; and transmitting the control signal in a WiFi management frame.

In an example embodiment of any of the above-described methods, the method further includes determining channel availability for the first channel and the second channel.

In an example embodiment of any of the above-described methods, the determining includes performing a Clear Channel Assessment (CCA) on the first channel and the second channel.

In an example embodiment of any of the above-described methods, the determining includes: generating a Request-To-Send (RTS) Frame and transmitting the RTS Frame over the first channel and the second channel; receiving a Clear to Send (CTS) Frame over the first channel and the second channel; and determining that the first channel and the second channel are available based on receiving the CTS Frame over the first channel and the second channel.

In an example embodiment of any of the above-described methods, the CTS Frame protects the first channel and the second channel.

In an example embodiment of any of the above-described methods, the determining includes: transmitting the control signal over the first channel; receiving a response to the control signal over the second channel; and determining that the first channel and the second channel are available based on receiving the response over the first channel and the second channel.

In an example embodiment of any of the above-described methods, one or both of the first channel and the second channel is a primary channel.

In an example embodiment of any of the above-described methods, the first channel and the second channel are each a primary channel in different bands.

In an example embodiment of any of the above-described methods, the method further includes: receiving a response to the control signal; and protecting, in response to the receiving, the first channel and the second channel.

In an example embodiment of any of the above-described methods, the method further includes: transmitting at least one first transmission over the first channel; and receiving at least one second transmission over the second channel, wherein the at least one second transmission has overlap in time with the at least one first transmission.

In an example embodiment of any of the above-described methods, the transmitting includes transmitting the at least one first transmission to a first station (STA), and the receiving includes receiving the at least one second transmission from a second STA.

In an example embodiment of any of the above-described methods, the method further includes, when a last transmission of the at least one first transmission ends after a last transmission of the at least one second transmission, transmitting an acknowledgment frame over the first channel in response to the at least one second transmission and after time unit Short InterFrame Space (SIFS) from the last transmission of the at least one transmission.

In an example embodiment of any of the above-described methods, the method further includes, when a last transmission of the at least one second transmission ends after a last transmission of the at least one first transmission, receiving an acknowledgement frame over the second channel in response to the at least one first transmission and after time unit Short InterFrame Space (SIFS) from the last transmission of the at least one second transmission.

In an example embodiment of any of the above-described methods, the transmitting of the control signal includes broadcasting the control signal or transmitting a beacon frame that includes the control signal.

In an example embodiment of any of the above-described methods, the wireless communication device is a Station (STA), an access point (AP), or a personal basic service set (PBSS) control point (PCP).

Another example embodiment is a method implemented by a wireless communication device, the method including: receiving a control signal in a WiFi management frame that includes an identification of both a first channel for transmission in one direction and a second channel for simultaneous transmission in a reverse direction; transmitting a response to the control signal; and protecting the first channel and the second channel.

In an example embodiment of any of the above-described methods, the receiving includes receiving the control signal from a second wireless communication device, wherein the protecting includes protecting the first channel and the second channel for communication between the wireless communication device and the second wireless communication device.

In an example embodiment of any of the above-described methods, the protecting excludes use of the first channel and the second channel by devices other than the wireless communication device and the second wireless communication device.

In an example embodiment of any of the above-described methods, the first channel and the second channel is protected for any wireless communication devices that responds to the control signal.

In an example embodiment of any of the above-described methods, the method further includes receiving a Request-To-Send (RTS) Frame over the first channel and the second channel, wherein the protecting includes transmitting a Clear to Send (CTS) Frame over the first channel and the second channel.

In an example embodiment of any of the above-described methods, the receiving includes receiving the control signal over the first channel and the second channel, and the transmitting includes transmitting the response over the first channel and the second channel.

In an example embodiment of any of the above-described methods, the method further includes: receiving at least one first transmission over the first channel; and transmitting at least one second transmission over the second channel, wherein the at least one second transmission has overlap in time with the at least one first transmission.

In an example embodiment of any of the above-described methods, the method further includes, when a last transmission of the at least one second transmission ends after a last transmission of the at least one first transmission, transmitting an acknowledgement frame over the second channel in response to the at least one first transmission and after time unit Short InterFrame Space (SIFS) from the last transmission of the at least one second transmission.

In an example embodiment of any of the above-described methods, the method further includes, when a last transmission of the at least one first transmission ends after a last transmission of the at least one second transmission, receiving an acknowledgement frame over the first channel in response to the at least one second transmission and after time unit Short InterFrame Space (SIFS) from the last transmission of the at least one first transmission.

An example embodiment is a wireless communication device, comprising an antenna; a processing device; a memory associated with the processing device for storing instructions that when executed by the processing device causes the processing device to perform any of the described methods, processes or functions.

An example embodiment is a non-transitory computer-readable medium which stores instructions that when

executed by a processing device causes the processing device to perform any of the described methods, processes or functions.

An example embodiment is a non-transitory computer-readable medium which stores instructions that when executed by a processing device causes the processing device to perform any of the described methods, processes or functions.

The example embodiments described above may be implemented by using hardware only or by using software and a necessary universal hardware platform. Based on such understandings, the technical solution of some example embodiments may be embodied in the form of a software product. The software product may be stored in a non-volatile or non-transitory storage medium, which can be a compact disk read-only memory (CD-ROM), USB flash disk, or a removable hard disk. The software product includes a number of instructions that enable a computer device (personal computer, server, or network device) to execute the methods provided in the example embodiments. The software product may additionally include a number of instructions that enable a computer device to execute operations for configuring or programming a digital logic apparatus in accordance with example embodiments.

Example apparatuses and methods described herein, in accordance with example embodiments, can be implemented by one or more controllers. The controllers can comprise hardware, software, or a combination of hardware and software, depending on the particular application, component or function. In some example embodiments, the one or more controllers can include analog or digital components, and can include one or more processors, one or more non-transitory storage mediums such as memory storing instructions executable by the one or more processors, one or more transceivers (or separate transmitters and receivers), one or more signal processors (analog and/or digital), and/or one or more analog circuit components.

In the described methods or block diagrams, the boxes may represent events, steps, functions, processes, modules, messages, and/or state-based operations, etc. Although some of the above examples have been described as occurring in a particular order, it will be appreciated by persons skilled in the art that some of the steps or processes may be performed in a different order provided that the result of the changed order of any given step will not prevent or impair the occurrence of subsequent steps. Furthermore, some of the messages or steps described above may be removed or combined in other embodiments, and some of the messages or steps described above may be separated into a number of sub-messages or sub-steps in other embodiments. Even further, some or all of the steps may be repeated, as necessary. Elements described as methods or steps similarly apply to systems or subcomponents, and vice-versa. Reference to such words as "sending" or "receiving" could be interchanged depending on the perspective of the particular device.

The above discussed embodiments are considered to be illustrative and not restrictive. Example embodiments described as methods would similarly apply to systems, and vice-versa.

Variations may be made to some example embodiments, which may include combinations and sub-combinations of any of the above. The example embodiments presented above are merely examples and are in no way meant to limit the scope of this disclosure. Variations of the innovations described herein will be apparent to persons of ordinary skill in the art, such variations being within the intended scope of the present disclosure. In particular, features from one or more of the above-described embodiments may be selected to create alternative embodiments comprised of a sub-combination of features which may not be explicitly described above. In addition, features from one or more of the above-described embodiments may be selected and combined to create alternative embodiments comprised of a combination of features which may not be explicitly described above. Features suitable for such combinations and sub-combinations would be readily apparent to persons skilled in the art upon review of the present disclosure as a whole. The subject matter described herein intends to include all suitable changes in technology.

The specification and drawings are, accordingly, to be regarded simply as an illustration, and are contemplated to cover any and all modifications, variations, combinations or equivalents.

What is claimed is:

1. A method implemented by a wireless communication device capable of simultaneously transmitting and receiving wireless signals, the method comprising:

generating a control signal that identifies a first channel for the wireless communication device to transmit on, and a second channel for the wireless communication device to simultaneously receive on while transmitting on the first channel, wherein the first channel and the second channel are primary channels in two different bands, the two different bands being separate and distinct from one another; and

transmitting the control signal in a WiFi management frame.

2. The method as claimed in claim **1**, further comprising determining channel availability for the first channel and the second channel.

3. The method as claimed in claim **2**, wherein the determining includes performing a Clear Channel Assessment (CCA) on the first channel and the second channel.

4. The method as claimed in claim **2**, wherein the determining includes:

generating a Request-To-Send (RTS) Frame and transmitting the RTS Frame over the first channel and the second channel;

receiving a Clear to Send (CTS) Frame over the first channel and the second channel; and

determining that the first channel and the second channel are available based on receiving the CTS Frame over the first channel and the second channel.

5. The method as claimed in claim **4**, wherein the CTS Frame protects the first channel and the second channel.

6. The method as claimed in claim **2**, wherein the determining includes:

transmitting the control signal over the first channel;

receiving a response to the control signal over the second channel; and

determining that the first channel and the second channel are available based on receiving the response over the first channel and the second channel.

7. The method as claimed in claim **1**, further comprising:

receiving a response to the control signal; and

protecting, in response to the receiving, the first channel and the second channel.

8. The method as claimed in claim **1**, further comprising:

transmitting at least one first transmission over the first channel; and

receiving at least one second transmission over the second channel, wherein the at least one second transmission has overlap in time with the at least one first transmission.

9. The method as claimed in claim **8**, wherein the transmitting includes transmitting the at least one first transmission to a first station (STA), and the receiving includes receiving the at least one second transmission from a second STA.

10. The method as claimed in claim **8**, further comprising, when a last transmission of the at least one first transmission ends after a last transmission of the at least one second transmission, transmitting an acknowledgment frame over the first channel in response to the at least one second transmission and after time unit Short InterFrame Space (SIFS) from the last transmission of the at least one first transmission.

11. The method as claimed in claim **8**, further comprising, when a last transmission of the at least one second transmission ends after a last transmission of the at least one first transmission, receiving an acknowledgement frame over the second channel in response to the at least one first transmission and after time unit Short InterFrame Space (SIFS) from the last transmission of the at least one second transmission.

12. The method as claimed in claim **1**, wherein the transmitting of the control signal includes broadcasting the control signal or transmitting a beacon frame that includes the control signal.

13. The method as claimed in claim **1**, wherein the wireless communication device is a Station (STA), an access point (AP), or a personal basic service set (PBSS) control point (PCP).

14. The method of claim **1**, wherein a lower band of the two different bands is at least 2.4 GHz, or wherein at least one of the two different bands includes at least ii channels.

15. The method of claim **1**, wherein the first channel and the second channel are in two different non-licensed bands.

16. A method implemented by a wireless communication device, the method comprising:

receiving a control signal in a WiFi management frame that identifies both a first channel for transmission in one direction and a second channel for simultaneous reception in a reverse direction, wherein the first channel and the second channel are primary channels in two different bands, the two different bands being separate and distinct from one another;

transmitting a response to the control signal; and

protecting the first channel and the second channel.

17. The method as claimed in claim **16**, wherein the receiving includes receiving the control signal from a second wireless communication device, wherein the protecting includes protecting the first channel and the second channel for communication between the wireless communication device and the second wireless communication device.

18. The method as claimed in claim **17**, wherein the protecting excludes use of the first channel and the second channel by devices other than the wireless communication device and the second wireless communication device.

19. The method as claimed in claim **16**, wherein the first channel and the second channel are protected for any wireless communication devices that responds to the control signal.

20. The method as claimed in claim **16**, further comprising receiving a Request-To-Send (RTS) Frame over the first channel and the second channel, wherein the protecting includes transmitting a Clear to Send (CTS) Frame over the first channel and the second channel.

21. The method as claimed in claim **16**, wherein the receiving includes receiving the control signal over the first channel and the second channel, and the transmitting includes transmitting the response over the first channel and the second channel.

22. The method as claimed in claim **16**, further comprising:

receiving at least one first transmission over the first channel; and

transmitting at least one second transmission over the second channel, wherein the at least one second transmission has overlap in time with the at least one first transmission.

23. The method as claimed in claim **22**, further comprising, when a last transmission of the at least one second transmission ends after a last transmission of the at least one first transmission, transmitting an acknowledgement frame over the second channel in response to the at least one first transmission and after time unit Short InterFrame Space (SIFS) from the last transmission of the at least one second transmission.

24. The method as claimed in claim **22**, further comprising, when a last transmission of the at least one first transmission ends after a last transmission of the at least one second transmission, receiving an acknowledgement frame over the first channel in response to the at least one second transmission and after time unit Short InterFrame Space (SIFS) from the last transmission of the at least one first transmission.

25. A wireless communication device, comprising:

an antenna;

a processing device;

a memory associated with the processing device for storing instructions that when executed by the processing device causes the processing device to:

generate a control signal that identifies a first channel for the wireless communication device to transmit on, and a second channel for the wireless communication device to simultaneously receive on while transmitting on the first channel, wherein the first channel and the second channel are primary channels in two different bands, the two different bands being separate and distinct from one another; and

transmit the control signal in a WiFi management frame.

26. A non-transitory computer-readable medium which stores instructions that when executed by a wireless communication device causes the wireless communication device to perform operations including:

generating a control signal that identifies a first channel for the wireless communication device to transmit on, and a second channel for the wireless communication device to simultaneously receive on while transmitting on the first channel, wherein the first channel and the second channel are primary channels in two different bands, the two different bands being separate and distinct from one another; and

transmitting the control signal in a WiFi management frame.

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