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Chu et al.

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(54) **MEDIUM ACCESS CONTROL FOR MULTI-CHANNEL OFDM IN A WIRELESS LOCAL AREA NETWORK**

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(73) Assignee: **Marvell World Trade Ltd.**, St. Michael (BB)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 880 days.

(21) Appl. No.: **14/538,573**

(22) Filed: **Nov. 11, 2014**

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Related U.S. Application Data

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(51) **Int. Cl.**

H04L 5/00	(2006.01)
H04W 72/00	(2009.01)
H04W 84/12	(2009.01)

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

CPC ***H04W 72/005*** (2013.01); ***H04L 5/0007*** (2013.01); ***H04L 5/0037*** (2013.01); ***H04L 5/0055*** (2013.01); *H04W 84/12* (2013.01)

(58) **Field of Classification Search**

CPC H04W 72/0453; H04W 72/044; H04W 84/10; H04W 84/12

See application file for complete search history.

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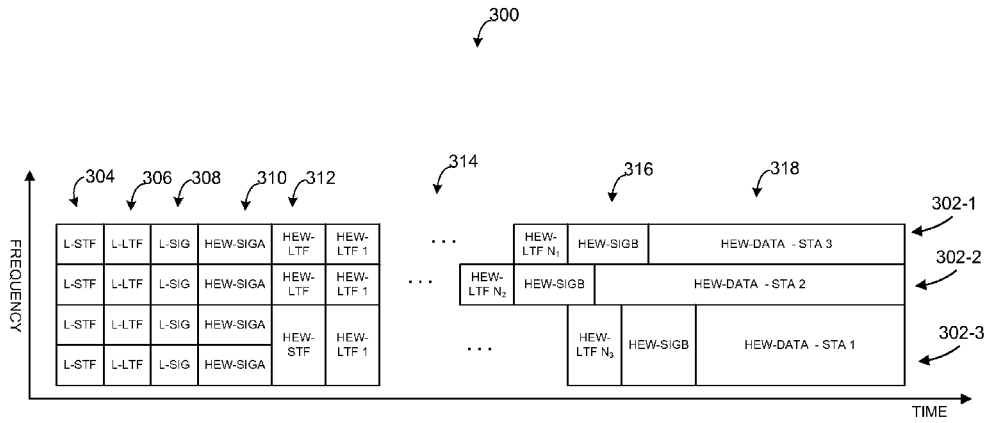
Primary Examiner — Robert M Morlan

(57) **ABSTRACT**

A first communication device allocates respective sub-channels of an orthogonal frequency division multiplexing (OFDM) channel to two or more second communication devices for uplink orthogonal frequency division multiple access (OFDMA) transmission from the two or more second communication devices. A first sub-channel is allocated to a first one of the second communication devices and a second sub-channel is allocated to a second one of the second communication devices. The first communication device provides, to the second communication devices, indications of the respective sub-channels allocated to the second communication devices. The first communication device receives an uplink OFDMA data unit that includes a first OFDM data unit transmitted from the first one of the second communication devices via the first sub-channel, and a second OFDM data unit transmitted from the second one of the second communication devices via the second sub-channel.

42 Claims, 27 Drawing Sheets



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2015/0078215	A1*	3/2015	Zhou	H04L 5/003 370/277
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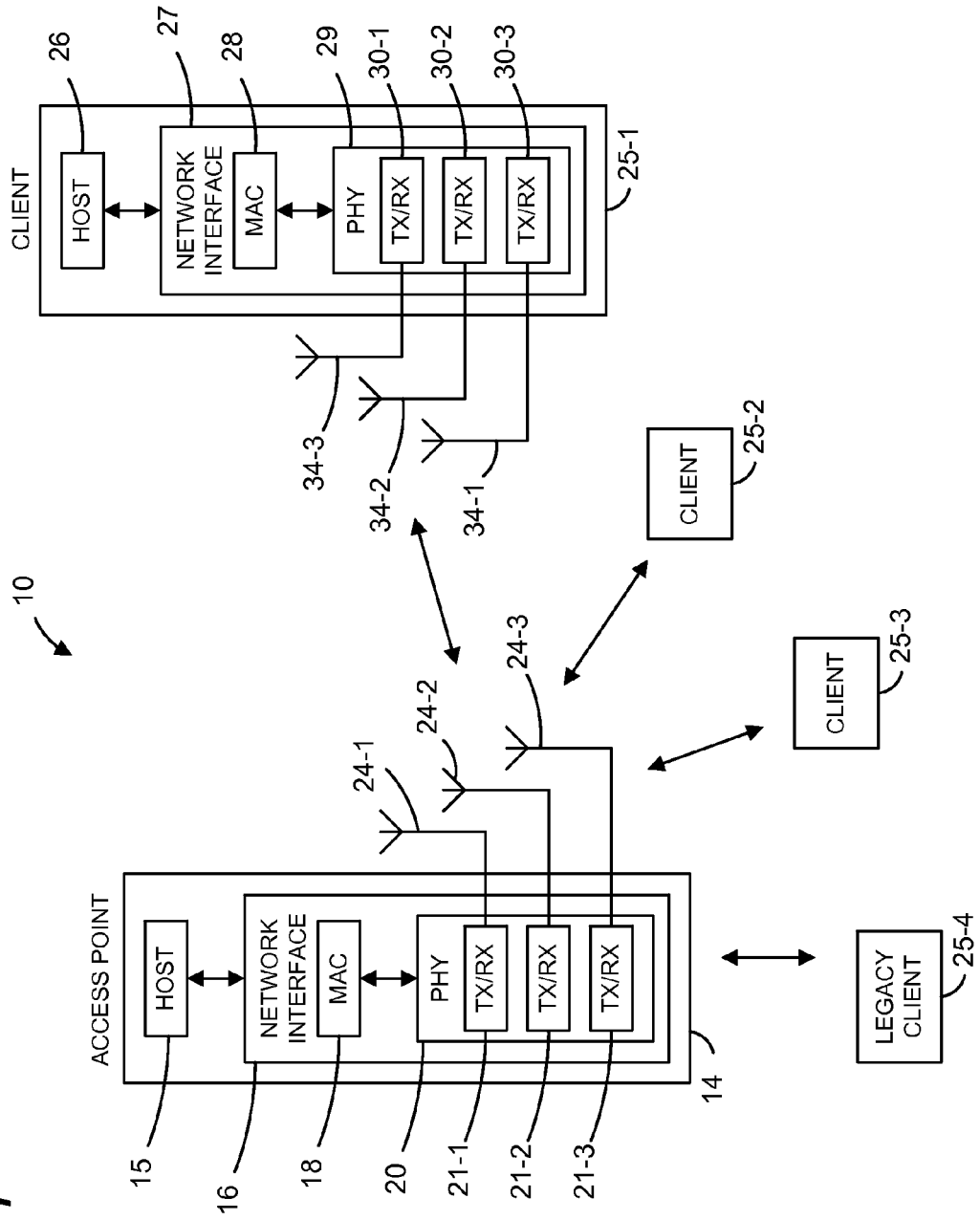
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PHY
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TX/RX
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24-1
ACCESS POINT
HOST
NETWORK INTERFACE
MAC
PHY
TX/RX
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18
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14
LEGACY CLIENT
25-4

FIG. 1

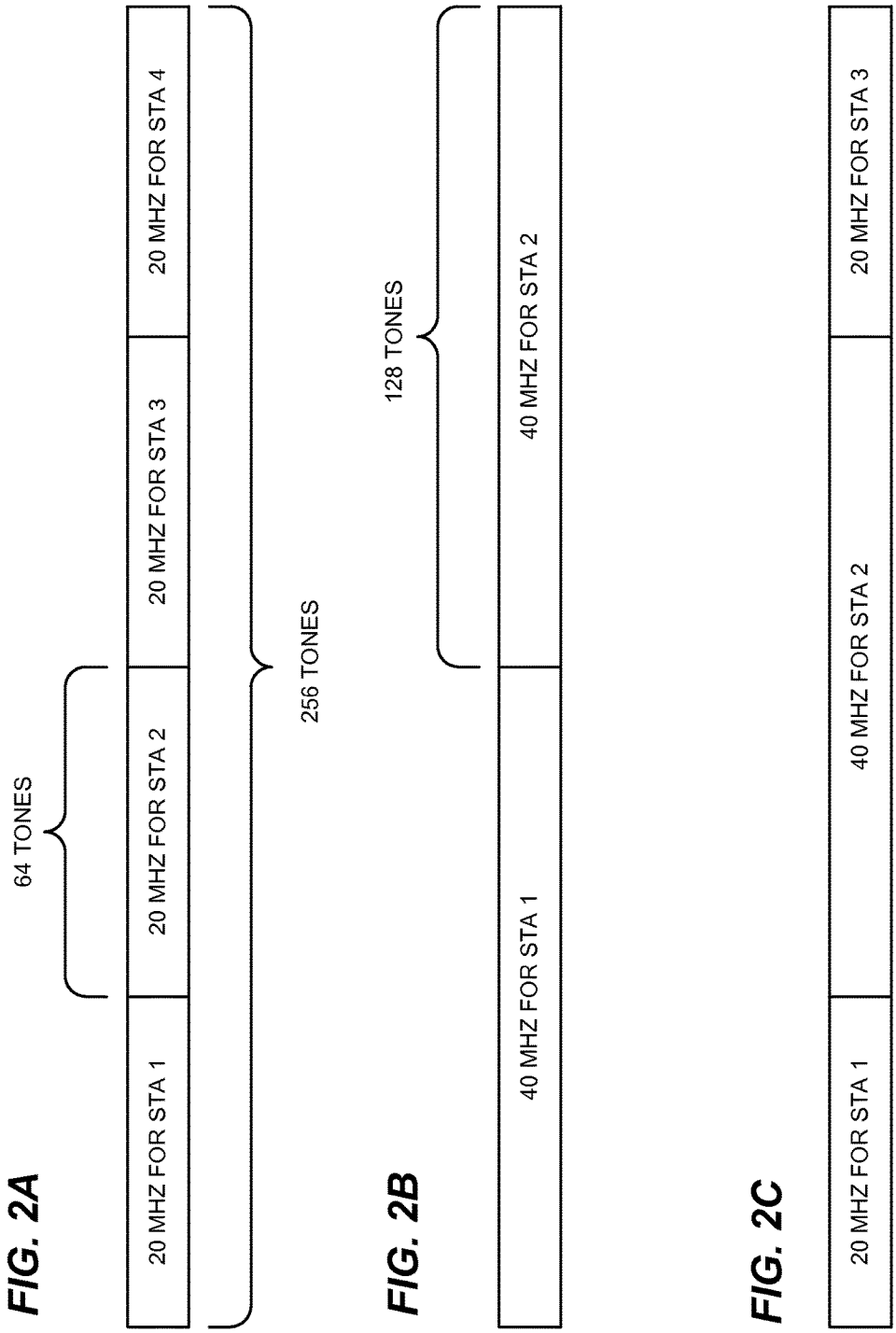
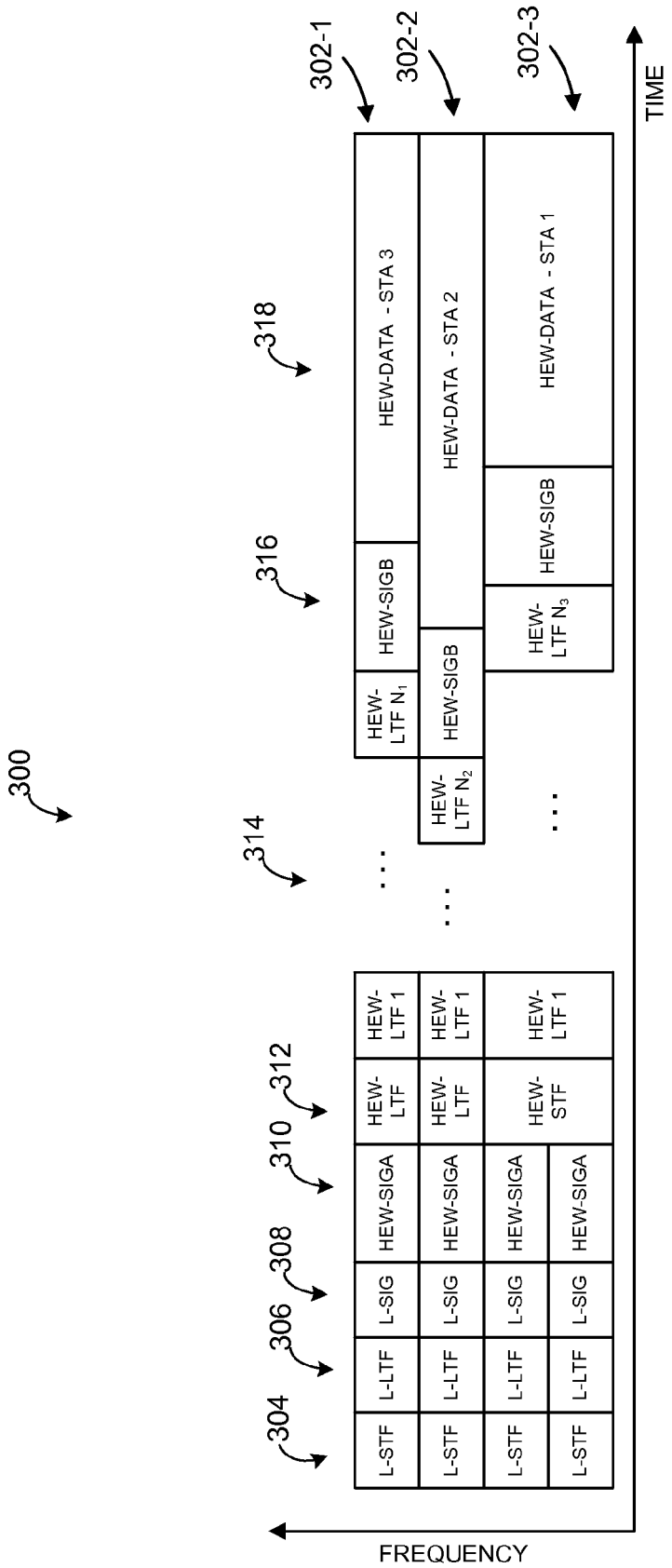


FIG. 2A

FIG. 2B

FIG. 2C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HEW-DATA - STA 1
HEW-SIGB
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HEW-SIGB
HEW-LTF N1
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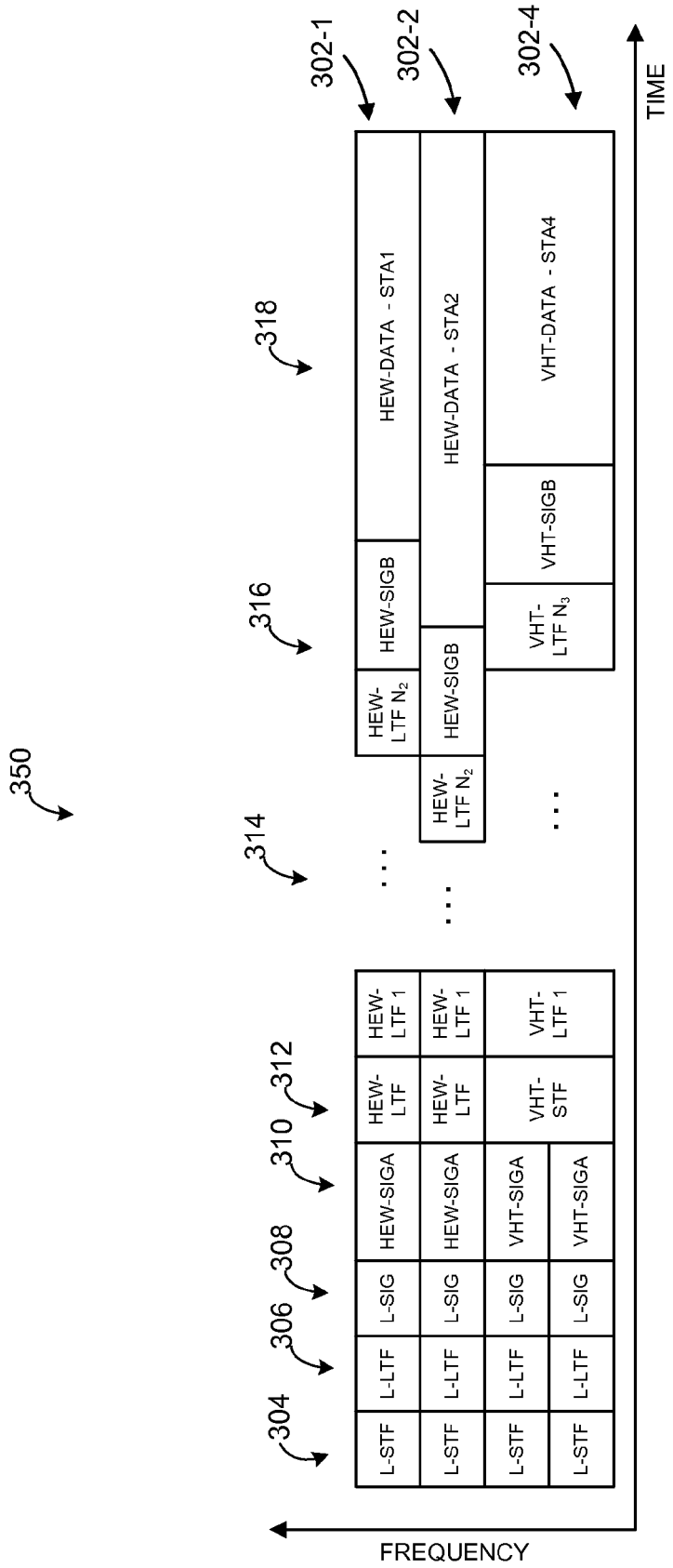
FIG. 3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VHT-DATA - STA4
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HEW-SIGB
VHT-SIGB
HEW-LTF N2
HEW-LTF N2
VHT-LTF N3
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FREQUENCY

FIG. 4

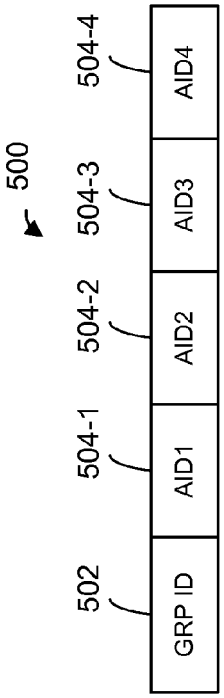
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FIG. 5A

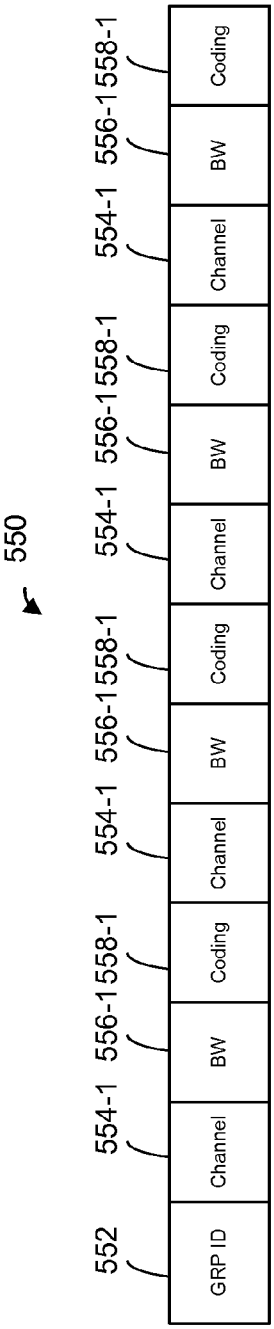
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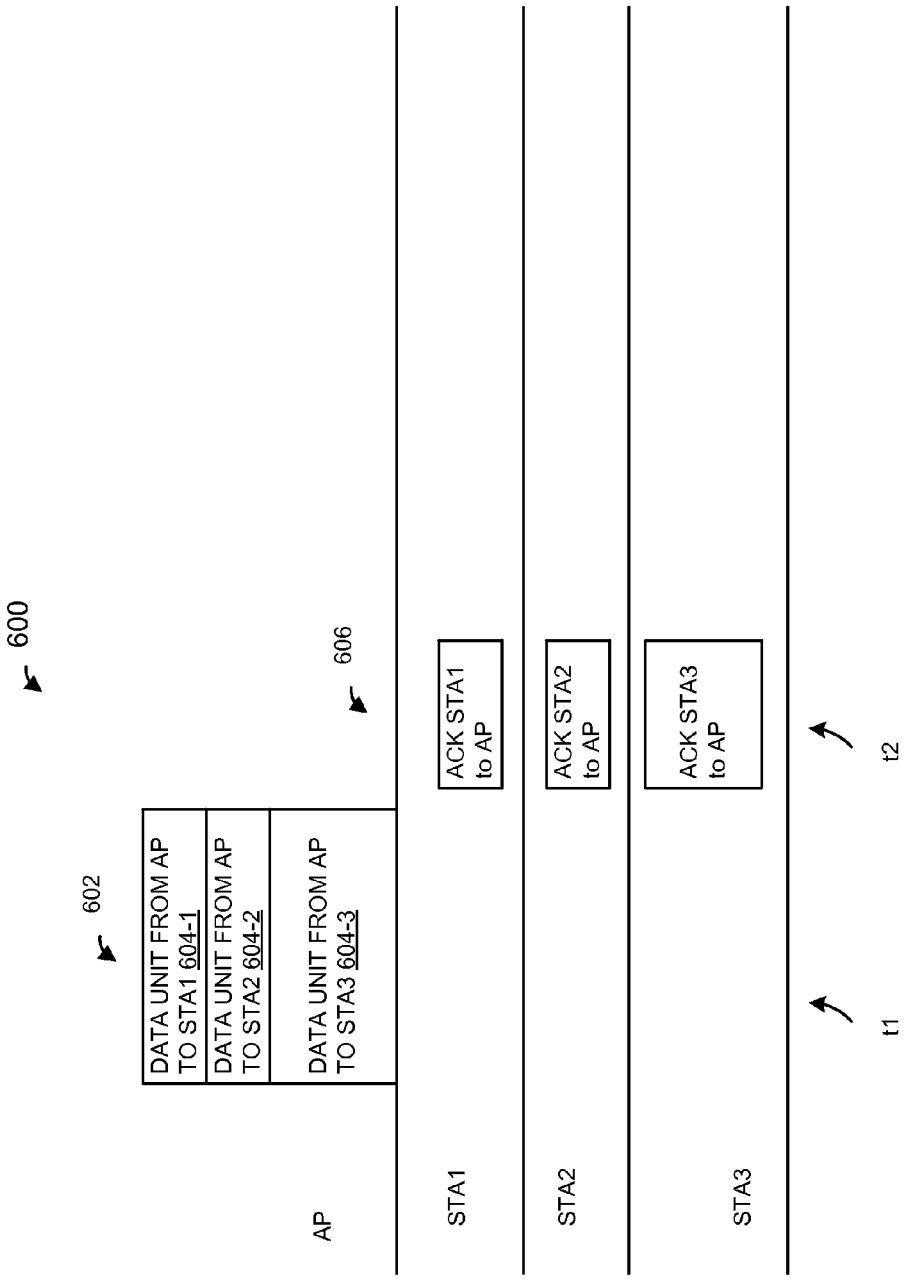
FIG. 5B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STA1
STA2
STA3
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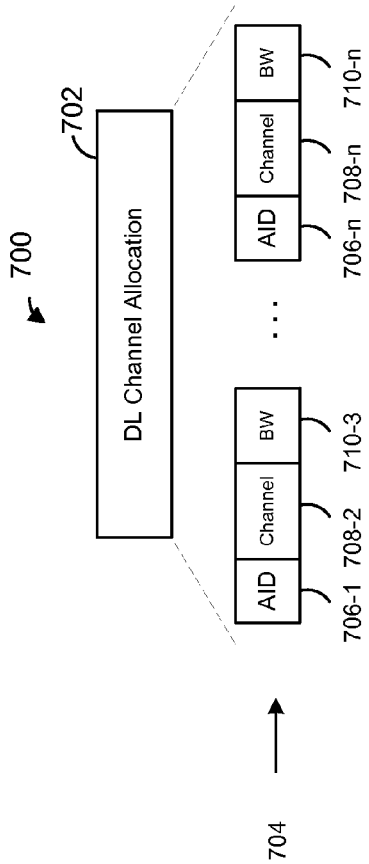
t2

FIG. 6


700
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AID
Channel
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708-n
710-n
704

FIG. 7A

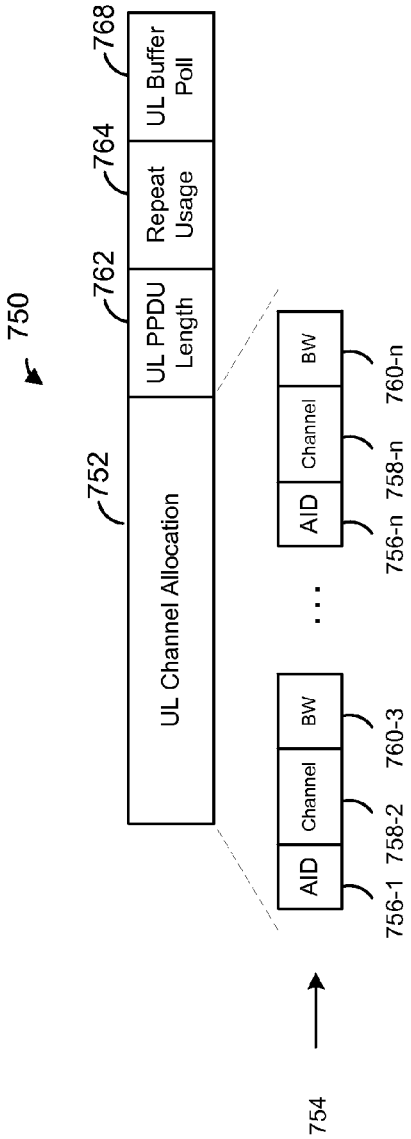

750
752
UL Channel Allocation
762
UL PPDU Length
764
Repeat Usage
768
UL Buffer Poll
AID
Channel
BW
756-1
758-2
760-3
756-n
758-n
760-n
754

FIG. 7B

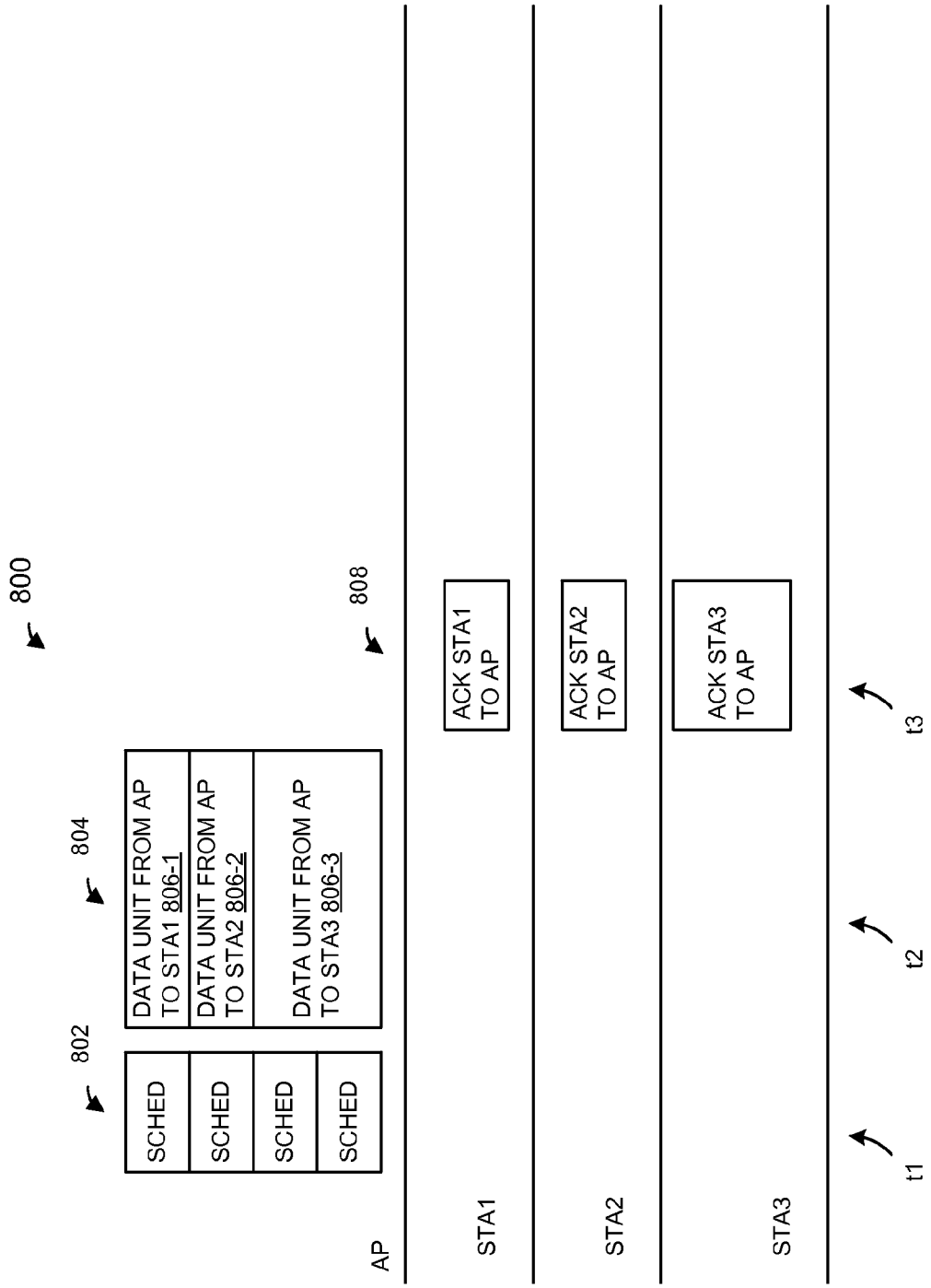

800
802
804
808
SCHED
SCHED
SCHED
SCHED
DATA UNIT FROM AP TO STA1 806-1
DATA UNIT FROM AP TO STA2 806-2
DATA UNIT FROM AP TO STA3 806-3
ACK STA1 TO AP
ACK STA2 TO AP
ACK STA3 TO AP
AP
STA1
STA2
STA3
t1
t2
t3

FIG. 8A

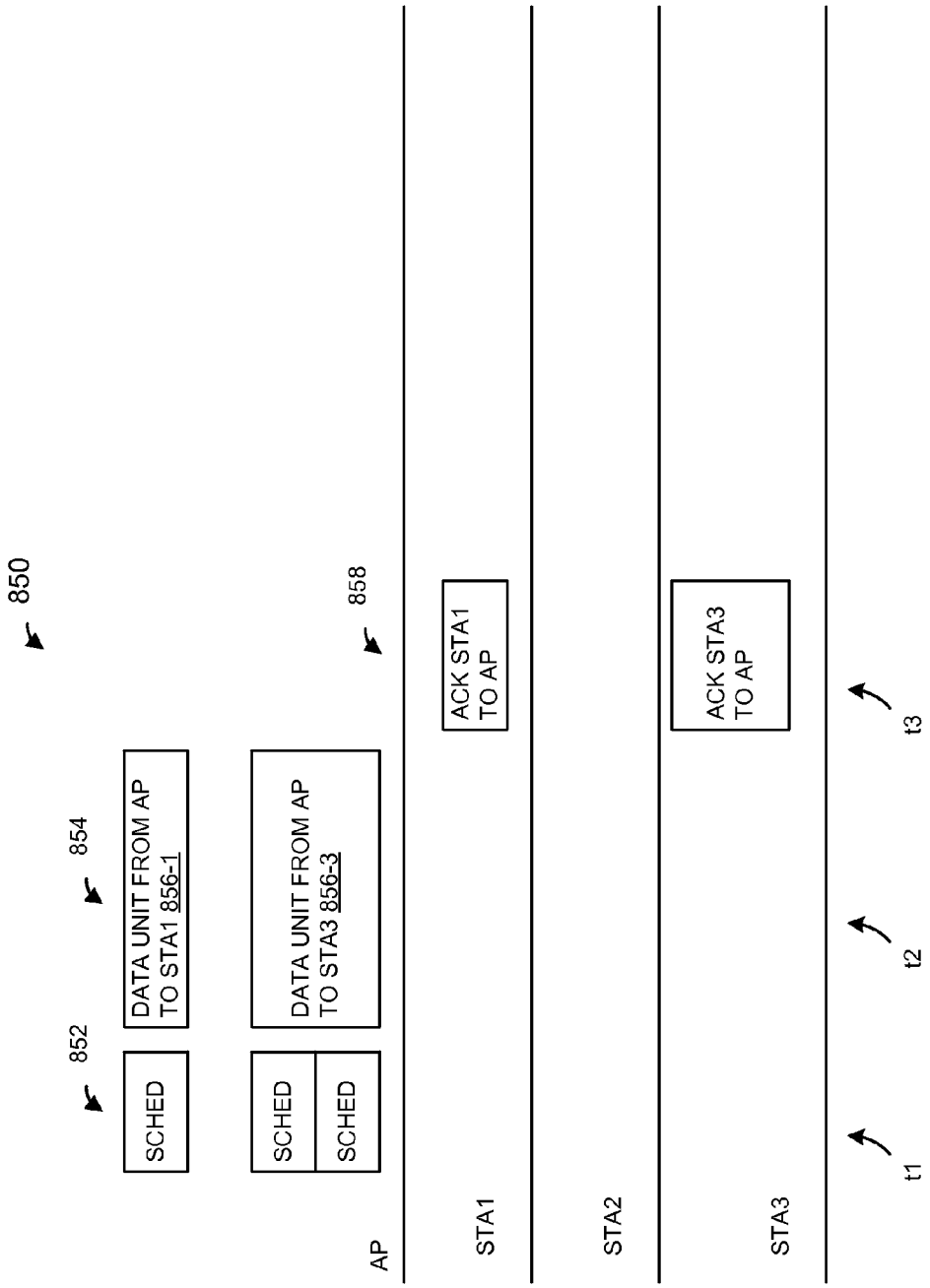

850
852
854
858
SCHED
DATA UNIT FROM AP TO STA1 856-1
SCHED
SCHED
DATA UNIT FROM AP TO STA3 856-3
ACK STA1 TO AP
ACK STA3 TO AP
AP
STA1
STA2
STA3
t1
t2
t3

FIG. 8B

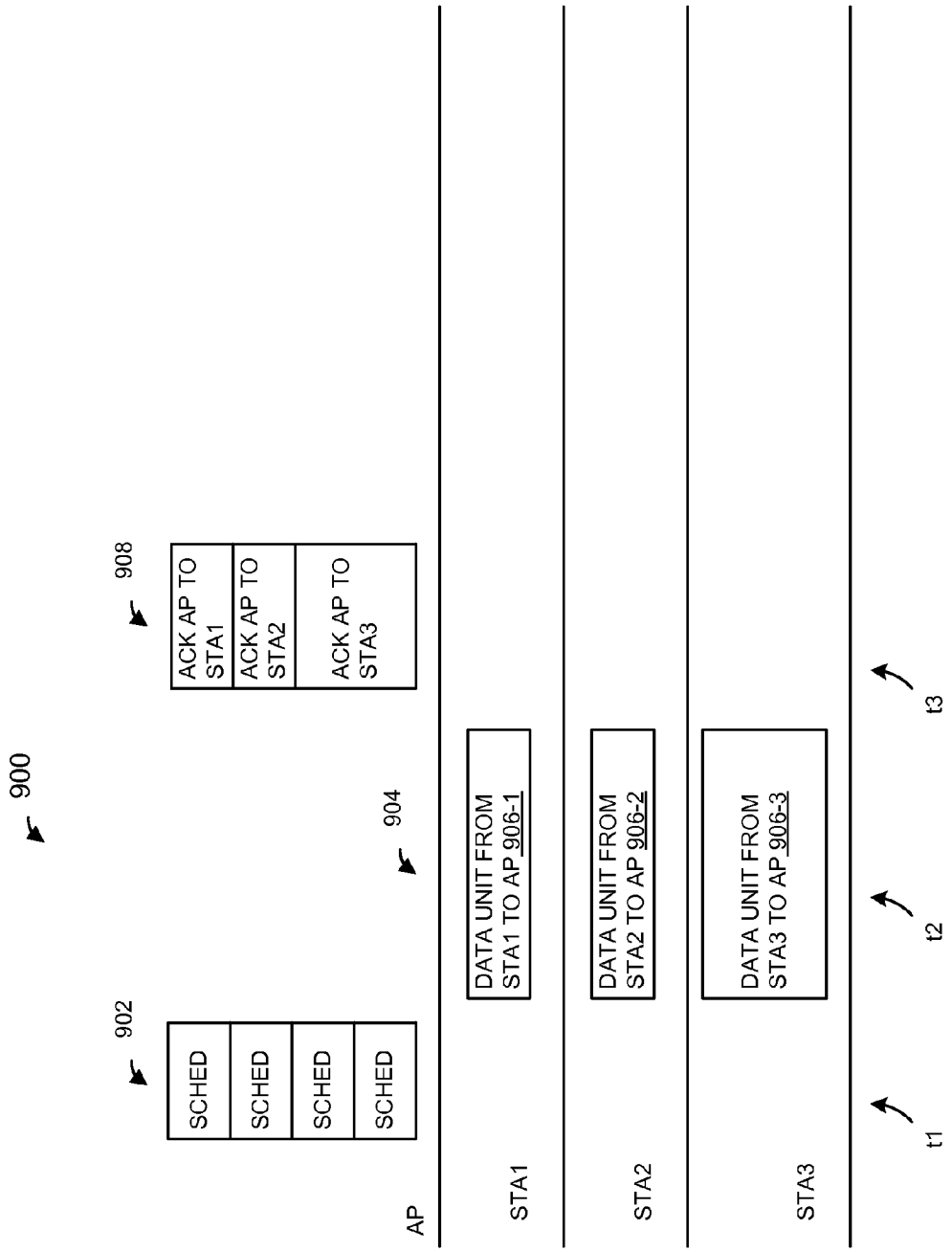

900
902
SCHED
SCHED
SCHED
SCHED
904
908
ACK AP TO STA1
ACK AP TO STA2
ACK AP TO STA3
AP
STA1
STA2
STA3
DATA UNIT FROM STA1 TO AP 906-1
DATA UNIT FROM STA2 TO AP 906-2
DATA UNIT FROM STA3 TO AP 906-3
t1
t2
t3

FIG. 9A

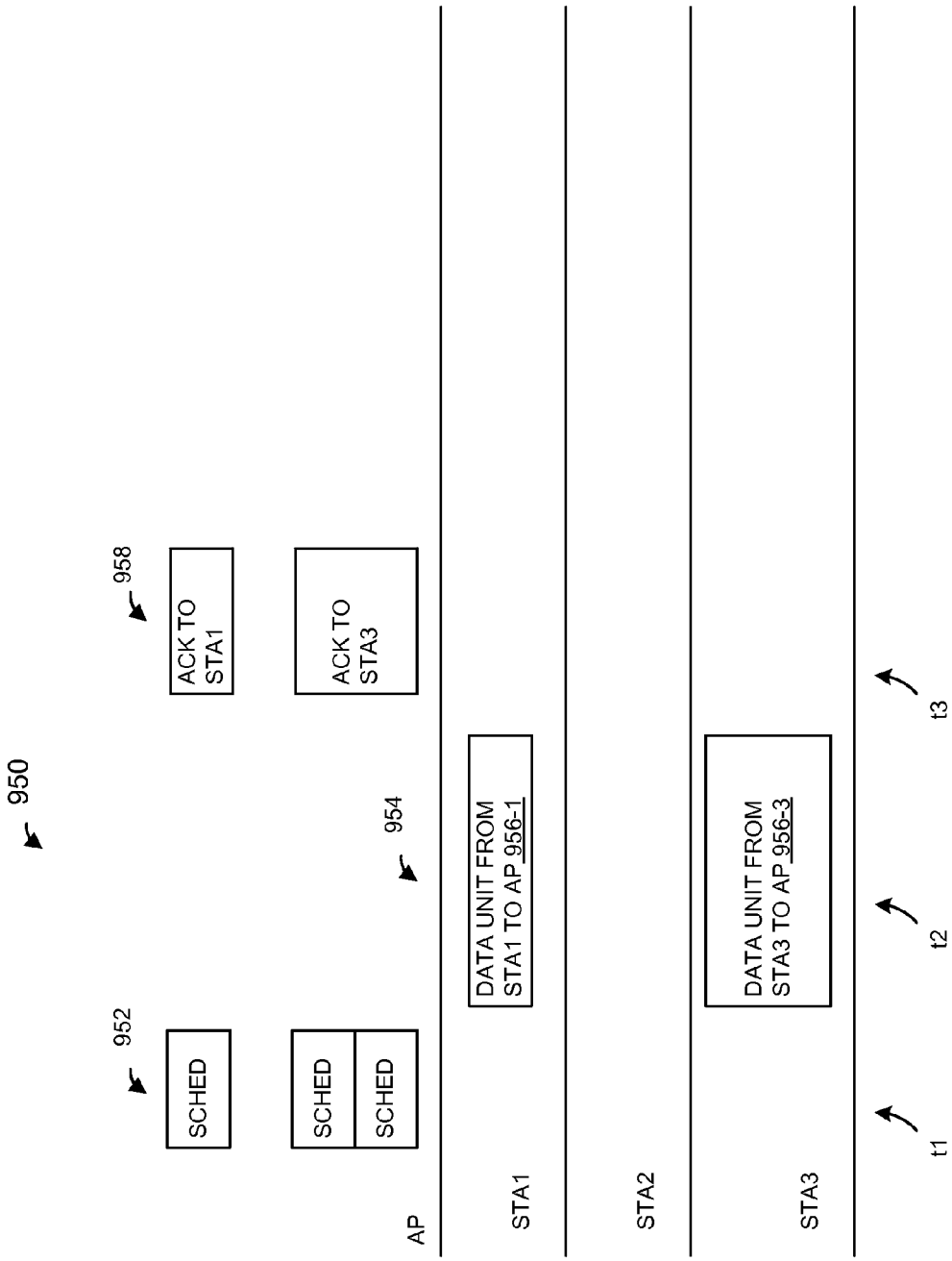

950
952
958
954
SCHED
SCHED
SCHED
ACK TO STA1
ACK TO STA3
DATA UNIT FROM STA1 TO AP 956-1
DATA UNIT FROM STA3 TO AP 956-3
AP
STA1
STA2
STA3
t1
t2
t3

FIG. 9B

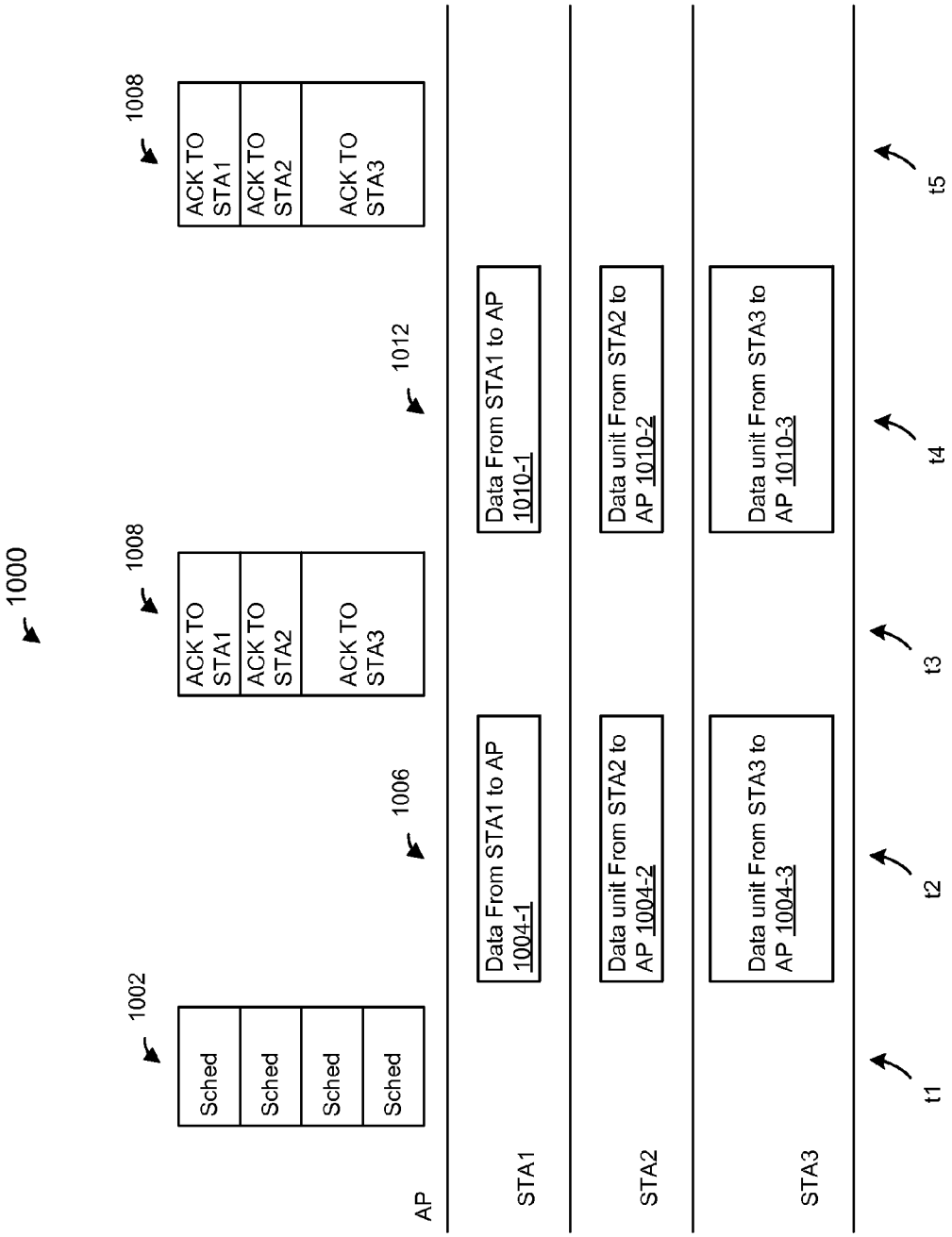

1000
1002
Sched
Sched
Sched
Sched
1008
ACK TO STA1
ACK TO STA2
ACK TO STA3
1006
1008
ACK TO STA1
ACK TO STA2
ACK TO STA3
1012
AP
STA1
STA2
STA3
Data From STA1 to AP 1004-1
Data unit From STA2 to AP 1004-2
Data unit From STA3 to AP 1004-3
Data From STA1 to AP 1010-1
Data unit From STA2 to AP 1010-2
Data unit From STA3 to AP 1010-3
t1
t2
t3
t4
t5

FIG. 10A

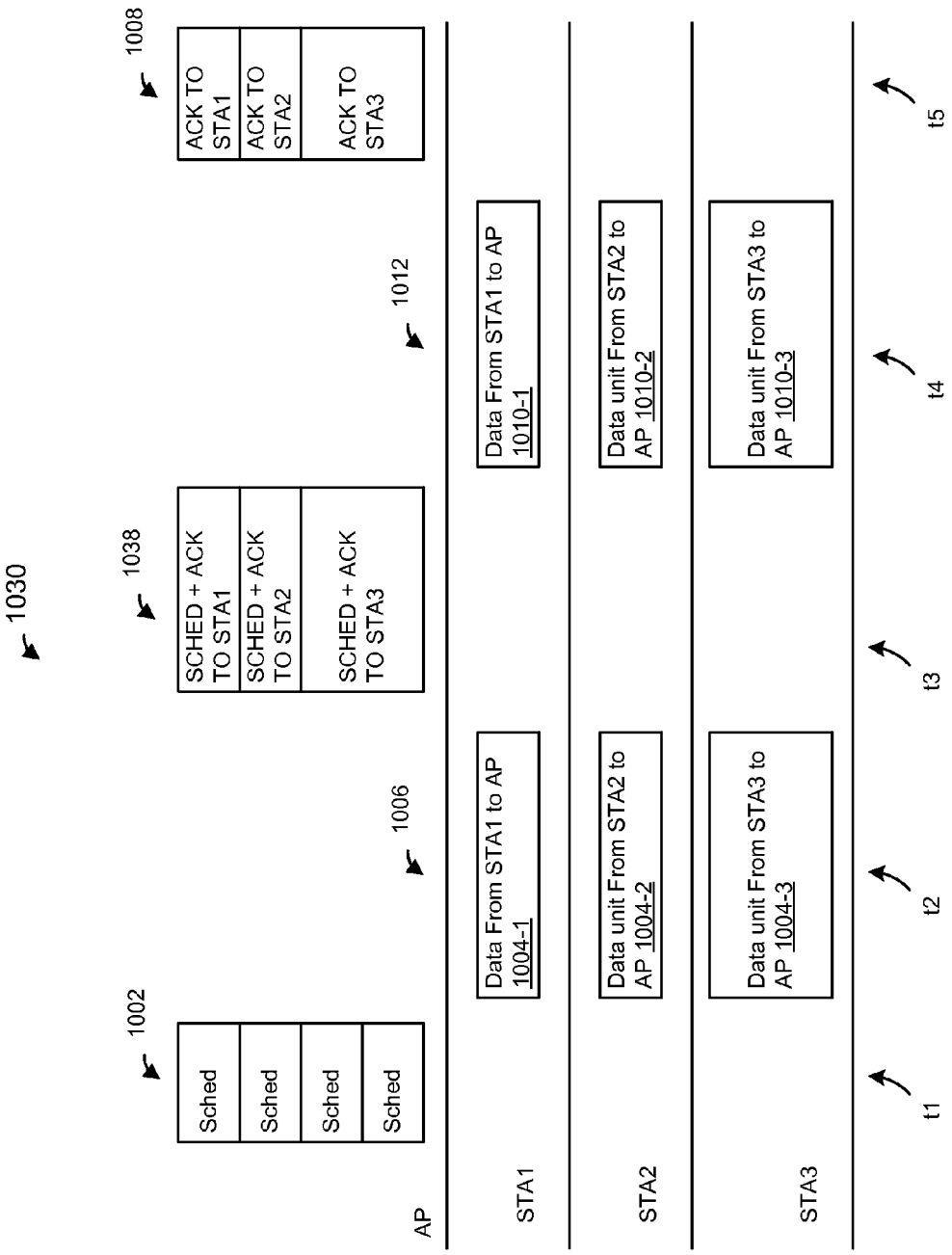

1030
1002
1006
1038
1012
1008
AP
STA1
STA2
STA3
Sched
Sched
Sched
Sched
Data From STA1 to AP 1004-1
Data unit From STA2 to AP 1004-2
Data unit From STA3 to AP 1004-3
SCHED + ACK TO STA1
SCHED + ACK TO STA2
SCHED + ACK TO STA3
Data From STA1 to AP 1010-1
Data unit From STA2 to AP 1010-2
Data unit From STA3 to AP 1010-3
ACK TO STA1
ACK TO STA2
ACK TO STA3
t1
t2
t3
t4
t5

FIG. 10B

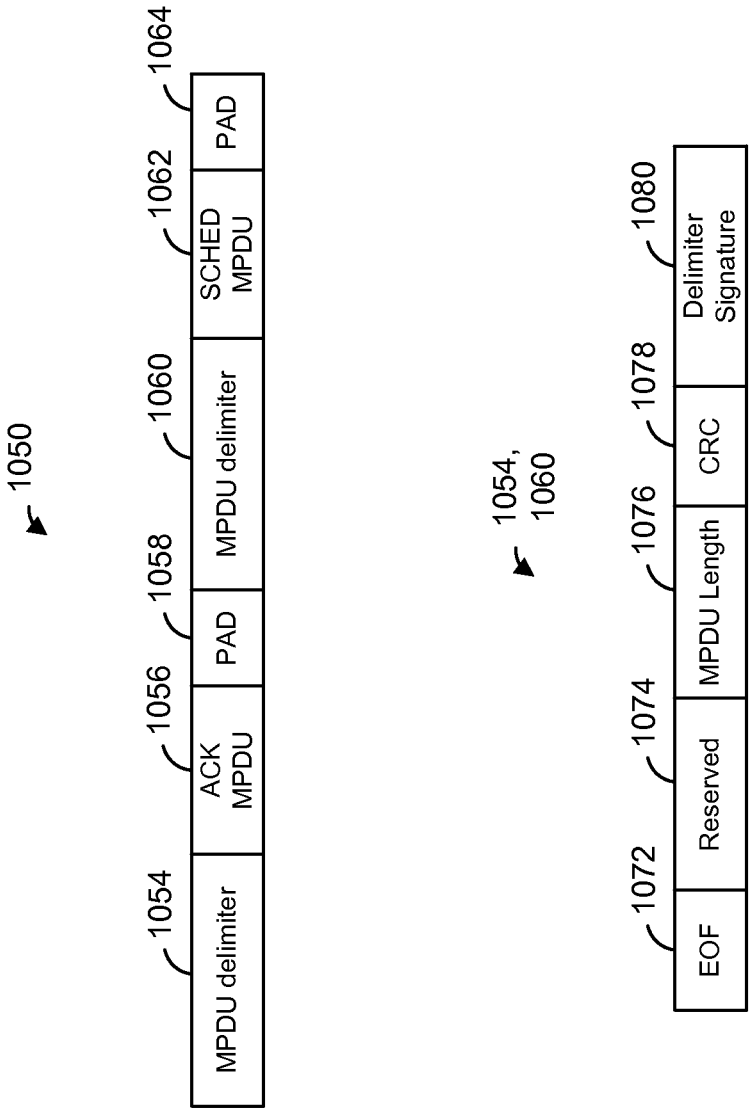

1050
1054
MPDU delimiter
1056
ACK MPDU
1058
PAD
1060
MPDU delimiter
1062
SCHED MPDU
1064
PAD
1054, 1060
1072
EOF
1074
Reserved
1076
MPDU Length
1078
CRC
1080
Delimiter Signature

FIG. 10C

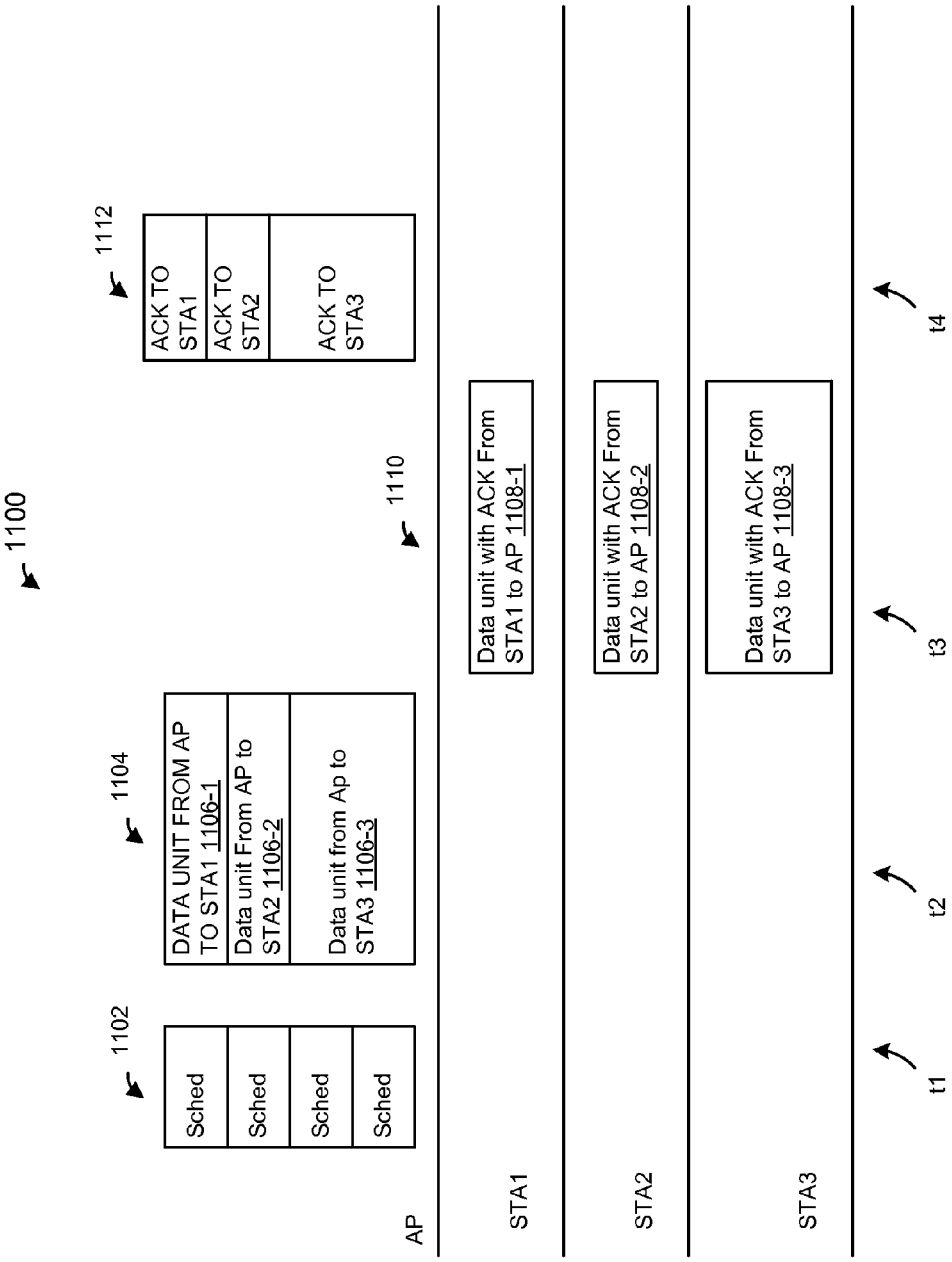

1100
1102
1104
1110
1112
Sched
Sched
Sched
Sched
DATA UNIT FROM AP TO STA1 1106-1
Data unit From AP to STA2 1106-2
Data unit from Ap to STA3 1106-3
ACK TO STA1
ACK TO STA2
ACK TO STA3
AP
STA1
STA2
STA3
Data unit with ACK From STA1 to AP 1108-1
Data unit with ACK From STA2 to AP 1108-2
Data unit with ACK From STA3 to AP 1108-3
t1
t2
t3
t4

FIG. 11A

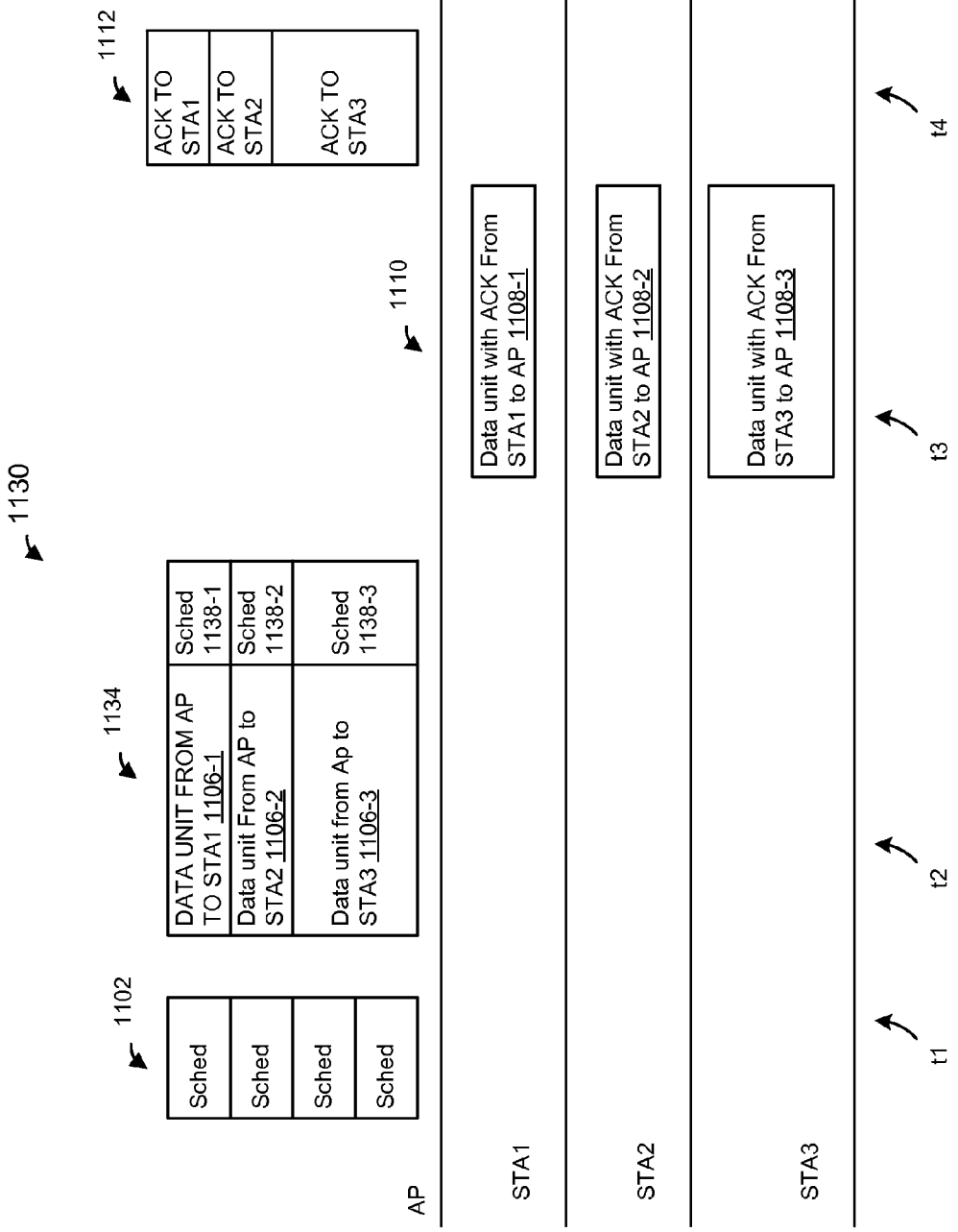

1130
1102
Sched
Sched
Sched
Sched
1134
DATA UNIT FROM AP TO STA1 1106-1
Data unit From AP to STA2 1106-2
Data unit from Ap to STA3 1106-3
Sched 1138-1
Sched 1138-2
Sched 1138-3
1112
ACK TO STA1
ACK TO STA2
ACK TO STA3
1110
Data unit with ACK From STA1 to AP 1108-1
Data unit with ACK From STA2 to AP 1108-2
Data unit with ACK From STA3 to AP 1108-3
AP
STA1
STA2
STA3
t1
t2
t3
t4

FIG. 11B

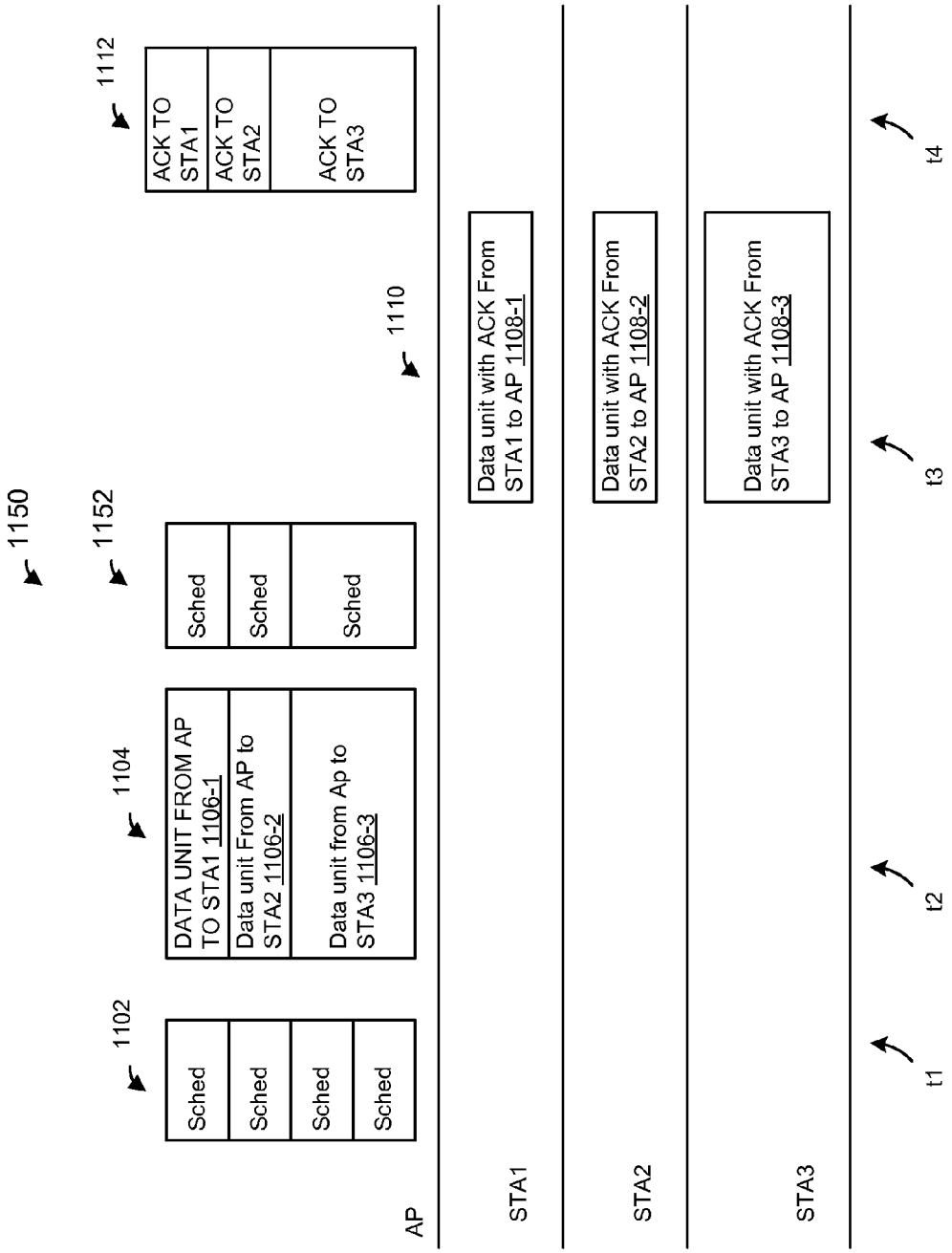

1150
1102
1104
1152
1110
1112
AP
Sched
Sched
Sched
Sched
DATA UNIT FROM AP TO STA1 1106-1
Data unit From AP to STA2 1106-2
Data unit from Ap to STA3 1106-3
Sched
Sched
Sched
Data unit with ACK From STA1 to AP 1108-1
Data unit with ACK From STA2 to AP 1108-2
Data unit with ACK From STA3 to AP 1108-3
ACK TO STA1
ACK TO STA2
ACK TO STA3
STA1
STA2
STA3
t1
t2
t3
t4

FIG. 11C

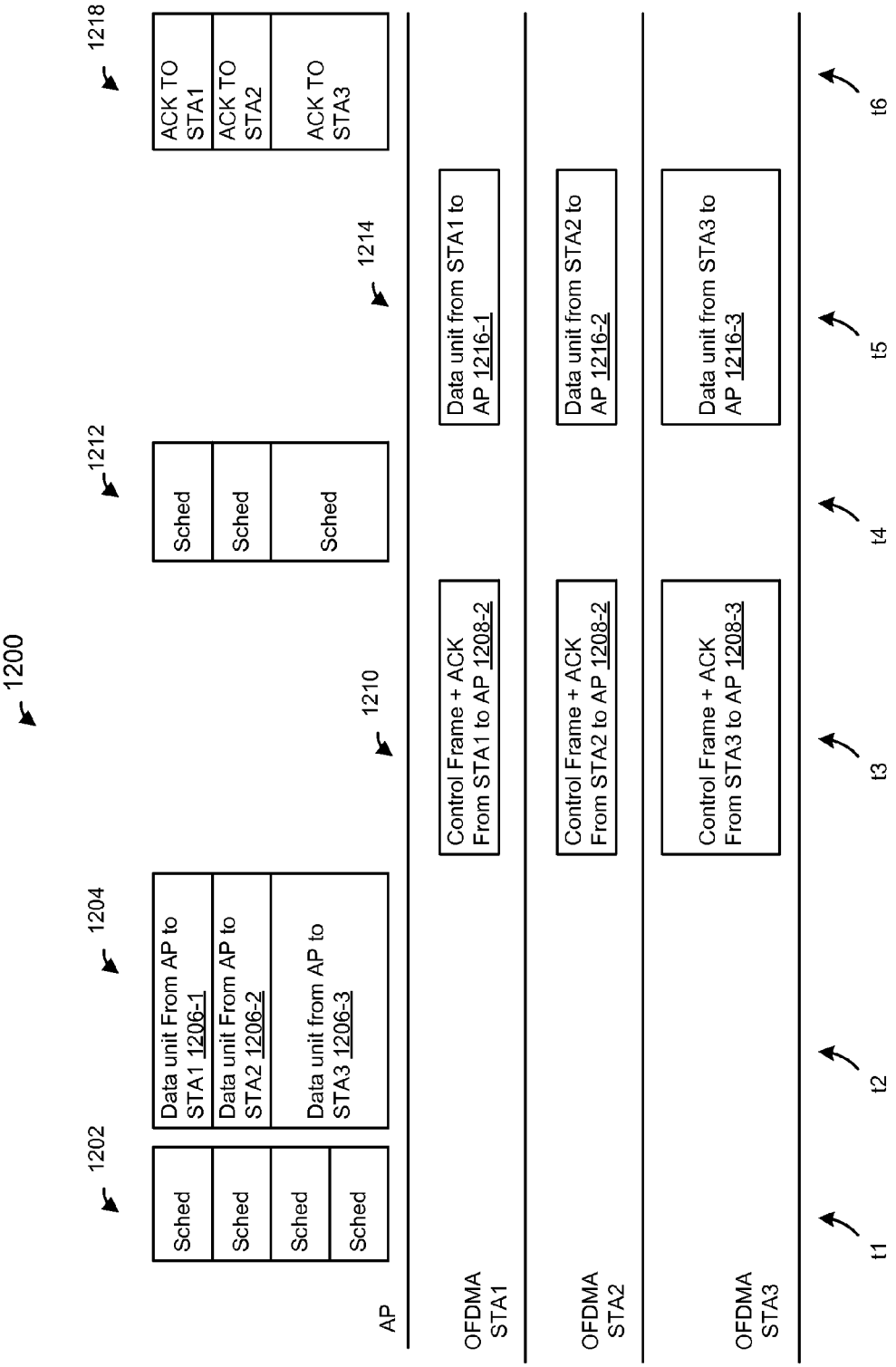

1200
1202
1204
1210
1212
1214
1218
AP
Sched
Sched
Sched
Sched
Data unit From AP to STA1 1206-1
Data unit From AP to STA2 1206-2
Data unit from AP to STA3 1206-3
Sched
Sched
Sched
ACK TO STA1
ACK TO STA2
ACK TO STA3
OFDMA STA1
Control Frame + ACK From STA1 to AP 1208-2
Data unit from STA1 to AP 1216-1
OFDMA STA2
Control Frame + ACK From STA2 to AP 1208-2
Data unit from STA2 to AP 1216-2
OFDMA STA3
Control Frame + ACK From STA3 to AP 1208-3
Data unit from STA3 to AP 1216-3
t1
t2
t3
t4
t5
t6

FIG. 12

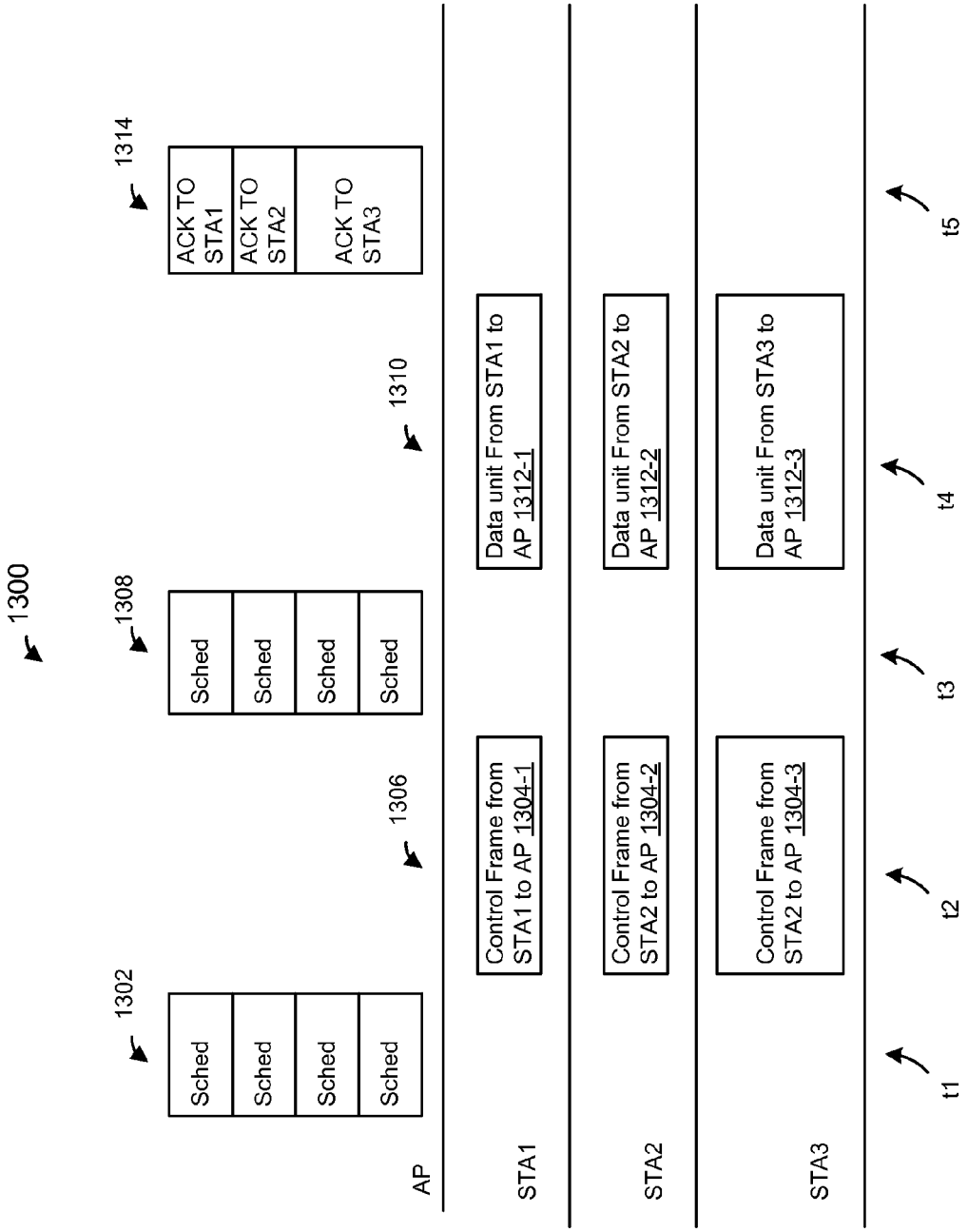

1300
1302
1308
1314
Sched
Sched
Sched
Sched
Sched
Sched
Sched
Sched
ACK TO STA1
ACK TO STA2
ACK TO STA3
AP
1306
1310
Control Frame from STA1 to AP 1304-1
Data unit From STA1 to AP 1312-1
STA1
Control Frame from STA2 to AP 1304-2
Data unit From STA2 to AP 1312-2
STA2
Control Frame from STA2 to AP 1304-3
Data unit From STA3 to AP 1312-3
STA3
t1
t2
t3
t4
t5

FIG. 13A

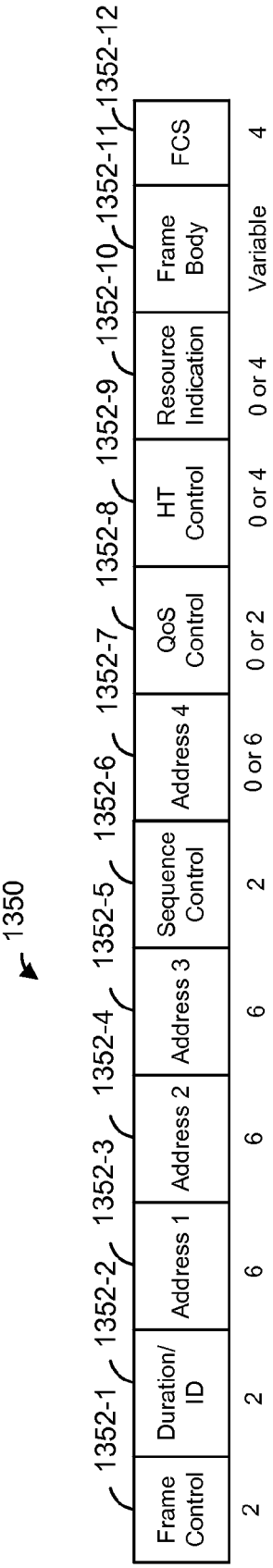

1350
1352-1
Frame Control
2
1352-2
Duration/ ID
2
1352-3
Address 1
6
1352-4
Address 2
6
1352-5
Address 3
6
1352-6
Sequence Control
2
1352-7
Address 4
0 or 6
1352-8
QoS Control
0 or 2
1352-9
HT Control
0 or 4
1352-10
Resource Indication
0 or 4
1352-11
Frame Body
Variable
1352-12
FCS
4

FIG. 13B

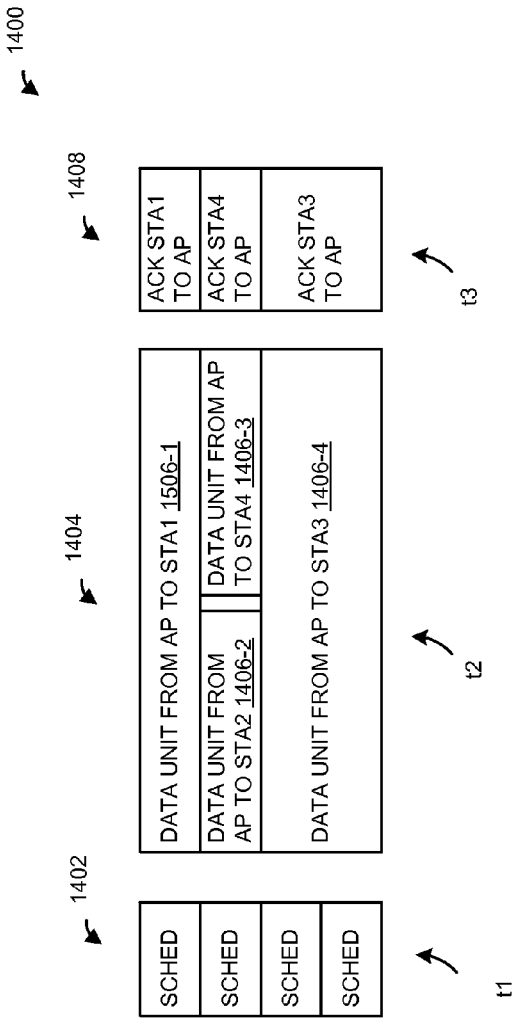


FIG. 14A

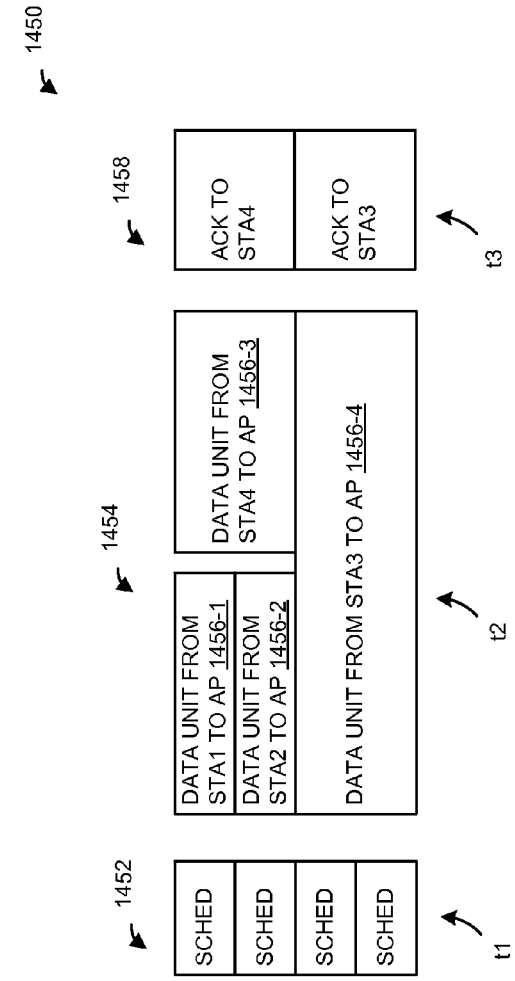


FIG. 14B

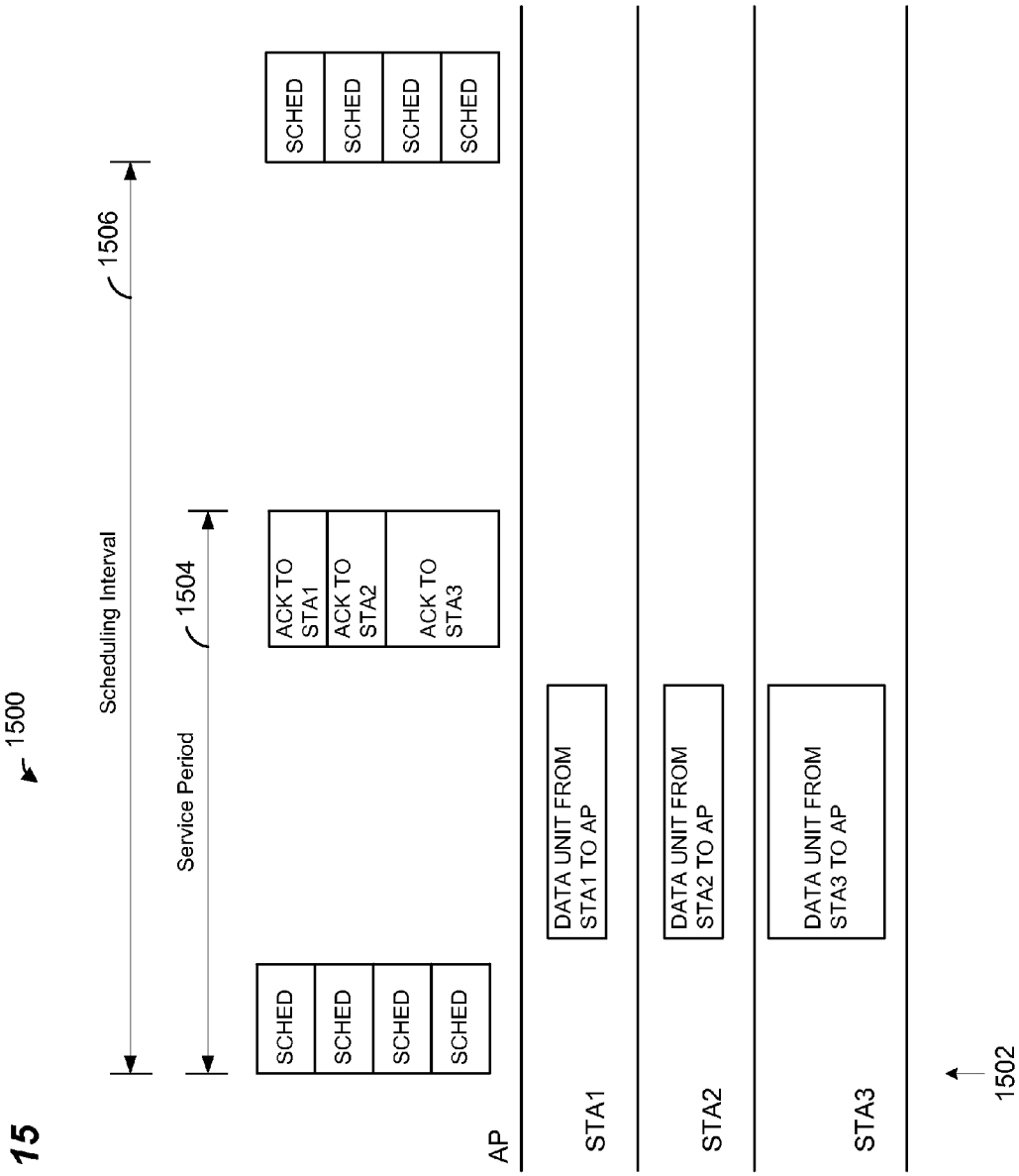

1500
Scheduling Interval
1506
Service Period
1504
SCHED
SCHED
SCHED
SCHED
ACK TO STA1
ACK TO STA2
ACK TO STA3
SCHED
SCHED
SCHED
SCHED
AP
DATA UNIT FROM STA1 TO AP
STA1
DATA UNIT FROM STA2 TO AP
STA2
DATA UNIT FROM STA3 TO AP
STA3
1502

FIG. 15

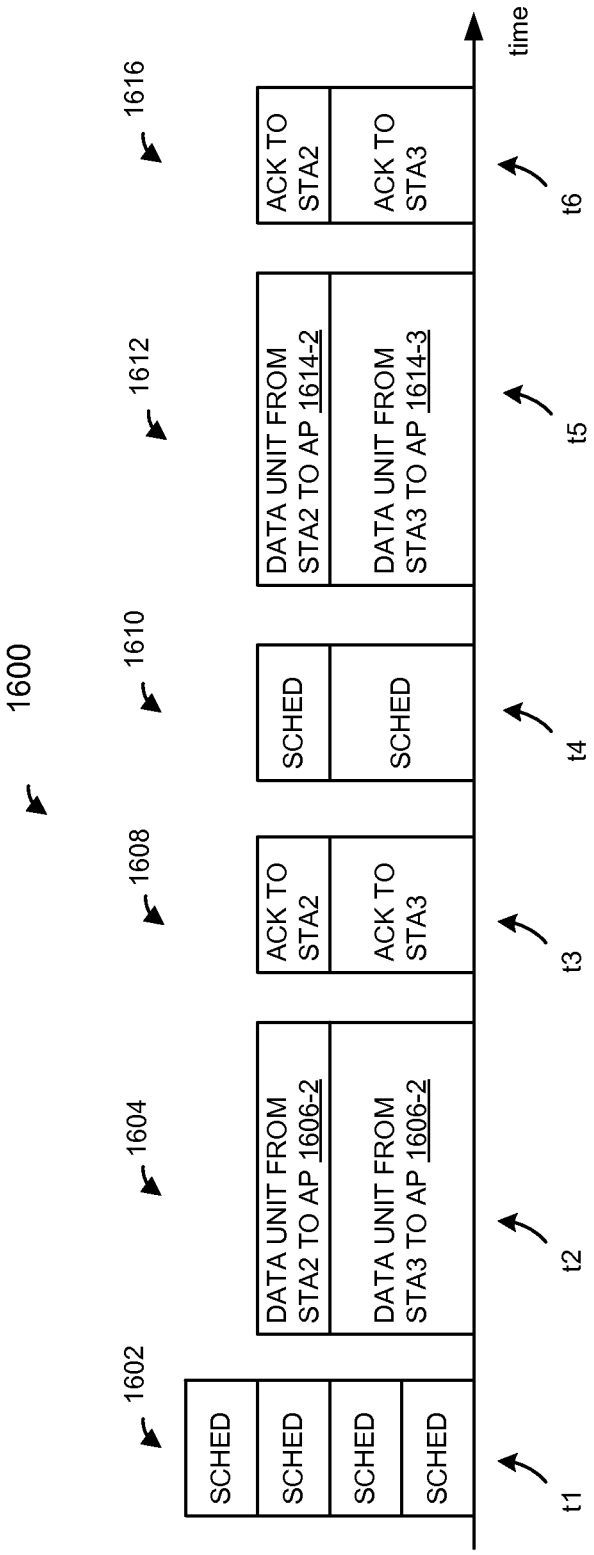

1600
1602
SCHED
SCHED
SCHED
SCHED
1604
DATA UNIT FROM STA2 TO AP 1606-2
DATA UNIT FROM STA3 TO AP 1606-2
1608
ACK TO STA2
ACK TO STA3
1610
SCHED
SCHED
1612
DATA UNIT FROM STA2 TO AP 1614-2
DATA UNIT FROM STA3 TO AP 1614-3
1616
ACK TO STA2
ACK TO STA3
t1
t2
t3
t4
t5
t6
time

FIG. 16

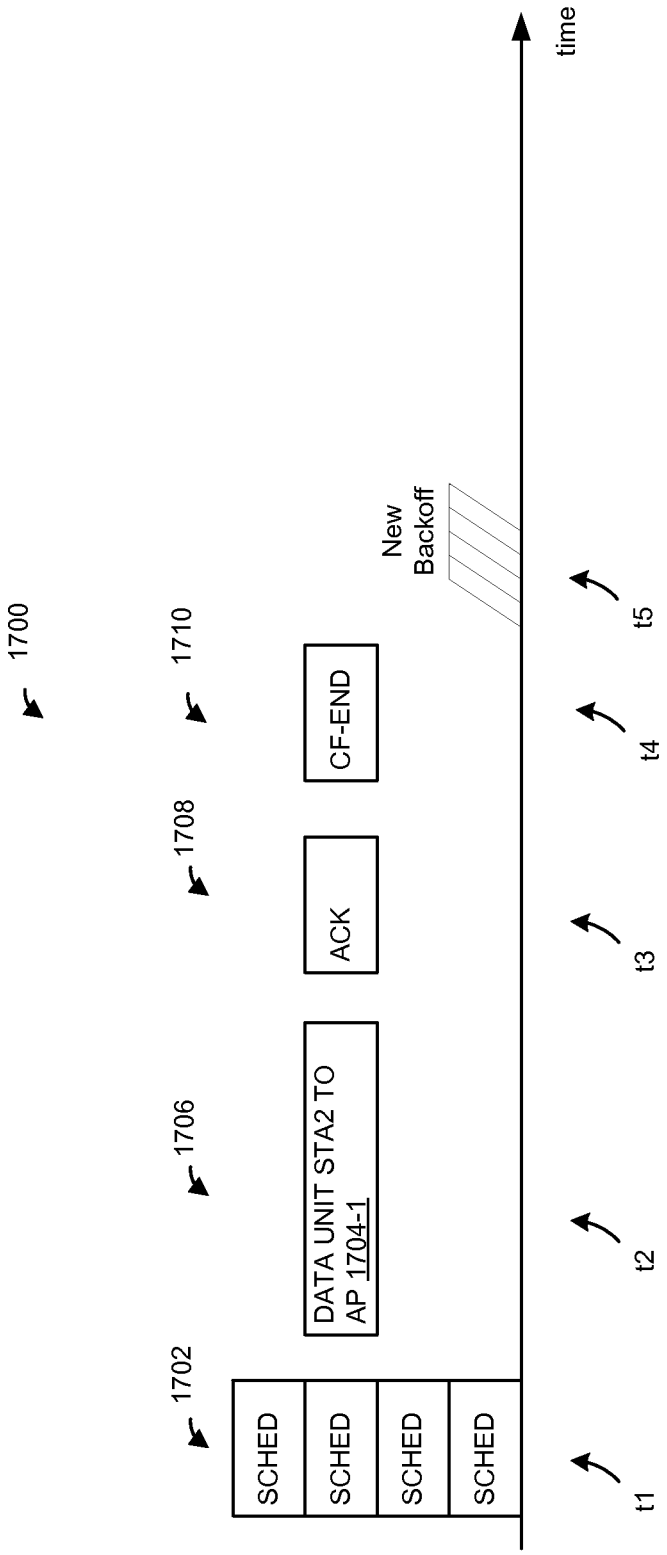

1700
1702
1706
1708
1710
SCHED
SCHED
SCHED
SCHED
DATA UNIT STA2 TO AP 1704-1
ACK
CF-END
New Backoff
t1
t2
t3
t4
t5
time

FIG. 17

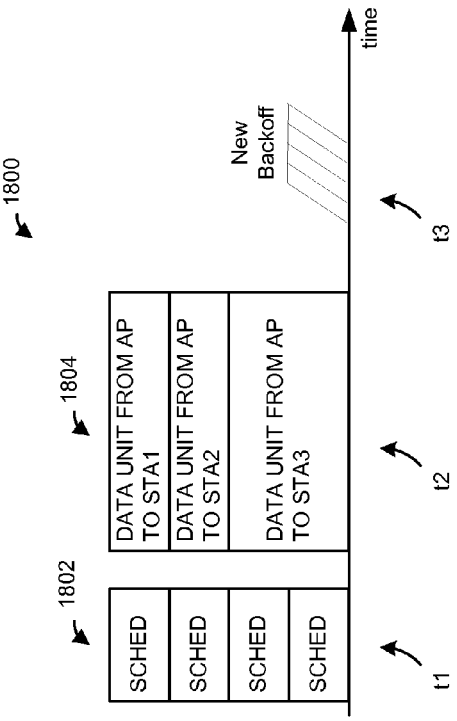


FIG. 18A

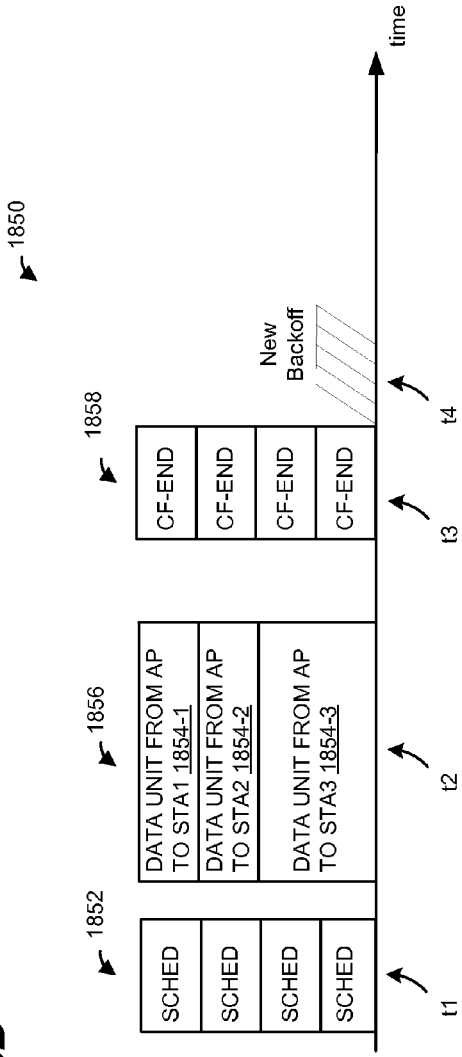


FIG. 18B

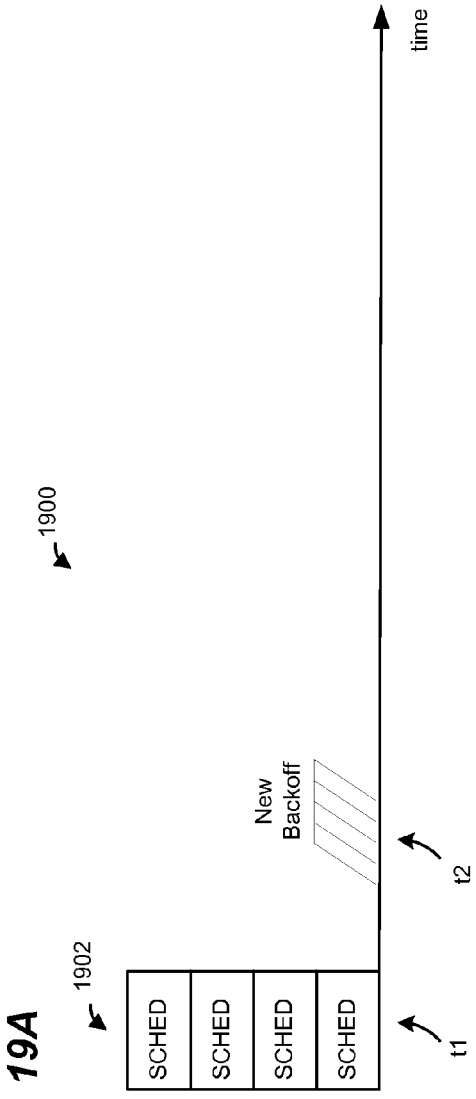


FIG. 19A

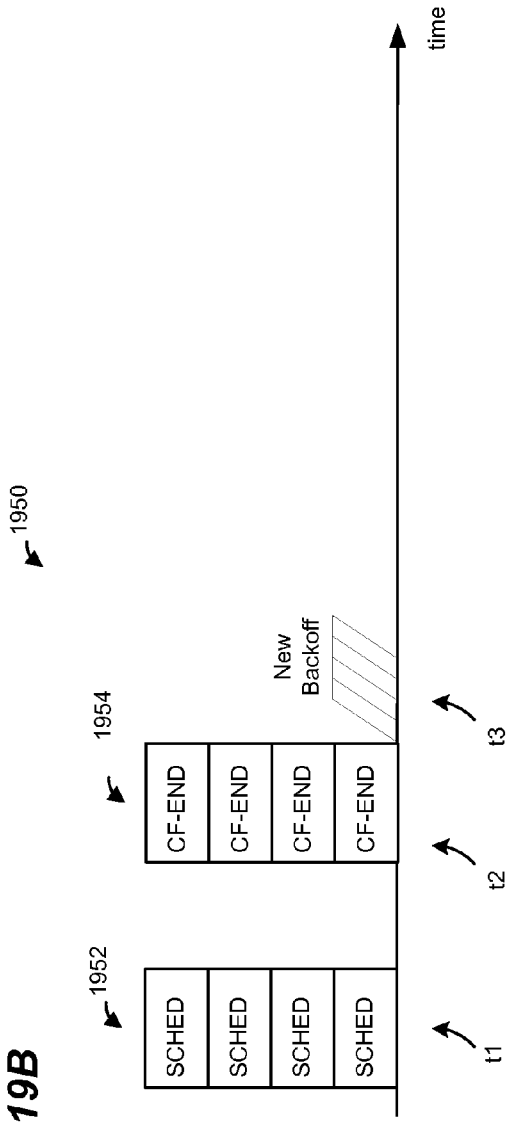


FIG. 19B

FIG. 20A

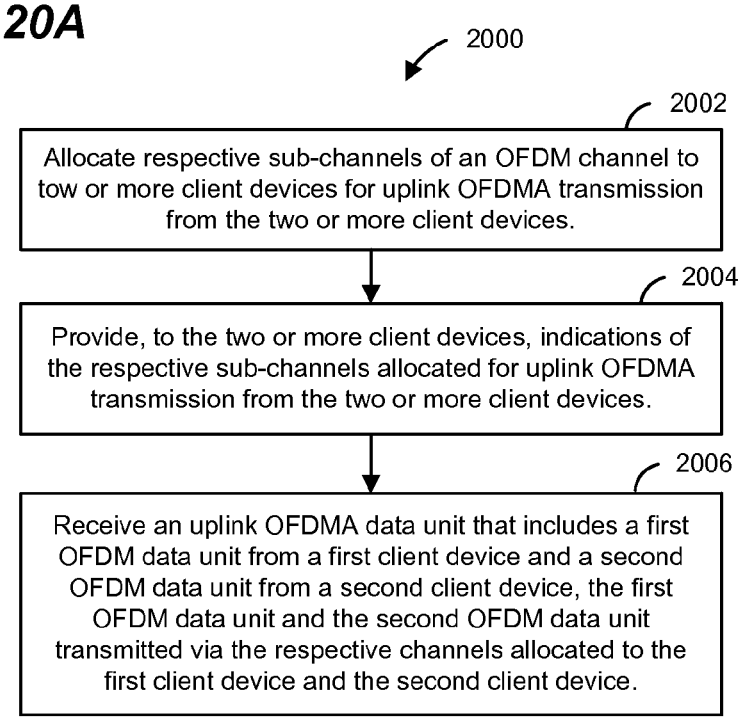
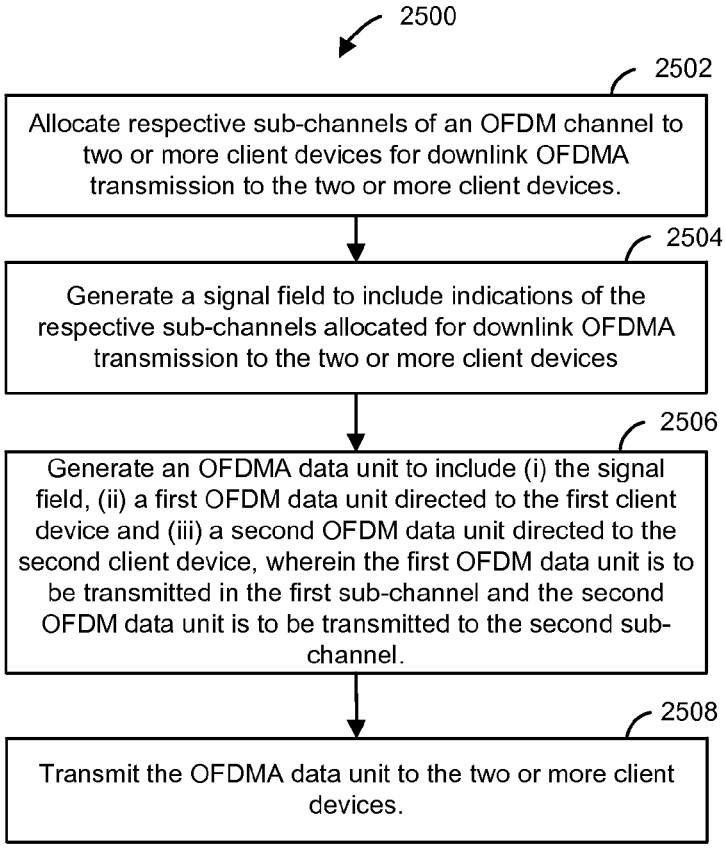


FIG. 20B



MEDIUM ACCESS CONTROL FOR MULTI-CHANNEL OFDM IN A WIRELESS LOCAL AREA NETWORK

CROSS-REFERENCE TO RELATED APPLICATION

This disclosure claims the benefit of U.S. Provisional Patent Application Nos. 61/902,413, filed Nov. 11, 2013, and 61/947,922, filed Mar. 4, 2014, both entitled "OFDMA MAC Consideration," the disclosures of which are hereby expressly incorporated herein by reference in their entireties.

FIELD OF THE DISCLOSURE

The present disclosure relates generally to communication networks and, more particularly, to wireless local area networks that utilize orthogonal frequency division multiplexing (OFDM).

BACKGROUND

When operating in an infrastructure mode, wireless local area networks (WLANs) typically include an access point (AP) and one or more client stations. WLANs have evolved rapidly over the past decade. Development of WLAN standards such as the Institute for Electrical and Electronics Engineers (IEEE) 802.11a, 802.11b, 802.11g, and 802.11n Standards has improved single-user peak data throughput. For example, the IEEE 802.11b Standard specifies a single-user peak throughput of 11 megabits per second (Mbps), the IEEE 802.11a and 802.11g Standards specify a single-user peak throughput of 54 Mbps, the IEEE 802.11n Standard specifies a single-user peak throughput of 600 Mbps, and the IEEE 802.11ac Standard specifies a single-user peak throughput in the gigabits per second (Gbps) range. Future standards promise to provide even greater throughputs, such as throughputs in the tens of Gbps range.

These WLANs operate in either a unicast mode or a multicast mode. In the unicast mode, the AP transmits information to one client station at a time. In the multicast mode, the same information is transmitted to a group of client stations concurrently.

SUMMARY

In an embodiment, a method for simultaneously communication with multiple communication devices in a wireless local area network includes allocating, by a first communication device, respective sub-channels of an orthogonal frequency division multiplexing (OFDM) channel to two or more second communication devices for uplink orthogonal frequency division multiple access (OFDMA) transmission from the two or more second communication devices, including allocating a first sub-channel to a first one of the two or more second communication devices and a second sub-channel to a second one of the two or more second communication devices. The method further includes providing, from the first communication device to the two or more second communication devices, indications of the respective sub-channels allocated for uplink OFDMA transmission from the two or more second communication devices. The method additionally includes receiving, at the first communication device, an uplink OFDMA data unit that includes at least a first OFDM data unit from the first one of the two or more second communication devices and a second OFDM data unit from the second one of the two or more second communication devices, wherein the first OFDM data unit is transmitted from the first one of the two or more second communication devices via the first sub-channel allocated to the first one of the two or more second communication devices and the second OFDM data unit is transmitted from the second one of the two or more second communication devices via the second sub-channel allocated to the second one of the two or more second communication devices.

In another embodiment, a first communication device comprises a network interface configured to allocate respective sub-channels of an orthogonal frequency division multiplexing (OFDM) channel to two or more second communication devices for uplink orthogonal frequency division multiple access (OFDMA) transmission from the two or more second communication devices, including allocating a first sub-channel to a first one of the two or more second communication devices and a second sub-channel to a second one of the two or more communication devices. The network interface is also configured to provide, to the two or more second communication devices, indications of the respective sub-channels allocated for uplink transmission from the two or more second communication devices. The network interface is additionally configured to receive an uplink OFDMA data unit that includes a first OFDM data unit from the first one of the two or more second communication devices and a second OFDM data unit from the second one of the two or more second communication devices, wherein the first OFDM data unit is transmitted from the first one of the two or more second communication devices via the first sub-channel allocated to the first of the two or more second communication devices and the second OFDM data unit is transmitted from the second one of the two or more second communication devices via the second sub-channel allocated to the second one of the two or more second communication devices.

In yet another embodiment, a method for simultaneously communication with multiple communication devices in a wireless local area network includes allocating, by a first communication device, respective sub-channels of an orthogonal frequency division multiplexing (OFDM) channel to two or more second communication devices for downlink orthogonal frequency division multiple access (OFDMA) transmission to the two or more second communication devices, including allocating a first sub-channel to a first one of the two or more second communication devices and a second sub-channel to a second one of the two or more communication devices. The method further includes generating a signal field of an OFDMA data unit to include indications of the respective sub-channels allocated for downlink OFDMA transmission from the two or more second communication devices. The method further still includes generating an OFDMA data unit to include (i) the signal field, (ii) a first OFDM data unit directed to the first one of the two or more second communication devices and (iii) a second OFDM data unit directed to the second one of the two or more second communication devices, wherein the first OFDM data unit is to be transmitted to the first sub-channel and the second OFDM data unit is to be transmitted in the second sub-channel. The method additionally includes transmitting the OFDMA data unit to the two or more second communication devices.

In still another embodiment, a first communication device comprises a network interface configured to allocate respective sub-channels of an orthogonal frequency division multiplexing (OFDM) channel to two or more second communication devices for downlink orthogonal frequency division

multiple access (OFDMA) transmission to the two or more second communication devices, including allocating a first sub-channel to a first one of the two or more second communication devices and a second sub-channel to a second one of the two or more communication devices. The network interface is further configured to generate a signal field of an OFDMA data unit to include indications of the respective sub-channels allocated for downlink OFDMA transmission from the two or more second communication devices. The network interface is further still configured to generate an OFDMA data unit to include (i) the signal field, (ii) a first OFDM data unit directed to the first one of the two or more second communication devices and (iii) a second OFDM data unit directed to the second one of the two or more second communication devices, wherein the first OFDM data unit is to be transmitted to the first sub-channel and the second OFDM data unit is to be transmitted in the second sub-channel. The network interface is additionally configured to transmit the OFDMA data unit to the two or more second communication devices.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of an example wireless local area network (WLAN), according to an embodiment;

FIGS. **2**A, **2**B, and **2**C are diagrams illustrating example orthogonal frequency division multiplexing (OFDM) sub-channel blocks for an 80 MHz communication channel, according to an embodiment;

FIG. **3** is a diagram of an example OFDMA data unit, according to an embodiment.

FIG. **4** is a diagram of an example OFDMA data unit, according to another embodiment.

FIG. **5**A is an example group definition field, according to an embodiment.

FIG. **5**B is a diagram of a channel allocation field for providing channel allocation information to members of an OFDMA group, according to an embodiment.

FIG. **6** is diagram illustrating a frame exchange between an AP and multiple client stations, according to an embodiment.

FIG. **7**A is an example of an OFDMA downlink scheduling element, according to an embodiment.

FIG. **7**B is an example of an OFDMA uplink scheduling element, according to an embodiment.

FIG. **8**A is a frame exchange between an AP and a plurality of client stations that includes downlink OFDMA transmission of data from the AP to the plurality client stations, according to an embodiment.

FIG. **8**B is a frame exchange between an AP and a plurality of client stations that includes downlink OFDMA transmission of data from the AP to the plurality client stations, according to another embodiment.

FIG. **9**A is a frame exchange between an AP and a plurality of client stations that includes uplink OFDMA transmission of data from the plurality client stations to the AP, according to an embodiment.

FIG. **9**B is a frame exchange between an AP and a plurality of client stations that includes uplink OFDMA transmission of data from the plurality client stations to the AP, according to another embodiment.

FIG. **10**A is a frame exchange between an AP and a plurality of client stations that includes uplink OFDMA transmission of data from the plurality client stations to the AP, according to another embodiment.

FIG. **10**B is a frame exchange between an AP and a plurality of client stations that includes uplink OFDMA transmission of data from the plurality client stations to the AP, according to another embodiment

FIG. **10**C is an example aggregated control frame format that can be used with the frame exchange of FIG. **10**B, according to an embodiment.

FIG. **11**A is a frame exchange between an AP and a plurality of client stations that includes both downlink OFDMA transmission of data from the AP to the plurality client stations and uplink OFDMA transmission of data from the plurality client stations the AP, according to an embodiment.

FIG. **11**B is a frame exchange between an AP and a plurality of client stations that includes both downlink OFDMA transmission of data from the AP to the plurality client stations and uplink OFDMA transmission of data from the plurality client stations the AP, according to an embodiment.

FIG. **11**C is a frame exchange between an AP and a plurality of client stations that includes both downlink OFDMA transmission of data from the AP to the plurality client stations and uplink OFDMA transmission of data from the plurality client stations the AP, according to an embodiment.

FIG. **12** is a frame exchange between an AP and a plurality of client stations that includes both downlink OFDMA transmission of data from the AP to the plurality client stations and uplink OFDMA transmission of data from the plurality client stations the AP, according to another embodiment.

FIG. **13**A is a frame exchange between an AP and a plurality of client stations that includes uplink OFDMA transmission of data from the plurality client stations the AP, according to an embodiment.

FIG. **13**B is a diagram of an example control field included in a control frame transmitted by a client station to indicate amount of buffered data at the client station, in an embodiment.

FIG. **14**A is a diagram of an example frame exchange between an AP and a plurality of client stations in a sub-channel is allocated for downlink transmission to multiple client stations, according to an embodiment.

FIG. **14**B is a diagram of an example frame exchange between an AP and a plurality of client stations in a sub-channel is allocated for uplink transmission from multiple client stations, according to an embodiment.

FIG. **15** is a diagram illustrating example uplink OFDMA parameters for an OFDMA group of client stations, and communications between an AP and client stations of the OFDMA group that occur during time periods defined by the OFDMA parameters, according to an embodiment.

FIG. **16** is a diagram of an example frame exchange between an AP and a plurality of client stations in which a collision is encountered in sub-channels allocated to one or more client stations, according to an embodiment.

FIG. **17** is a diagram of an example frame exchange between an AP and a plurality of client stations in which a collision is encountered in sub-channels allocated to one or more client stations, according to another embodiment.

FIG. **18**A is a diagram of an example frame exchange between an AP and a plurality of client stations in which a collision is encountered in sub-channels allocated to one or more client stations, according to another embodiment.

FIG. **18**B is a diagram of an example frame exchange between an AP and a plurality of client stations in which a collision is encountered in sub-channels allocated to one or more client stations, according to another embodiment.

FIG. **19**A is a diagram of an example frame exchange between an AP and a plurality of client stations in which a collision is encountered in sub-channels allocated to one or more client stations, according to another embodiment.

FIG. **19**B is a diagram of an example frame exchange between an AP and a plurality of client stations in which a collision is encountered in sub-channels allocated to one or more client stations, according to another embodiment.

FIG. **20**A is a flow diagram of an example method that is implemented by an AP in a WLAN, according to an embodiment.

FIG. **20**B is a flow diagram of another example method that is implemented by an AP in a WLAN, according to another embodiment.

DETAILED DESCRIPTION

In embodiments described below, a wireless network device such as an access point (AP) of a wireless local area network (WLAN) simultaneously transmits independent data streams to multiple client stations and/or receives independent data streams simultaneously transmitted by multiple client stations. In particular, the AP transmits data for the multiple clients in different orthogonal frequency division multiplexing (OFDM) sub-channels of an orthogonal frequency division multiple access (OFDMA) transmission, in an embodiment. Similarly, multiple client stations transmit data to the AP simultaneously, in particular, each client station transmits data in a different OFDM sub-channel of an OFDMA transmission, in an embodiment.

The AP is configured to operate with client stations according to at least a first communication protocol. The first communication protocol is sometimes referred to herein as "high efficiency WiFi," "high efficiency WLAN," "HEW" communication protocol, or 802.11 ax communication protocol. The first communication protocol supports OFDMA communication between the AP and the client stations. In some embodiments, different client stations in the vicinity of the AP are configured to operate according to one or more other communication protocols that define operation in the same frequency band as the HEW communication protocol but with generally lower data throughputs. The lower data throughput communication protocols (e.g., IEEE 802.11a, IEEE 802.11n, and/or IEEE 802.11ac) are collectively referred herein as "legacy" communication protocols. The legacy communication protocols do not support OFDMA communication, in an embodiment.

In an embodiment, client stations that are configured to operate according to the HEW communication protocol generally support OFDMA communication initiated by the AP. In some embodiments, client stations that are configured to operate according to the HEW communication protocol optionally support OFDMA communication initiated by the client stations.

FIG. **1** is a block diagram of an example wireless local area network (WLAN) **10**, according to an embodiment. An AP **14** includes a host processor **15** coupled to a network interface **16**. The network interface **16** includes a medium access control (MAC) processing unit **18** and a physical layer (PHY) processing unit **20**. The PHY processing unit **20** includes a plurality of transceivers **21**, and the transceivers **21** are coupled to a plurality of antennas **24**. Although three transceivers **21** and three antennas **24** are illustrated in FIG. **1**, the AP **14** includes different numbers (e.g., **1**, **2**, **4**, **5**, etc.) of transceivers **21** and antennas **24** in other embodiments.

The WLAN **10** includes a plurality of client stations **25**. Although four client stations **25** are illustrated in FIG. **1**, the WLAN **10** includes different numbers (e.g., **1**, **2**, **3**, **5**, **6**, etc.) of client stations **25** in various scenarios and embodiments. Two or more of the client stations **25** are configured to receive corresponding data streams that are transmitted simultaneously by the AP **14**. Additionally, two or more of the client stations **25** are configured to transmit corresponding data streams to the AP **14** such that the AP **14** receives the data streams simultaneously.

A client station **25-1** includes a host processor **26** coupled to a network interface **27**. The network interface **27** includes a MAC processing unit **28** and a PHY processing unit **29**. The PHY processing unit **29** includes a plurality of transceivers **30**, and the transceivers **30** are coupled to a plurality of antennas **34**. Although three transceivers **30** and three antennas **34** are illustrated in FIG. **1**, the client station **25-1** includes different numbers (e.g., **1**, **2**, **4**, **5**, etc.) of transceivers **30** and antennas **34** in other embodiments.

In an embodiment, one or more of the client stations **25-2**, **25-3**, and **25-4** has a structure the same as or similar to the client station **25-1**. In these embodiments, the client stations **25** structured like the client station **25-1** have the same or a different number of transceivers and antennas. For example, the client station **25-2** has only two transceivers and two antennas (not shown), according to an embodiment.

According to an embodiment, the client station **25-4** is a legacy client station that is not enabled to receive a data stream that is transmitted by the AP **14** simultaneously with other independent data streams as part of an OFDMA transmission to multiple client stations **25**. Similarly, according to an embodiment, the legacy client station **25-4** is not enabled to transmit a data stream that to the AP **14** as part of OFDMA transmission from multiple client stations **25**. According to an embodiment, the legacy client station **25-4** includes a PHY processing unit that is generally capable of receiving a data stream that is transmitted by the AP **14** simultaneously with other independent data streams that are intended for other client stations **25**. But the legacy client station **25-4** includes a MAC processing unit that is not enabled with MAC layer functions that support receiving the data stream that is transmitted by the AP **14** simultaneously with other independent data streams that are intended for other client stations **25**. According to an embodiment, the legacy client station **25-4** includes a PHY processing unit that is generally capable of transmitting a data stream to the AP **14** at the same time that other client stations **25** transmit data to the AP **14**. But the legacy client station **25-4** includes a MAC processing unit that is not enabled with MAC layer functions that support transmitting a data stream to the AP **14** at the same time that other client stations **25** transmit data to the AP **14**.

In an embodiment, the AP **14** and the client stations **25** contend for communication medium using carrier sense multiple access with collision avoidance (CSMA/CA) protocol or another suitable medium access protocol. Further, in an embodiment, the AP **14** or a client station **25** dynamically selects a bandwidth for a transmission based on channels available for the transmission. In an embodiment, communication between the AP **14** and a legacy client station (e.g., the legacy client station **25-4**) occur in a primary channel of the WLAN **10**, or in a wider channel that includes the primary channel of the WLAN **10**. For example, the legacy communication protocol requires that each transmission includes the primary channel, in an embodiment. On the other hand, communication between the AP **14** and a non-legacy client station **25** (e.g., the client station **25-1**) can occur in one or more communication channels that do not include the primary channel, in an embodiment. For

example, the non-legacy communication protocol, such as the HEW communication protocol, allows communication between the AP and the client stations to occur in a communication channel that does not include the primary channel, in an embodiment.

In an embodiment, the AP **14** is configured to transmit different OFDM units to different client stations **25** simultaneously by forming an OFDMA data unit that includes the different OFDM data units modulated in respective sub-channel blocks of the OFDMA data unit. In an embodiment, the AP **14** allocates different sub-channels to different client stations and forms the OFDMA data unit that includes OFDM data units directed to by modulating the different client stations in sub-channel blocks corresponding to the sub-channels assigned to the client stations. In an embodiment, when the one or more client stations include a legacy client station, the AP assigns a channel that includes a primary channel of the WLAN **10** to the legacy client station, and assigns one or more non-primary communication channels of the WLAN **10** to one or more non-legacy client stations. When the one or more client stations do not include any legacy client stations, the AP assigns the primary and the non-primary communication channels in any suitable manner to the one or more client stations, in various embodiments.

FIGS. **2**A, **2**B, and **2**C are diagrams illustrating example OFDM sub-channel blocks for an 80 MHz communication channel, according to an embodiment. In FIG. **2**A, the communication channel is partitioned into four contiguous OFDM sub-channel blocks, each having a bandwidth of 20 MHz. The OFDM sub-channel blocks include independent data streams for four client stations. In FIG. **2**B, the communication channel is partitioned into two contiguous OFDM sub-channel blocks, each having a bandwidth of 40 MHz. The OFDM sub-channel blocks include independent data streams for two client stations. In FIG. **2**C, the communication channel is partitioned into three contiguous OFDM sub-channel blocks. Two OFDM sub-channel blocks each have a bandwidth of 20 MHz. The remaining OFDM sub-channel block has a bandwidth of 40 MHz. The OFDM sub-channel blocks include independent data streams for three client stations.

Although in FIGS. **2**A, **2**B, and **2**C, the OFDM sub-channel blocks are contiguous across the communication channel, in other embodiments the OFDM sub-channel blocks are not contiguous across the communication channel (i.e., there are one or more gaps between the OFDM sub-channel blocks). In an embodiment, each gap is at least as wide as one of the OFDM sub-channel blocks. In another embodiment, at least one gap is less than the bandwidth of an OFDM sub-channel block. In another embodiment, at least one gap is at least as wide as 1 MHz. In an embodiment, different OFDM sub-channel blocks are transmitted in different channels defined by the IEEE 802.11a and/or 802.11n Standards. In one embodiment, the AP includes a plurality of radios and different OFDM sub-channel blocks are transmitted using different radios.

FIG. **3** is a diagram of an example OFDMA data unit **300**, according to an embodiment. The OFDMA data unit **300** includes a plurality of OFDM data unit **302-1**, **302-2** and **302-3**. In an embodiment, the AP **14** transmits the OFDM data units **302-1**, **302-2**, **302-3** to different client stations **25** via respective OFDM sub-channels within the OFDMA data unit **300**. In another embodiment, different client stations **25** transmit respective OFDM data units **302-1**, **302-2**, **302-3** to the AP **14** in respective OFDM sub-channels within the OFDMA data unit **300**. In this embodiment, The AP **14** receives the OFDM data units **302-1**, **302-2**, **302-3** from the client stations **25** via respective OFDM sub-channels of within the OFDMA data unit **300**, in this embodiment.

Each of the OFDM data units **302-1**, **302-2**, **302-3** conforms to a communication protocol that defines OFDMA communication, such as the HEW communication protocol, in an embodiment. In an embodiment in which the OFDMA data unit **300** corresponds to a downlink OFDMA data unit, the OFDMA data unit **300** is generated by the AP **14** such that each OFDM data unit **302** is transmitted to a respective client station **25** via a respective sub-channel of the WLAN **10** allocated for downlink transmission of the OFDMA data unit **300** to the client station. Similarly, an embodiment in which the OFDMA data unit **300** corresponds to an uplink OFDMA data unit, the AP **14** receives the OFDM data units **302** via respective sub-channels of the WLAN **10** allocated for uplink transmission of the OFDM data units **302** from the client stations, in an embodiment. For example, the OFDM data unit **302-1** is transmitted via a first 20 MHZ sub-channel of the WLN **10**, the OFDM data unit **302-2** is transmitted via a second 20 MHz sub-channel of the WLAN **10**, and the OFDM data unit **302-3** is transmitted via a 40 MHz sub-channel of the WLAN **10**, in the illustrated embodiment.

In an embodiment, each of the OFDM data units **302** includes a preamble including one or more legacy short training fields (L-STF) **304**, one or more legacy long training fields (L-LTF) **306**, one or more legacy signal fields (L-SIG) **308**, one or more first high efficiency WLAN signal field (HEW-SIG-A) **310**, N HEW long training fields (HEW-LTF) and a second HEW signal field (HEW-SIGB) **314**. Additionally, each OFDM data unit **302** includes a high efficiency WLAN data portion (HEW-DATA) **318**. In an embodiment, each L-LSF field **306**, each L-LTF field **308**, each L-SIG field **310** and each HEW-SIGA field **312** occupies a smallest bandwidth supported by the WLAN **10** (e.g., 20 MHz). In an embodiment, if an OFDM data unit **302** occupies a bandwidth that is greater than the smallest bandwidth of the WLAN **10**, then each L-LSF field **306**, each L-LTF field **308**, each L-SIG field **310** and each HEW-SIGA field **312** is duplicated in each smallest bandwidth portion of the OFDM data unit **302** (e.g., in each 20 MHz portion of the data unit **302**). On the other hand, each HEW-STF field **312**, each HEW-LTF field **314**, each HEW-SIGB field **316** and each HEW data portion **318** occupies an entire bandwidth of the corresponding OFDM data unit **302**, in an embodiment. For example, the OFDM data unit **302-3** occupies 40 MHz, wherein L-LSF field **306**, the L-LTF field **308**, L-SIG field **310** and HEW-SIGA fields **312** is duplicated in the upper and the lower 20 MHz bands of the OFDM data unit **302-3**, while each of the HEW-STF field **312**, each of the HEW-LTF fields **314**, each of the HEW-SIGB field **316** and each of the HEW data portion **318** occupies the entire 40 MHz bandwidth of the data unit **302**, in the illustrated embodiment.

In an embodiment, padding is used in one or more of the OFDM data units **302** to equalize lengths of the OFDM data units **302**. Accordingly, the length of each of the OFDM data units **302** correspond to the length of the OFDMA data unit **302**, in this embodiment. Ensuring that the OFDM data units **302** are of equal lengths synchronizes transmission of acknowledgment frames by client stations **25** that receive the data units **302**, in an embodiment. In an embodiment, each of one or more of the OFDM data units **302** is an aggregate MAC service data units (A-MPDU) (e.g., a very high throughput (VHT) A-MPDU, an HEW MPDU, or another suitable aggregated data unit), which is in turn included in a PHY protocol data unit (PPDU). In another

embodiment, each of one or more of the OFDM data units **302** is a single MPDU (e.g., a VHT MPDU, an HEW MPDU, or another suitable non-aggregated data unit) which is in turn included in a PPDU. In an embodiment, padding (e.g., zero-padding) within one or more of the A-MPDUs **302** or single MPDUs **302** is used to equalize the lengths of the data units **302**, and to synchronize transmission of acknowledgement frames corresponding to the OFDMA data unit **300**.

FIG. **4** is a diagram of an example OFDMA data unit **350**, according to another embodiment. The OFDMA data unit **350** is similar to the OFDMA data unit **300** of FIG. **3** accept that the OFDMA data unit **350** includes an OFDMA data unit **302-4** formatted according to a legacy communication protocol that does not support OFDMA communication (e.g., the IEEE 802.11ac Standard).

In an embodiment, the AP **14** forms OFDMA groups of client stations **25**, and informs the client stations **25** that the client stations **25** are members of particular OFDMA groups. For example, in an embodiment, the AP assigns a group number to an OFDMA group of client stations **25**, and transmits a management or a control frame that signals the group ID number to the client stations **25** that belong to the OFDMA group. For example, the management or control frame includes the group ID number and a respective unique identifier of each of the client stations **25** that belongs to the group, in an embodiment. In an embodiment, the AP **14** allocates respective OFDM sub-channels to client stations **25** that belong to an OFDMA group, and provides channel allocation information to the client stations **25** of the OFDMA group. The client stations **25** of the OFDMA group subsequently receive data in the respective OFDM sub-channels allocated to the client stations **25** when the data is transmitted to the client stations **25** in an OFDMA transmission from the AP **14** to the client stations **25**, in an embodiment and/or scenario. In another embodiment and/or scenario, the client stations **25** of the OFDMA group subsequently transmit respective data as part of an OFDMA transmission to the AP **14** by transmitting the data in the respective OFDM sub-channels allocated to the client stations **25** by the AP **14**.

FIG. **5**A is an example group definition field **500**, according to an embodiment. In an embodiment, the group definition field **500** is included in a management or a control frame that the AP **14** transmits to client stations **25**. The group definition field **500** includes a group identifier (group ID) subfield **502** and one or more association identifier (AID) subfields **504**. The AID subfields **504** include as many subfields as there are client stations **25** assigned to an OFDMA group identified by the group ID subfield **502**. For example, as shown in FIG. **5**A, the AID subfields **504** include a first AID (AID**1**) subfield **504-1**, a second AID (AID**2**) subfield **504-2**, a third AID (AID**3**) subfield **504-3**, and a fourth AID (AID**4**) subfield **504-4**. In one embodiment, the group definition field **500** is generated by the host processor **15** (e.g., by a management processing unit of the host processor **15**). In another embodiment, at least one of the AID subfields **504**, and/or information included therein, are generated at least in part by the MAC processing unit **18**.

Each of the AID subfields **504** includes an AID of one of the client stations **25** that the AP **14** has assigned to the OFDMA group identified by the group ID subfield **502**. Each one of the client stations **25** is configured to receive the entire group definition field **500** and, after detecting its own AID within one of the AID subfields **504**, determine that the particular client station **25** is a member of the OFDMA group identified by the group ID subfield **502**. In an embodiment, each client station **25** further determines, based on the placement of its own AID relative to the AIDs of the other client stations **25** in the AID subfields **164**, the order in which its own channel allocation information, relative to channel allocations for the other client stations **25**.

For example, the client station **25-2** detects the first AID subfield **504-1** and determines that the AID in the first AID subfield **504-1** does not match the AID of the client station **25-2**. The client station **25-2** then detects the second AID subfield **504-2** and determines that the AID in the second AID subfield **504-2** matches the AID of the client station **25-2**. The client station **25-2** therefore determines that it is a member of the OFDMA group identified by the group ID subfield **502**, and further determines that its unique index value is the number two, i.e., that the channel allocation information corresponding to the client station **25-2** will be second in order of receipt when channel allocation information is received by the client station **25-2**, for example as part of a signal field of an OFDMA data unit directed to the OFDMA group.

FIG. **5**B is a diagram of a channel allocation field **550** for providing channel allocation information to members of an OFDMA group, according to an embodiment. In an embodiment, the cannel allocation field **550** is included in the HEW-SIGA field **310** of the OFDMA data unit **300** of FIG. **4**. The channel allocation field **550** includes a group identifier (group ID) subfield **552**, one or more channel position subfields **554** and corresponding one or more channel bandwidth subfields **556**, each channel position subfield **554** and corresponding channel bandwidth subfield **556** indicating a channel position and a channel bandwidth, respectively, allocated for a particular member of the OFDMA group identified by the group ID subfield **552**. In particular, in an embodiment, each channel position subfield **554** identifies a 20 MHz channel position, within the WLAN **10**, allocated to a particular client station in the OFDMA group identified by the OFDMA group subfield **552**. For example, for an 80 MHz WLAN **10** composed of four non-overlapping 20 MHz sub-channels, each channel position subfield **554** includes two bits, wherein the binary value of 00 of the two bits indicates the lowest 20 MHz sub-channel, the binary value of 01 of the two bits indicates the second lowest sub-channel 20 MHz channel, the binary value of 10 of the two bits indicates the second highest 20 MHz channel and the of the two bits binary value of 11 of the two bits indicates the highest 20 MHz channel, in an embodiment. Similarly, in an embodiment, each channel bandwidth subfield **556** indicates a bandwidth allocated to a particular member of the OFDMA group identified by the OFDMA group subfield **552**, in an embodiment. For example, each channel bandwidth subfield **556** includes two bits, wherein the binary value of 00 of the two bits indicates a 20 MHz bandwidth, the binary value of 01 of the two bits indicates a 40 MHz bandwidth, the binary value of 10 of the two bits indicates 80 MHz bandwidth and the binary value of 11 of the two bits indicates 160 MHZ or a non-contiguous 80+80 MHz bandwidth, in an embodiment.

In some embodiments, sub-channel allocating with granularity of less than 20 MHz is utilized. For example, the AP **14** is configured to allocate sub-channels having bandwidths less than 20 MHz, such as 10 MHz sub-channels, 5 MHz sub-channels, 1 MHz sub-channels, or other suitable bandwidth sub-channels to at least some of the client stations **25**. Each of one or more of the channel position subfields **554** and corresponding one or more of the channel bandwidth subfields **556** include greater than two bits to accommodate the higher sub-channel granularity, in such embodiments.

In an embodiment, non-legacy client stations **25** are configured to receive the channel allocation field **550** in the primary channel of the WLAN **10**. For example, the non-legacy client stations **25** receive the channel allocation field as part of a signal field of an OFDMA data unit (e.g., HEW-SIGA field **410** of FIG. **4**) in the primary channel of the WLAN **10**. For example, the signal field includes a channel allocation field such as the channel allocation field **550** of FIG. **5**B, in an embodiment. A non-legacy client station **25** is configured to determine, based on the group ID subfield **552** of the channel allocation field **550** whether the client station **25** is a member of the OFDMA group to which the OFDMA data unit is directed, in an embodiment. Further, if the client station **25** determines that the client station **25** belongs to the OFDMA group to which the OFDMA data unit is directed, the client station **25** determines a position and bandwidth of the sub-channel allocated to the client station **25** based on the channel position subfield **554** and channel bandwidth subfield **556**, respectively, corresponding to the client station **25**, in an embodiment. In particular, the client station **25** determines the channel position and bandwidth allocated to the client station **25** based on the channel position subfield **554** and the channel bandwidth subfield **556** corresponding to the unique value that the client station **25** determined based on a group definition field, such as the group definition field **500** of FIG. **5**, previously received by the client station **25**, in an embodiment.

In another embodiment, the signal field includes an identifier, such as an AID or a partial AID, corresponding to each client station **25** to which the OFDMA data unit is directed. In this embodiment, the signal field omits a group ID. For example, the signal field includes a channel allocation field similar to the channel allocation field **550** of FIG. **5**B, except that the channel allocation field omits the Group ID field **552**. In this embodiment, a client station **25** determines whether the client station **25** is an intended recipient of a portion of an OFDMA data unit based on detecting its identifier in the signal field of the OFDMA data unit.

Upon determining the allocated channel position and bandwidth for a client station **25**, the client station **25** tunes to the determined channel and channel bandwidth for receiving the particular OFDM data unit, within the OFDMA data unit, that is directed to the client station **25**, in an embodiment. For example, with reference to FIG. **3**, after receiving the HEW-SIGA field **310** in the primary channel of the WLAN **10** and determining, based on a channel allocation field (e.g., the channel allocation field **550** of FIG. **5**B) included in the HEW-SIGA field **310**, that the second highest 20 MHz sub-channel is allocated to the client station **25-2**, the client station **25-2** tunes to the second highest 20 MHz channel and receives remainder of the OFDMA data unit **300** in the second highest 20 MHz sub-channel, i.e. the portion of the OFDMA data unit **300** corresponding to the OFDM data unit **302-2** directed to the client station **25-2**, in an example embodiment.

FIG. **6** is diagram illustrating a frame exchange **600** between an AP (e.g., the AP **14**) and multiple client stations (e.g., multiple client stations **25**), according to an embodiment. During a time t**1**, the AP **14** transmits an OFDMA data unit **602** directed to a plurality of client stations. The OFDMA data unit **600** occupies an 80 MHz channel, in the illustrated embodiment. In an embodiment, the data unit **600** is the same as or similar to the data unit **300** of FIG. **3**. In an embodiment, prior to transmission of the OFDMA data unit **602**, the AP **14** conducts a suitable channel assessment procedure, such as a carrier sense multiple access with collision avoidance procedure (CSMA/CA) procedure, and based on the channel assessment procedure determines a bandwidth available for transmission by the AP **14**. In an embodiment, the OFDM channel includes the primary channel of the WLAN **10** and one or more secondary channels of the WLAN **10**. For example, the AP **14** determines that the primary 20 MHz channel and three secondary 20 MHz channels of the WLAN **10** are available for 80 MHz transmission by the AP **14**, in the illustrated embodiment.

In an embodiment, the OFDMA data unit **602** includes a plurality of OFDM data units **604** directed to respective client stations **25**, each OFDM data unit **604** transmitted in a respective sub-channel of the WLAN **10** to a particular client station **25**. In particular, a first OFDM data unit **602-1** is directed to a first client station STA**1** (e.g., the client station **25-1**), a second OFDM data unit **602-2** is directed to a second client station STA**2** (e.g., the client station **25-2**), and a third OFDM data unit **602-3** is directed to a third client station STA**3** (e.g., the client station **25-3**), in the illustrated embodiment. In an embodiment, the first OFDM data unit **602-1** occupies the highest 20 MHz sub-channel of the 80 MHz channel, the second OFDM data unit **602-3** occupies the second highest 20 MHz sub-channel of the 80 MHz channel, and the third OFDM data unit **602-3** is transmitted in a 40 MHZ sub-channel that includes the lowest two 20 MHZ sub-channels of the 80 MHz channel.

In an embodiment, the preamble of the OFDMA data unit **600** is transmitted in each of the 20 MHz sub-channels occupied by the OFDMA data unit **602**. In an embodiment, the preamble of the OFDMA data unit **600** includes a channel allocation field (e.g., in a signal field of the preamble such as the HEW-SIGA field of the preamble) that indicates to the client stations **25** to which the OFDMA data unit **600** is directed that the client station **25** are intended recipients of different portions of the OFDMA data unit **600**. In an embodiment, the channel allocation field includes a group number corresponding to an OFDMA group that includes the client stations **25** to which the OFDMA data unit **602** is directed. In another embodiment, the channel allocation field identifies each client station to which the OFDMA data unit **600** is directed by including an identifier, such as an AID or a partial AID, corresponding to the client station **25**. The channel allocation field included in the preamble omits a group ID subfield, in this embodiment. The channel allocation field also indicates to each of the client stations **25** which portion (e.g., which sub-channel block) of the OFDMA data unit **600** contains data directed to the client station **25**, in an embodiment. For example, the channel allocation field indicates to each of the client stations **25** a channel position and bandwidth that includes an OFDM data unit directed to the client station **25**, in an embodiment. In an embodiment, the preamble of the OFDMA data unit **602** includes the channel allocation field **550** of FIG. **5**B. In another embodiment, the preamble of the OFDMA data unit **602** includes a suitable channel allocation field other than the channel allocation field **550** of FIG. **5**B. The channel allocation field indicates that the highest 20 MHz channel of the 80 MHz channel is allocated to the client station STA**1**, the second highest 20 MHz channel of the 80 MHz channel is allocated to the client station STA**2**, and the two lowest 20 MHz channels of the 80 MHz channel are allocated to the client station STA**3**, in the illustrated embodiment.

Each of the client stations **25** receives the channel allocation field in the primary channel of the WLAN **10** (e.g., in the lowest 20 MHz channel) and determines, based on the channel allocation field, which channel of the WLAN **10** includes data directed to the client station **25**, respectively, in an embodiment. The client stations **25** tune to the appro-

priate sub-channels indicated in the channel allocation field and receive data directed to the client stations **25** via the respective sub-channels allocated to the client station **25**. During a time t**2**, in an embodiment, client stations **25** that successfully receive data in the respective sub-channels allocated to the client stations **25** transmit respective acknowledgement (ACK or BlkAck) frames **606** to the AP **14**. In an embodiment, each client station **25** transmits its acknowledgement (ACK or BlkAck) frame **606** in the respective sub-channel allocated to the client station **25**. In an embodiment, the AP **14** synchronizes transmission of the ACK frames **606** from the client stations **25** by ensuring that the OFDM data units **604-1**, **604-2**, **604-3** are of equal length. For example, the AP adds padding bits (e.g., bits having predetermined values such as zero bits or one bits) to data bits in one or more of the data units **604** to equalize lengths of the data units **604**, in an embodiment. For example, in an embodiment in which the OFDM data units **604-1**, **604-2**, **604-3** are A-MPDUs, and the AP **14** utilizes A-MPDU padding in one or more of the data units **604-1**, **604-2**, **604-3** to ensure that the data units **604-1**, **604-2**, **604-3** are of the same length. As another example, in an embodiment in which the OFDM data units **604-1**, **604-2**, **604-3** are MPDUs, and the AP **14** utilizes MPDU padding in one or more of the data units **604-1**, **604-2**, **604-3** to ensure that the data units **604-1**, **604-2**, **604-3** are of the same length.

In another embodiment, the ACK frames **606** are not simultaneously transmitted by the client stations **25**. For example, transmission of the ACK frames **506** is staggered among the client stations **25**, in an embodiment. For example, the AP provides to the client stations **25** indications of different specific times at which to transmit their respective ACK frames **606**, or a specific order in which to transmit their respective ACK frames **606**, and the client stations **25** transmit the ACK frames **606** at the specific times or in the specific order indicated by the AP, in an embodiment.

In an embodiment, the ACK frames **606** are block acknowledgement (Blk Ack) frames that indicate successful or unsuccessful reception of a plurality of data units, such as of a plurality of data units aggregated in the corresponding A-MPDU **602**. Generally speaking, as used herein, the terms "acknowledgement frame" and "ACK frame" are used interchangeably and encompass both an acknowledgement frame that acknowledges successful or unsuccessful receipt of a single data unit, and a block acknowledgement frame that acknowledges successful or unsuccessful receipt of multiple data units (e.g., multiple data units transmitted as parts of an aggregated data unit).

In some embodiments, the AP **14** transmits a control frame, such as a scheduling frame, to the client stations **25** prior to transmission of an OFDMA data unit to the client stations **25**. In an embodiment, the control frame that the AP **14** transmits to the client stations **25** prior to transmission of an OFDMA data unit to the client stations **25** is a legacy (e.g., an IEEE 802.11 a or an IEEE 802.11 g) duplicate control frame that is replicated in each smallest bandwidth band (e.g., each 20 MHz band) of the WLAN **10**. In an embodiment, the AP **14** transmits the control frame at the beginning of a transmission opportunity (TXOP) to inform the client stations **25** whether the client stations **25** are to receive data from the AP **14** and/or are to transmit data to the AP **14** during the TXOP. The control frame includes downlink and/or uplink channel allocation information that indicates to the client stations **25** that are to receive and/or transmit data which sub-channels to use for reception and/or transmission of data, in an embodiment. In an embodiment, the client stations **25** are configured to determine their respective downlink sub-channels based on downlink channel allocation information included in the control frame and to subsequently receive, via the downlink sub-channels, data from the AP **14** simultaneously with the other client stations **25** as part of a downlink OFDMA transmission from the AP **14**. Similarly, the client stations **25** are configured to determine their respective uplink channels based on uplink channel allocation information included in the control frame and to subsequently transmit data to the AP **14** simultaneously with the other client stations **25** as part of an uplink OFDMA transmission to the AP **14**, in an embodiment.

In at least some embodiments in which the AP **14** transmits a control frame to the client stations **25** to signal downlink channel allocation to the client stations **25** for a downlink OFDMA transmission to the client stations **25**, such channel allocation information need not be included in a preamble of each of the OFDM data unit transmitted as part of the OFDMA transmission. In one such embodiment, the preamble of each data unit in an OFDMA transmission is generally the same as a preamble used for regular OFDM transmission to single client station **25**. For example, with reference to FIGS. **3** and **4**, the signal field **310** of each of the data units **302** is the same as a HEW-SIGA field of a data unit transmitted as a regular transmission to a single client station **25**. In another embodiment, the preamble of each OFDM data unit included in the OFDMA transition is substantially the same as a preamble used for regular OFDM transmission to single client station **25**, but includes an indication that the OFDM data unit is part of an OFDMA transmission to multiple client stations **25**. For example, with reference to FIGS. **3** and **4**, one or more bits of the signal field **310** is/are set to indicate that the OFDM data units **302** are part of an OFDMA transmission, in an embodiment.

FIG. **7**A is an example of an OFDMA downlink scheduling element **700**, according to an embodiment. The OFDMA downlink scheduling element **700** is included in a control frame, such as a scheduling frame, that the AP **14** transmits to client stations **25** to provide channel allocation information to the client stations **25**, in an embodiment. The OFDMA downlink scheduling element **700** includes a downlink channel allocation field **702** which, in turn, includes a plurality of user subfields **704**. Each user field **704** corresponds to a particular client station **25** and includes downlink channel allocation information for the particular station **25**, in an embodiment. For example, each user field **704** includes a station identifier subfield **706**, a channel subfield **708** and a bandwidth subfield **710**. The channel identifier subfield **706** includes an identifier, such as an AID or a partial AID, corresponding to a client station **25**, in an embodiment. The channel subfield **708** identifies a channel position, within the WLAN **10**, corresponding to a sub-channel allocated to the client station identified in the identifier subfield **706**. For example, in an embodiment in which the channel allocation subfield indicates channel allocation within an 80 MHz channel composed of four non-overlapping 20 MHz sub-channels, the channel subfield **708** includes two bits, wherein the binary value of 00 of the two bits indicates the lowest 20 MHz sub-channel, the binary value of 01 of the two bits indicates the second lowest 20 MHz sub-channel, the binary value of 10 of the two bits indicates the second highest 20 MHz sub-channel and the of the two bits binary value of 11 of the two bits indicates the highest 20 MHz sub-channel, in an embodiment. Similarly, the bandwidth subfield **710** corresponding to a client station **25** indicates bandwidth allocated to the client station **25**, in

an embodiment. For example, the bandwidth subfield **710** includes two bits, wherein the binary value of 00 of the two bits indicates a 20 MHz bandwidth, the binary value of 01 of the two bits indicates a 40 MHz bandwidth, the binary value of 10 of the two bits indicates 80 MHz bandwidth and the binary value of 11 of the two bits indicates 160 MHZ or a non-contiguous 80+80 MHz bandwidth, in an embodiment. In at least some embodiments, each user field **704** includes one or more additional sub-fields to indicate additional information, such as, for example, an indication of a modulation and coding scheme (MCS) to be used for the user in the downlink OFDMA transmission, transmission power to be used for the user in the downlink OFDMA transmission, etc.

In some embodiments, sub-channels with granularity less than 20 MHz are utilized. For example, the AP **14** is configured to allocate sub-channels having bandwidths less than 20 MHz, such as 10 MHz sub-channels, 5 MHz sub-channels, 1 MHz sub-channels, or other suitable bandwidth sub-channels, to at least some of the client stations **25**, in some embodiments. Each of one or more of the channel position subfields **708** and corresponding one or more of the channel bandwidth subfields **710** include greater than two bits to accommodate the higher sub-channel granularity, in such embodiments.

FIG. **7**B is an example of an OFDMA uplink scheduling element **750**, according to an embodiment. The OFDMA uplink scheduling element **750** is similar to the OFDMA downlink element **700** of FIG. **7**A, except that the OFDMA uplink scheduling element **750** indicates channel allocation for uplink transmission, in an embodiment. The OFDMA uplink scheduling element **750** is included in a control frame, such as a scheduling frame, that the AP **14** transmits to client stations **25** to provide uplink channel allocation information to the client stations **25**, in an embodiment.

Similar to the OFDMA downlink scheduling element **700**, the OFDMA uplink scheduling element **750** includes a channel allocation field **752** which, in turn, includes a plurality of user fields **754**. Each user field **754** corresponds to a particular client station **25** and includes uplink channel allocation information for the particular station **25**, in an embodiment. In an embodiment, each user field **754** includes a station identifier subfield **756**, a channel subfield **758** and a bandwidth subfield **760**. In at least some embodiments, each user field **754** includes one or more additional sub-fields to indicate additional information, such as, for example, an indication of a modulation and coding scheme (MCS) to be used by the user in the uplink OFDM transmission, transmission power to be used by the user in the uplink OFDM transmission, etc. In an embodiment, the station identifier subfields **756**, a channel subfields **758** and a bandwidth subfields **760** are the same as or similar to the station identifier subfields **706**, a channel subfields **708** and a bandwidth subfields **710** described with respect to the OFDMA downlink scheduling element **700** of FIG. **7**A. Additionally, in some embodiment, the OFDMA uplink scheduling element **750** includes one or more of an uplink length field **762**, a repeat usage field **764** and an uplink buffer poll field **768** to be described in more detail below. In some embodiment, the OFDMA uplink scheduling element **750** omits one or more of the uplink length field **762**, the repeat usage field **764** and the uplink buffer poll field **768**.

FIG. **8**A is a frame exchange **800** between the AP **14** and a plurality of client stations **25**, according to another embodiment. During a time t**1**, the AP **14** transmits a scheduling frame **802** to a plurality of client stations **25**. In an embodiment, the time t**1** begins at the beginning of a TXOP obtained by (e.g., based on a suitable channel assessment procedure, such as CSMA/CA) or scheduled by the AP **14**. In an embodiment, the scheduling frame **802** provides OFDMA downlink scheduling information to the plurality of client stations **25**. In particular, in an embodiment, the scheduling frame **802** includes downlink channel allocation information to be used for transmission of downlink OFDMA data units during the TXOP. In an embodiment, the scheduling frame **802** includes the OFDMA downlink scheduling element **700** of FIG. **7**. In other embodiments, the scheduling frame **802** provides downlink channel allocation information in other suitable manners.

In an embodiment, the scheduling frame **802** is a control frame. In an embodiment, the scheduling frame **802** is a non-data packet (NDP) frame that omits a PHY payload. In one embodiment in which the scheduling frame **802** in an NDP frame, MAC layer information, e.g., the MAC address of the receiving device, the MAC address of the transmitting device, etc., is included in a signal field of a PHY preamble of the scheduling frame **802**. In an embodiment and/or scenario, the uplink scheduling frame **802** is duplicated in each smallest bandwidth portion (e.g., in each 20 MHz) of the entire bandwidth of the TXOP. In another embodiment and/or scenario, the scheduling frame **802** occupies the entire bandwidth of the TXOP, for example when each of the client stations **25** to which the scheduling frame **902** is transmitted is capable of operating in the entire bandwidth of the TXOP. In another embodiment and/or scenario, the uplink scheduling frame **902** is a legacy control frame duplicated in every smallest bandwidth portion of the entire bandwidth of the TXOP so as to protect the TXOP from transmissions by client stations **25** that are not intended participants in the TXOP. For example, in an embodiment, if the entire bandwidth of the TXOP is 160 MHz, then the scheduling frame **902** is duplicated in each 20 MHz portion of the 160 MHz channel, in an embodiment. Client stations **25** that are not intended participants in the TXOP determine duration of the TXOP based on a length or duration indicated by the scheduling frame **1102** and defer medium access for the determined duration, in an embodiment.

The scheduling frame **802** indicates respective sub-channels allocated for downlink OFDA transmission to three client stations **25** (STA**1**, STA**2** and STA**3**), in the illustrated embodiment. For example, the scheduling frame **802** indicates channel allocation within an 80 MHz channel, and indicates that (i) the highest 20 MHz sub-channel of the 80 MHz channel is allocated to STA**1**, (ii) the second highest 20 MHz sub-channel of the 80 MHz channel is allocated to STA**2** and (iii) a 40 MHz sub-channel that includes the second lowest 20 MHz sub-channel and the lowest 20 MHz sub-channel is allocated to STA**3**, in an embodiment. In an embodiment, the client stations STA**1**, STA**2** and STA**3** is each a non-legacy client station enabled for OFDMA communication. For example, the client stations STA**1**, STA**2** and STA**3** correspond to non-legacy client stations **25-1**, **25-2** and **25-3**, respectively, in an embodiment. In another embodiment, at least one of the client stations STA**1**, STA**3** and STA**3** is a legacy client station that is not enabled for OFDMA communication. For example, the client stations STA**1** and STA**2** respectively correspond to non-legacy client stations **25-1** and **25-2**, while the STA**3** corresponds to the legacy client stations **25-4**, in another embodiment.

During a time t**2**, the AP **14** transmits an OFDMA data unit **804** directed to the plurality of client stations **25**. The OFDMA data unit **804** includes respective OFDM data units **806** transmitted to each of the client stations **25** in respective sub-channels allocated to the client station **25**. Time t**2**

begins upon expiration of a predetermined time interval, such as a time interval corresponding to a short inter-frame space (SIFS), after the end of time t**1**, i.e., after completion of transmission of the scheduling frame **802**, in an embodiment.

In an embodiment in which the scheduling frame **802** is directed to a plurality of non-legacy client stations **25** enabled for OFDMA communication, each of the client stations **25** determines, based on the scheduling frame **802**, the particular sub-channel and sub-channel bandwidth allocated to the client station **25**. The client station **25** then tunes to the sub-channel allocated to the client station **25**, and receives the OFDM data unit **806** directed to the client station **25** in the sub-channel allocated to the client station **25**, in an embodiment.

In an embodiment, if the data unit **804** is directed to a plurality of client stations **25** that includes a legacy client station **25**, then the AP **14** allocates the primary channel of the WLAN **10**, or a wider channel that includes the primary channel of the WLAN **10**, to the legacy station **25**. In this example scenario, the non-legacy client stations **25** determine the respective sub-channels allocated to the non-legacy station **25** based on channel information included in the scheduling frame **802**, and tune to the allocated sub-channels for reception of their respective OFDM data units **806** within the OFDMA data unit **804**. The legacy client station **25**, on the other hand, receives the OFDM data unit **806** directed to the legacy client station **25** in the primary channel of the WLAN **10**, or in a channel that includes the primary channel of the WLAN **10**, in this embodiment. Thus, the legacy client station **25** need not be enabled to decode and interpret channel allocation information in the scheduling frame **802**, in an embodiment. The legacy client station **25** receives the OFDM data unit **806** directed to the client station **25** without knowledge that the OFDM data unit **806** is transmitted simultaneously with the other OFDM data units **806** and as a part of the OFDMA data unit **804**, in an embodiment.

During a time t**3**, each client station **25** that successful receives the OFDM data unit **806** directed to the client station **25** transmits an acknowledgement (ACK) frame **808** to the AP **14** as part of an OFDMA transmission to the AP **14**, in the illustrated embodiment. Time t**3** at each client station **25** begins upon expiration of a predetermined time interval, such as for example a time interval corresponding to a short inter-frame space (SIFS), after completion of reception, at the client station **25**, of the data unit **806** directed to the client station **25**. In an embodiment, each client station **25** transmits its ACK frame **808** in the respective channel allocated to the client station **25** indicated in the scheduling frame **802**. In an embodiment, the AP **14** synchronizes transmission of the ACK frames **808** from the client station **25** by ensuring that the OFDM data units **806** are of equal length. In an embodiment, the AP adds padding bits (e.g., bits having predetermined values such as "zero" bits or "one" bits) to data bits of one or more of the data units **806** to equalize lengths of the data units **806**. For example, in an embodiment in which the OFDM data units **806** are A-MPDUs, and the AP **14** utilizes A-MPDU padding in one or more of the data units **806** to ensure that the data units **806** are of the same length. As another example, in an embodiment in which the OFDM data units **806-1**, **806-2**, **806-3** are MPDUs, and the AP **14** utilizes MPDU padding in one or more of the data units **806-1**, **806-2**, **806-3** to ensure that the data units **806-1**, **806-2**, **806-3** are of the same length.

In another embodiment, the ACK frames **808** are not simultaneously transmitted by the client stations **25**. For example, transmission of the ACK frames **808** is staggered among the client stations **25**, in an embodiment. For example, the AP provides to the client stations **25** indications of different specific times at which to transmit their respective ACK frames **808**, or a specific order in which to transmit their respective ACK frames **708**, and the client stations **25** transmit the ACK frames **808** at the specific times or in the specific order indicated by the AP, in an embodiment. In an embodiment, the ACK frames **808** are block acknowledgement (Blk Ack) frames that indicate successful or unsuccessful reception of a plurality of data units, such as of a plurality of data units aggregated in the corresponding A-MPDU **702**.

FIG. **8**B is a frame exchange **850** between the AP **14** and a plurality of client stations **25**, according to another embodiment. The frame exchange **850** is generally similar to the frame exchange **800** of FIG. **8**A except that in the frame exchange **850**, a scheduling frame **852** indicates noncontiguous channel allocation to a plurality of client stations **25**. In an embodiment, prior to transmitting the scheduling frame **852**, the AP **14** detects that a particular sub-channel is currently not available (e.g., busy). For example, the AP **14** detects that the second highest 20 MHz sub-channel of the 80 MHz channel is busy, while the remaining 20 MHz sub-channels of the 80 MHz are available. Then, during a time t**1**, the AP **14** transmits the scheduling frame **852** on each of the available sub-channels of the 80 MHz channel. The scheduling frame **852** is similar to the scheduling frame **802** except that the scheduling frame **852** indicates channels allocated to STA**1** and STA**3**, but nor STA**2**, in the illustrated embodiment. In particular, the scheduling frame **852** indicates that (i) the highest 20 MHz sub-channel of the 80 MHz channel is allocated to STA**1**, and (ii) a 40 MHz sub-channel that includes the second lowest 20 MHz sub-channel and the lowest 20 MHz sub-channel is allocated to STA**3**, in an embodiment. In another embodiment, a signal field (e.g., the HEW-SIGA field) of the OFDMA data unit **854**, rather than the scheduling frame **852**, includes noncontiguous channel allocation indications. For example, the OFDMA data unit **854** is similar to the OFDMA data unit **602** of FIG. **6**, except that the signal field of the OFDMA data unit **854** indicates noncontiguous channel allocation, in some embodiments. In some such embodiments, the frame exchange **850** omits transmission of the scheduling frame **852**.

During a time t**2**, the AP **14** transmits an OFDMA data unit **854** that includes respective OFDM data units **856** directed to each of two client stations STA**1** and STA**3**. In an embodiment, the OFDM data units **856** are transmitted to the client stations STA**1** and STA**3** in the respective noncontiguous channels allocated to the client station STA**1** and STA**3** . During a time t**3**, each of the client stations STA**1** and STA**3** that successful receives the OFDM data unit **856** directed to the client station STA**1**, STA**3** transmits an acknowledgement (ACK) frame **858** to the AP **14** as part of an OFDMA transmission to the AP **14**, in the illustrated embodiment. In an embodiment, each client station STA**1**, STA**3** transmits its ACK frame **858** in the respective channel allocated to the client station STA**1**, STA**3** indicated in the scheduling frame **852**.

FIG. **9**A is a diagram of a frame exchange **900** between the AP **14** and a plurality of client stations **25**, according to another embodiment. During a time t**1**, the AP **14** transmits an uplink scheduling frame **902** to a plurality of client stations **25**. In an embodiment, the time t**1** begins at the beginning of a TXOP obtained by (e.g., based on a suitable channel assessment procedure, such as CSMA/CA), or scheduled for, the AP **14**. In an embodiment, the uplink

scheduling frame **902** provides, to the plurality of client stations **25**, OFDMA uplink scheduling information to be used for transmission of an uplink OFDMA data unit during the TXOP. In an embodiment, the uplink scheduling frame **902** includes the OFDMA uplink scheduling element **750** of FIG. **7**B. In another embodiment, the uplink scheduling frame **902** provides uplink OFDMA scheduling information in another suitable manner. In an embodiment, the scheduling frame **902** further indicates, to each of the client stations STA**1**, STA**2**, STA**3**, a length or duration (e.g., using the UL PPDU length field **762** of FIG. **7**B) to be used for transmission of an uplink data unit during the TXOP.

In an embodiment, the scheduling frame **902** is a control frame. In an embodiment, the scheduling frame **902** is a non-data packet (NDP) frame that omits a payload. In one embodiment in which the scheduling frame **902** in an NDP frame, MAC layer information, e.g., receiver address, transmitter address, etc., is included in a signal field of a PHY preamble of the scheduling frame **902**. In an embodiment and/or scenario, the uplink scheduling frame **902** is duplicated in each smallest bandwidth portion (e.g., in each 20 MHz) of the entire bandwidth of the TXOP. In another embodiment and/or scenario, the scheduling frame **902** occupies the entire bandwidth of the TXOP, for example when each of the client stations **25** to which the scheduling frame **902** is transmitted is capable of operating in the entire bandwidth of the TXOP. In another embodiment and/or scenario, the uplink scheduling frame **902** is duplicated in every bandwidth portion of the entire bandwidth of the TXOP so as to allow each client station **25** to which the scheduling frame **902** is transmitted to receive and decode the scheduling frame **902**, according to capabilities of the client stations **25** to which the scheduling frame **902** is directed. For example, if the entire bandwidth of the TXOP is 160 MHz, but at least one of the client stations **25** to which the scheduling frame **902** is directed is capable to operate with a maximum bandwidth of 80 MHz, then the scheduling frame **902** occupies 80 MHz and is duplicated in each 80 MHz portion of the entire bandwidth of the TXOP (i.e., in the lower 80 MHz portion and the upper 80 MHz portion), in an embodiment.

The scheduling frame **902** indicates respective sub-channels allocated for uplink OFDMA transmission by three client stations STA**1**, STA**2** and STA**3**, in the illustrated embodiment. For example, the scheduling frame **902** indicates channel allocation within an 80 MHz channel, and indicates that (i) the highest 20 MHz sub-channel of the 80 MHz channel is allocated to STA**1**, (ii) the second highest 20 MHz sub-channel of the 80 MHz channel is allocated to STA**2** and (iii) a 40 MHz sub-channel that includes the second lowest 20 MHz sub-channel and the lowest 20 MHz sub-channel is allocated to STA**3**, in an embodiment.

During a time t**2**, the plurality of client stations **25** transmit respective OFDM data unit **906** that collectively form an OFDMA data unit **904** to the AP **14**. Time t**2** at each client station **25** begins upon expiration of a predetermined time interval, such as for example a time interval corresponding to a short inter-frame space (SIFS), after completion of reception, of the scheduling frame **902** at the client station **25**, in an embodiment. In another embodiment, a predetermined time period that is greater than SIFS is defined, and time t**2** at each client station **25** begins upon expiration of a predetermined time interval corresponding to the predetermined time interval greater than SIFS. For example, a predetermined time period that is greater than SIFS and less than point coordination function (PCF) inter-frame space (PIFS) is defined. The greater predetermined time interval may provide sufficient time for the client stations **25** to decode the scheduling frame **902** and to prepare for uplink transmission based on the uplink scheduling information provided by the scheduling frame **902**, in at least some embodiments. Additionally or alternatively, the scheduling frame **902** includes one or more padding bits at the end of the scheduling frame **902** to provide sufficient time for the client stations **25** to prepare for uplink transmission based on the uplink scheduling information provided by the scheduling frame **902**, in some embodiments. For example, a MAC header included in the scheduling frame **902** indicates a length of a valid payload, wherein the one or more padding bits follow the valid payload, in an embodiment. Further, a signal field of a PHY preamble of the scheduling frame **902** includes an indication of the entire length of the scheduling frame **902**, which includes the one or more padding bits at the end of the scheduling frame **902**, in an embodiment.

In an embodiment, each client station **25** transmits its OFDM data unit **906** during the time t**2** in a respective sub-channel, allocated to the client station **25**, as indicated in the scheduling frame **902**. In an embodiment, the length or duration of each of the OFDM data units **906** corresponds to the length or duration indicated in the scheduling frame **902**.

During a time t**3** , the AP **14** transmits respective ACK frames **908** to the client stations **25** (STA**1**, STA**2** and STA**3**) acknowledging receipt of the OFDM data units **906** from the client stations **25**. In another embodiment, the AP **14** transmits a broadcast acknowledgement frame that includes respective acknowledgements for the client stations **25** (STA**1**, STA**3** and STA**3**). Time t**3** begins upon expiration of a predetermined time interval, such as for example a time interval corresponding to a short inter-frame space (SIFS), after completion of reception of the OFDM data units **906** at the AP **14**, in an embodiment. In an embodiment, the AP **14** transmits the ACK frame **908** to the client stations **25**, as parts of an OFDMA transmission to the client statins **25**, in the respective sub-channels allocated to the client stations **25** indicated in the scheduling frame **902**.

FIG. **9**B is a frame exchange **950** between the AP **14** and a plurality of client stations **25**, according to another embodiment. The frame exchange **950** is generally similar to the frame exchange **900** of FIG. **9**A except that in the frame exchange **950**, a scheduling frame **952** indicates noncontiguous channel allocation to a plurality of client stations **25**. In an embodiment, prior to transmitting the scheduling frame **952**, the AP **14** detects that a particular sub-channel is currently not available (e.g., busy). For example, the AP **14** detects that the second highest 20 MHz sub-channel of the 80 MHz channel is busy, while the remaining 20 MHz sub-channels of the 80 MHz are available. Then, during a time t**1**, the AP **14** transmits the scheduling frame **952** on each of the available sub-channels of the 80 MHz channel. The scheduling frame **952** is similar to the scheduling frame **902** except that the scheduling frame **952** indicates channels allocated to STA**1** and STA**3**, but nor STA**2**, in the illustrated embodiment. In particular, the scheduling frame **952** indicates that (i) the highest 20 MHz sub-channel of the 80 MHz channel is allocated to STA**1**, and (ii) a 40 MHz sub-channel that includes the second lowest 20 MHz sub-channel and the lowest 20 MHz sub-channel is allocated to STA**3**, in the illustrated embodiment.

In an embodiment, during a time t**2**, stations STA**1** and STA**3** transmit respective OFDM data units **956** that collectively form an OFDMA data unit **954** to the AP **14**. In an embodiment, the client stations STA**1** and STA**3** transmit their respective OFDM data units **956** in a respective non-

contiguous sub-channels allocated to the client stations STA1 and STA3, as indicated in the scheduling frame **952**. During a time t3, the AP **14** transmits respective ACK frames **958** to the client stations SAT1 and STA3 acknowledging successful receipt of the OFDM data units **956** from the client stations STA1 and STA3, in an embodiment. The AP transmits the ACK frame **958** to the client stations STA1 and STA3, as parts of an OFDMA transmission to the client statins STA1 and STA3, in the respective non-contiguous sub-channels allocated to the client stations STA1 and STA3 , in an embodiment. In another embodiment, the AP **14** transmits a broadcast acknowledgement frame that includes respective acknowledgements for the client stations **25** (STA1, STA3 and STA3).

FIG. **10**A is a diagram of a frame exchange **1000** between the AP **14** and a plurality of client stations **25**, according to an embodiment. The frame exchange **1000** is similar to the frame exchange **900** of FIG. **9**A except that in the frame exchange **1000** channel allocation provided by a scheduling frame **1002** transmitted during a time t1 is used for multiple uplink OFDMA transmissions that follow the scheduling frame **1002**. In an embodiment, the scheduling frame **1002** includes the OFDMA uplink scheduling element **750**, and indicates repeat usage in the repeat usage field **764** of the OFDMA uplink scheduling element **750**. For example, the repeat usage indication **764** indicates a number of data units that can be transmitted to the AP **14** using the channel allocation provided in the scheduling frame **1002**, in an embodiment. The number of data units corresponds to the number of data units that can be transmitted during the TXOP to which the scheduling frame **1002** corresponds, in an embodiment. In another embodiment, the repeat usage indication indicates an amount of time for which the channel allocation provided in the scheduling frame **1002** can be used for uplink transmissions to the AP **14**. The amount of time indicated by the scheduling frame **1002** corresponds to the duration of the TXOP to which the scheduling frame **1002** corresponds, in an embodiment.

In the embodiment of FIG. **10**A, the client stations **25** use channel allocation provided by the scheduling frame **1002** to transmit two data units **1004**, **1010** as part of two respective OFDMA uplink transitions **1006**, **1012** to the AP **14**. In particular, during a time t2, the client stations **25** each transmit a respective first data unit **1004** as part of a first OFDMA transmission **1006** to the AP **14**. During a time t3, the client stations **25** receive, from the AP **14**, receive respective ACK frames **1008** acknowledging receipt of the data units **1004** by the AP **14**. The ACK frames **1008** are transmitted by the AP **14** in respective sub-channels as part of an OFDMA transmission to the client stations **25**, in the illustrated embodiment. After receiving the respective ACK frames **1008**, during a time t4, the client stations **25** each transmits a respective second data unit **1010**, using uplink channel allocation information provided in the scheduling frame **1002**, as part of a second OFDMA transmission **1012** to the AP **14**. During a time t5, the client stations **25** receive, from the AP **14**, receive respective ACK frames **1014** acknowledging receipt of the data units **1010** by the AP **14**. The ACK frames **1014** are transmitted by the AP **14** in respective sub-channels as part of an OFDMA transmission to the client stations **25**, in the illustrated embodiment.

FIG. **10**B is a diagram of a frame exchange **1030** between the AP **14** and a plurality of client stations **25**, according to an embodiment. The frame exchange **1030** is similar to the frame exchange **1000** of FIG. **10**A except that in the frame exchange **1030** scheduling for the second OFDMA transmission **1012** can be different from the scheduling of the first OFDMA transmission **1006**. In an embodiment, in response to receiving the OFDMA transmission **1006**, the AP **14** transmits a control frame **1038** as an OFDMA transmission to the of client stations **25**, wherein a respective control frame **1038** transmitted to a particular client station **25** combines an ACK frame to acknowledge receipt of the OFDM data unit **1004** received from the particular client station **25** and a scheduling frame that includes scheduling information for the second OFDMA transmission **1012** (e.g., scheduling information of the particular client station **25** or scheduling information the all of the client stations **25** (STA1, STA2 and STA3). In another embodiment, in response to receiving the OFDMA transmission **1006**, the AP **14** transmits a broadcast control frame (e.g., a legacy duplicate control frame) that combines an acknowledgement frame that includes acknowledgement of each of the OFDM data units **1004** and a scheduling frame that includes scheduling information for the second OFDMA transmission **1012**. In yet another embodiment, the AP **14** transmits a scheduling frame, or respective scheduling frames, to the client stations **25** as a separate transmission to the client stations **25** after expiration of a certain predetermined time interval, such as SIFS, after transmission of an acknowledgement frame, or respective acknowledgement frames, to the client stations **25**.

FIG. **10**C is a diagram of an example aggregated control frame **1050** that combines an ACK frame and a scheduling frame, according to an embodiment. In an embodiment, the control frame **1038** of FIG. **10**B corresponds to the aggregated control frame **1050**. In other embodiments, the control frame **1038** of FIG. **10**B is generated according to other suitable formats. As illustrated in FIG. **10**C, the aggregated control frame **1050** includes a first delimiter field **1054**, an ACK field **1056**, a first padding field **1058**, second delimiter field **1060**, a scheduling frame **1062**, and a second padding field **1064**, in the illustrated embodiment. As also illustrated in FIG. **10**C, each of the first delimiter field **1054** and the second delimiter field **1060** includes and end of frame (EOF) subfield **1072**, a reserved subfield **1074**, an MPDU length field **1076**, a cyclic redundancy check (CRC) subfield **1078** and a delimiter signature subfield **1080**.

FIG. **11**A is a diagram of a frame exchange **1100** between the AP **14** and a plurality of client stations **25**, according to an embodiment. In the frame exchange **1100**, a scheduling frame **1102** includes both (i) downlink channel allocation information for transmission from the AP **14** to a plurality of client station **25** (e.g., client stations **25-1**, **25-2** and **25-3**) and (ii) uplink channel allocation information for transmission from a plurality of client stations **25** e.g., client stations **25-1**, **25-2** and **25-3**) to the AP **14**. In an embodiment, the AP **14** transmits the scheduling frame **1102** during a time t1, which begins at the beginning of a TXOP, and channel allocation provided by the scheduling frame **1102** is used for communication between the AP **14** and the client stations **25** for the duration of the TXOP. In an embodiment and/or scenario, a same channel is allocated to a particular client station **25** for downlink transmission and for uplink transmission during the TXOP. In another embodiment and/or scenario, the channel allocated to a particular client station **25** for downlink transmission during the TXOP is different from the channel allocated to the particular client station **25** for uplink transmission during the TXOP.

In an embodiment, the scheduling frame **1102** includes both (i) the OFDMA downlink scheduling element **700** of FIG. **7**A and (ii) the OFDMA uplink scheduling element **750**

of FIG. 7B. In other embodiments, the scheduling frame **1102** provides downlink and uplink channel information in other suitable manners.

In an embodiment, the scheduling frame **1102** is a control frame. In an embodiment, the scheduling frame **1102** is a non-data packet (NDP) frame that omits a payload. In one embodiment in which the scheduling frame **1102** in an NDP frame, MAC layer information, e.g. MAC address of the receiving device, MAC address of the transmitting device, etc., is included in a signal field of a PHY preamble of the scheduling frame **1102**. In an embodiment and/or scenario, the uplink scheduling frame **1102** is duplicated in each smallest bandwidth portion (e.g., in each 20 MHz) of the entire bandwidth of the TXOP. In another embodiment and/or scenario, the uplink scheduling frame **1102** is a legacy control frame duplicated in every smallest bandwidth portion of the entire bandwidth of the TXOP so as to protect the TXOP from transmissions by client stations **25** that are not intended participants in the TXOP. For example, in an embodiment, if the entire bandwidth of the TXOP is 160 MHz, then the scheduling frame **1102** is duplicated in each 20 MHz portion of the 160 MHz channel, in an embodiment. Client stations **25** that are not intended participants in the TXOP determine duration of the TXOP based on a length or duration indicated by the scheduling frame **1102** and defer medium access for the determined duration, in an embodiment.

In an embodiment, the client stations **25** receive the scheduling frame **1102** in the primary channel of the WLAN **10** or in the entire bandwidth of the TXOP. Each of the client stations **25** determines, based on channel allocation information provided in the scheduling frame **1102**, a respective downlink channel and a respective uplink channel allocated to the client **25**. After transmission of the scheduling frame **1102**, during a time t**2**, the AP transmits an OFDMA downlink data unit **1104**. The OFDMA downlink data unit **1104** includes a respective OFDMA data unit **1106** directed to each of the client stations **25**. The OFDM data units **1106** are transmitted to the client stations **25** in the respective downlink channels allocated the client stations **25** as indicated in the scheduling frame **1102**. During a time t**3**, the client stations **25** transmit respective uplink OFDM data units **1108** as parts of an uplink OFDMA transmission **1110** to the AP **14**. In an embodiment, the respective uplink data units **1108** from the client stations **25** are transmitted in respective uplink channels allocated for uplink transmission by the client stations **25** as indicated by the scheduling frame **1102**. In an embodiment, each uplink data unit **1108** includes an acknowledgement indicating successful receipt of the corresponding OFDM downlink data unit **1106**. During a time t**3**, the AP **14** transmits respective acknowledgment frames **1112**, acknowledging successful receipt of the OFDM data units **1108**. In an embodiment, the respective acknowledgment frames **1112** are transmitted as parts of an OFDMA transmission to the client stations **25**, in the respective uplink channels allocated to the client stations **25**.

FIG. **11**B is a diagram of a frame exchange **1130** between the AP **14** and a plurality of client stations **25**, according to an embodiment. The frame exchange **1130** is similar to the frame exchange **1100** of FIG. **11**A except that in the frame exchange **1130** scheduling for the uplink OFDMA transmission **1110** is provided to the client stations **25** as part of the downlink OFDMA transmission **1134** to the client stations **25**. For example, respective scheduling frames **1138** are appended to the OFDM data units **1106** of the OFDMA transmission **1134**, in the illustrated embodiment. As another example, respective scheduling frames **1138** are prepended to the OFDM data units **1106** of the OFDMA transmission **1134**, in another embodiment. In some embodiments, each scheduling frames **1134** includes scheduling information for each of STA**1**, STA**2** and STA**3**. For example, each scheduling frame **1134** includes an OFDMA uplink scheduling element, such as the OFDMA uplink scheduling element **750** of FIG. **7**B, which includes a plurality of user fields **754** corresponding to the plurality of client stations **25**. In another embodiment, each scheduling frame **1134** includes scheduling information of only the client stations **25** to which the corresponding OFDM data unit **1106** is directed. For example, each scheduling frame **1134** includes an OFDMA uplink scheduling element, such as the OFDMA uplink scheduling element **750** of FIG. **7**B, which includes a single user field **754** corresponding to the one client station **25** to which the corresponding OFDM data unit **1106** is directed. Thus, for example, the scheduling frame **1138-1** includes a single user field **754** corresponding to STA **1**, the scheduling frame **1138-2** includes a single user field **754** corresponding to STA **2**, and the scheduling frame **1138-3** includes a single user field **754** corresponding to STA **3**, in an embodiment.

FIG. **11**C is a diagram of a frame exchange **1150** between the AP **14** and a plurality of client stations **25**, according to an embodiment. The frame exchange **1150** is similar to the frame exchange **1130** of FIG. **11**B, except that in the frame exchange **1150**, uplink scheduling information is provided to the client stations **25** by respective separate scheduling frames **1152** transmitted as control frames separate from the OFDM data units **1104**. The scheduling frames **1152** are generally the same as or similar to the scheduling frames **1138** of FIG. **11**C except that the scheduling frames **1152** are transmitted to the client stations **25** as separate control frames that follow transmission of the respective OFDM data units **1106** to the client stations **25**. In an embodiment, respective scheduling frames **1152** are transmitted to the client stations **25** via the downlink sub-channels allocated to the client stations **25**. In another embodiment, the scheduling frame **1152** is a legacy control frame duplicated in every smallest bandwidth portion of the entire bandwidth of the TXOP.

Referring to FIG. **11**B, the scheduling frame **1102** includes downlink channel allocation information and excludes uplink channel allocation information, in some embodiments. In some embodiments, the downlink channel allocation information is included in a signal field (e.g., the HEW-SIGA) field of a preamble of the OFDM data unit **1134**. For example, the signal field of the preamble of the OFDMA data unit **1134** includes a channel allocation field, such as the channel allocation field **550** of FIG. **5**, in some embodiments. In some such embodiment, the scheduling frame **1102** is omitted from the frame exchange **1130**, and the frame exchange **1130** begins with transmission of the downlink OFDMA data unit **1134**.

Referring to FIG. **11**C, the scheduling frame **1102** includes downlink channel allocation information and excludes uplink channel allocation information, in some embodiments. In some embodiments, the downlink channel allocation information is included in a signal field (e.g., the HEW-SIGA) field of the OFDMA data unit **1104**. For example, the signal field of the preamble of the OFDMA data unit **1104** includes a channel allocation field, such as the channel allocation field **550** of FIG. **5**, in some embodiments. In some such embodiment, the scheduling frame **1102** is omitted from the frame exchange **1150**, and the frame exchange **1150** begins with transmission of the downlink OFDMA data unit **1104**.

FIG. **12** is a diagram of a frame exchange **1200** between the AP **14** and a plurality of client stations **25**, according to an embodiment. During a time t**1**, the AP **14** transmits a scheduling frame **1202** to a plurality of client stations **25**. In an embodiment, the time t**1** begins at the beginning of a TXOP obtained by (e.g., based on a suitable channel assessment procedure, such as CSMA/CA) or scheduled for the AP **14**. In an embodiment, the scheduling frame **1202** provides OFDMA downlink scheduling information to the plurality of client stations **25**. For example, in an embodiment, the scheduling frame **1202** includes downlink channel allocation information to be used for transmission of downlink OFDMA data units during the TXOP. In an embodiment, the scheduling frame **1202** includes the OFDMA downlink scheduling element **700** of FIG. **7**A. In another embodiment, the scheduling frame **802** provides downlink channel allocation information in another suitable manner.

During a time t**2**, the AP **14** transmits an OFDMA data unit **1204** directed to the plurality of client stations **25**. The OFDMA data unit **1204** includes respective OFDM data units **1206** transmitted to each of the client stations **25** in respective sub-channels allocated to the client station **25**. During a time t**3**, the client stations **25** transmit respective control frames **1208** as parts of an OFDMA transmission **1210** to the AP **14**. In an embodiment, the client stations **25** transmit the control frames **1208** in the respective downlink sub-channels allocated to the client stations **25** indicated in the scheduling frame **1202**. The control frames **1208** include respective indications of the amount of data buffered at each client station **25** for transmission to AP **14**. In an embodiment, the control frames **1208** additionally include respective acknowledgements, acknowledging successful receipt of the respective OFDM data units **1206**.

In an embodiment, the scheduling frame **1202** indicates to the client station **25** that the client stations **25** should provide indications of the amount of buffered data at the client stations **25** and/or indications of requested medium time for an uplink transmission by the client station **25**. In another embodiment, such signaling is included in the OFDMA data unit **1204**, such as in a signal field of a preamble of each of the OFDM data units **1206**. In yet another embodiment, a client station **25** is configured to transmit a control frame, which includes an indication of amount of buffered data and/or requested medium time, automatically in response to receiving the OFDM data unit **1206**.

The AP **14** receives the respective indications of the amount of buffered data at the client stations **25** and/or indications of requested medium time for an uplink transmission by the client stations **25**, and allocates uplink sub-channels to the client stations **25** based on the indications of the amount of buffered data at the client stations **25** and/or indications of requested medium time for an uplink transmission by the client stations **25**, in an embodiment. Additionally or alternatively, in an embodiment, the AP **14** determines, based on the indications of the amount of buffered data at the client stations **25** and/or indications of requested medium time for an uplink transmission by the client stations **25**, a suitable length for an uplink OFDMA transmission by the client stations **25** (e.g., uplink PPDU length). For example, the AP **14** determines a suitable length to accommodate the client station **25** that has the greatest amount of buffered data to be transmitted to the AP **14** or the greatest requested medium time for an uplink transmission by the client station **25** to the AP **14**. In an embodiment, the AP **14** does not allocate uplink channels based on the indications of the amount of buffered data, and/or indications of requested medium time, received from the client stations **25**. Rather, the downlink channel allocation provided by the scheduling frame **1202** is maintained for uplink OFDMA transmission, in an embodiment.

During a time t**4**, the AP **14** transmits a second scheduling frame **1212** that includes uplink channel allocation information for OFDMA uplink transmission by the client stations **25**. In an embodiment, respective scheduling frames **1212** are transmitted to the client stations **25** via the downlink sub-channels allocated to the client stations **25**. In another embodiment, the scheduling frame **1212** is a legacy control frame duplicated in every smallest bandwidth portion of the entire bandwidth of the TXOP. In an embodiment, the scheduling frame **1212** includes uplink channel information that indicates uplink sub-channels allocated to the client stations **25** based on the indications of the amount of buffered data, and/or indications of requested medium time, received from the client stations **25**. The scheduling frame **1212** also includes an indication of the length of the OFDMA transmission (e.g., uplink PPDU length) that the AP **14** determined based on the indications of the amount of buffered data, and/or indications of requested medium time, received from the client stations **25**, in an embodiment. In an embodiment, the scheduling frame **1212** includes the OFDMA uplink scheduling element **750** of FIG. **7**B. In another embodiment, the scheduling frame **1212** indicates uplink channel allocation and/or uplink data unit length in another suitable manner.

In an embodiment, each client station **25** determines, based on the scheduling frame **1212**, the sub-channel allocated to the client station **25** and/or the length of the uplink transmission from the client stations **25**. During a time t**5**, the client stations **25** transmit respective uplink OFDM data units **1216** as parts of an OFDMA transmission **1214** to the AP **14**. In an embodiment, the respective OFDM units **1214** are transmitted via the respective uplink channels indicated in the scheduling frame **1212**. Additionally or alternatively, in an embodiment, each of the OFDM data units **1214** is of the length indicated in the scheduling frame **1212**. During a time t**6**, the AP **14** transmits respective acknowledgement frames **1218** that acknowledge successful receipt of the OFDM data units **1216**. In an embodiment, the respective acknowledgment frames **1218** are transmitted, as parts of an OFDMA transmission to the client stations **25**, in the respective uplink channels allocated to the client stations **25**. In another embodiment, the AP **14** transmits a broadcast acknowledgement frame that includes respective acknowledgements for the client stations **25** (STA**1**, STA**3** and STA**3**).

FIG. **13**A is a diagram of a frame exchange **1300** between the AP **14** and a plurality of client stations **25**, according to an embodiment. The AP **14** transmits a first scheduling frame **1302** to a plurality of client stations **25** (e.g., the client stations **25-1**, **25-2**, **25-3**). In an embodiment, the AP **14** transmits the scheduling frame **1302** at the beginning of a TXOP. In an embodiment, the scheduling frame **1302** includes uplink channel allocation information for the plurality of client stations **25**. In an embodiment, the scheduling frame **1302** includes the uplink channel scheduling element **705** of FIG. **7**B. In another embodiment, the scheduling frame **1302** indicates uplink channel allocation to the client stations **25** in another suitable manner. In an embodiment, the scheduling frame **1302** also indicates to the client stations **25** that the client stations **25** should provide indications of the amount of buffered data at the client stations **25** and/or indications of requested medium time for an uplink transmission by the client stations **25**. For example, the scheduling frame **1302** includes an uplink data unit

length field (e.g., the UL PPDU length field **762** of FIG. **7**B) set to a length corresponding to a length of a control frame defined for transmission of indication of amount of buffered data and/or indication of requested medium time, such as a QoS Null frame or another suitable control frame. Setting the uplink data unit length field to the length corresponding to the length of the control frame for transmission of buffered data indication and/or requested medium time indication indicates to the client stations **25** that the client stations **25** should transmit the control frame, in an embodiment. In another embodiment, the scheduling frame **1302** includes an indication field, such as a poll field (e.g., a 1-bit poll field, such as the UL Buffer Poll field **768** of FIG. **7**B) set to indicate to the client statins **25** that the client stations **25** should provide the buffered data indications and/or requested medium time indications to the AP **14**.

In an embodiment, in response to receiving the scheduling frame **1302**, the client stations **25** transmit respective control frames **1304** to the AP **14**. The control frames **1304** are transmitted in the respective uplink channels indicated in the scheduling frame **1302**, as parts of an OFDMA transmission **1306** from the client stations **25** to the AP **14**, in an embodiment. The control frames **1304** include respective indications of amount of buffered data at the respective client stations **25** and/or indications of requested medium time by the respective client stations **25**, in an embodiment.

FIG. **13**B is a diagram of an example control field **1350** included in a control frame transmitted by a client station **25** to indicate amount of buffered data at the client station **25** and/or requested medium time by the client station **25**. The control field **1350** is included in each of the control frames **1304** of FIG. **13**A, in an embodiment. The control field **1350** includes a plurality of sub-fields **1352**. In the illustrated embodiment, the sub-fields **1352** include a frame control sub-field **1352-1**, a duration/id sub-field **1352-2**, a first address sub-field **1352-3**, a second address sub-field **1352-4**, and third address sub-field **1352-5**, a sequence control sub-field **1352-6**, an optional fourth address sub-field **1352-7**, an optional QoS sub-field **1352-8**, an optional HT control sub-field **1352-9**, an optional resource indication **1352-10**, a variable length frame body sub-field **1352-11**, and a frame sequence check (FCS) sub-field **1352-12**. The number indicated in FIG. **13**B under each of the sub-fields **1352** indicates the number of octets of bits in the corresponding sub-field **1352**, according to an example embodiment. In other embodiments, one or more of the sub-fields **1352** include suitable numbers of bits other than the number of bits indicated in FIG. **13**B. Further, in another embodiment, a suitable control frames other than the example control frame **1350** is transmitted by a client station **25** to indicate amount of buffered data at the client station **25** and/or requested medium time by the client station **25**.

In an embodiment, the control field **1350** includes an indication of whether the resource indication sub-field **1352-10** is included in the control field **1350**. For example, the frame control sub-field **1352-2** includes an indication of whether the resource indication sub-field **1352-10** is included in the control field **1350**, in an embodiment. The resource indication sub-field **1352-10**, when present in the control field **1350**, indicates one or more traffic class identifiers (TID), and the amount of buffered data and/or requested medium time for each of the one or more TIDs, in an embodiment. Additionally or alternatively, the resource indication sub-field **1352-10**, when present in the control field **1350**, indicates the total amount of buffered data and/or the total requested medium time, in an embodiment. The resource indication sub-field **1352-10** allows a client station **25** to indicate amount of buffered data greater than 64768 octets and/or amount of buffered data less than 256 octets, in at least some embodiments. Referring back to FIG. **13**A, the AP **14** receives the respective indications of the amount of buffered data from the client stations **25**, and allocates uplink channels to the client stations **25** based on the indications of the amount of buffered data at the client stations **25** and/or indications of requested medium time by the client stations **25**, in an embodiment. In an embodiment, the AP determines, based on the indications of the amount of buffered data at the client stations **25** and/or indications of requested medium time by the client stations **25**, a suitable length for an uplink OFDMA transmission from the client stations **25** (e.g., uplink PPDU length). For example, the AP determines the suitable length to accommodate the client station **25** that has the greatest amount of buffered data to be transmitted to the AP **14**, in an embodiment. In another embodiment, the AP does not allocate uplink channels based on the indications of the amount of buffered data received from the client stations **25**. Rather, the uplink channel allocation provided in the scheduling frame **1302** is maintained for the duration of the TXOP transmission, in an embodiment.

During a time t**3**, the AP **14** transmits a second scheduling frame **1308** that includes uplink channel information for uplink transmission from the client stations **25** to the AP **14**. In an embodiment, the scheduling frame **1308** includes uplink channel allocation information that indicates uplink sub-channels allocated to the client stations based on the indications of the amount of buffered data received from the client stations **25**. The scheduling frame **1308** also includes an indication of the length of the OFDMA transmission (e.g., uplink PPDU length) determined based on the indications of the amount of buffered data received from the client stations **25**, in an embodiment. In an embodiment, the scheduling frame **1308** includes other information related to uplink transmission by the client stations **25**, such as an MCS, or respective MCSs, to be used for the uplink transmissions, transmission poser level, or respective transmission power levels, to be used for the uplink transmissions, etc. In an embodiment, the scheduling frame **1308** includes the OFDMA uplink scheduling element **750** of FIG. **7**B. In another embodiment, the scheduling frame **1308** provides channel allocation information and/or OFDMA uplink data unit length indication in another suitable manner.

In an embodiment, each client station **25** determines, based on the scheduling frame **1308**, the respective sub-channels allocated to the client station **25** and/or the indicated length of an uplink OFDM data unit that the client station **25** can transmit to the AP **14**. During a time t**4**, the client stations **25** transmit respective uplink OFDM data units **1312** as parts of an OFDMA transmission **1310** to the AP **14**. In an embodiment, the respective OFDM units **1312** are transmitted via the respective sub-channels allocated to the client stations **25** according to indications in the scheduling frame **1308**. In an embodiment, each of the OFDM data units **1312** is of the OFDM data unit length indicated in the scheduling frame **1308**. In an embodiment, the AP **14** receives the OFDMA transmission **1310** from the client stations **25** and obtains the data transmitted by the client stations **25** in respective OFDM sub-channels allocated to the client stations **25**. During a time t**5**, the AP **14** transmits respective acknowledgement frames **1314** that acknowledge successful receipt of the OFDM data units **1310**. In an embodiment, the respective acknowledgment frames **1314**

are transmitted, as parts of an OFDMA transmission to the client stations **25**, in the respective uplink channels allocated to the client stations **25**.

In some embodiments and/or scenarios, the AP **14** allocates a particular channel for downlink transmission to multiple client stations **25** as part of an OFDMA transmission to a plurality of client stations **25**. In this embodiment, the AP **14** transmits an OFDMA data unit that includes, in a sub-block corresponding to the particular sub-channel allocated to multiple client stations **25**, respective OFDM data units directed to each of the multiple client stations **25**. In an embodiment, transmission of multiple OFDM data units in a single channel allocated to multiple client stations **25** is multiplexed in time among the multiple client stations **25**. For example, in an embodiment, a sub-channel X is allocated to a first client station **25** and a second client station **25**. In an embodiment, data corresponding to the first client station is modulated onto a first subset of OFDM sub-carriers corresponding to channel X, and data corresponding to the second client station **25** is modulated onto a second subset OFDM sub-carriers corresponding to the sub-channel X, wherein the second subset of OFDM sub-carriers follows the first subset of OFDM sub-carriers in time domain. Accordingly, in this embodiment, an OFDM data unit directed to the first client station is transmitted in the sub-channel X, as part of an OFDMA transmission to a plurality of client stations, before transmission of an OFDM data unit directed to the second client station in the same sub-channel X as part of the OFDMA transmission to the plurality of client stations.

Continuing with the same example, in an embodiment, to prevent an acknowledgement frame from the first client station to interfere with transmission of the OFDM data unit to the second client station, OFDM data unit directed the first client station includes an indication that the first client station should not immediately acknowledge receipt of the data unit. For example, a PHY preamble or a MAC header of the OFDM data unit directed to the first client station includes an ACK policy field set to indicate that an immediate acknowledgement of the data unit is not required, in an embodiment. On the other hand, the OFDM data unit directed to the second client station indicates that an immediate acknowledgement is required, in an embodiment. Accordingly, the second client station transmits an acknowledgement frame after successfully receiving the OFDM data unit directed to the second client station, in an embodiment.

Similarly, in an embodiment, the AP allocates a particular sub-channel for uplink transmission by multiple client stations as part of an OFDMA transmission from a plurality of client stations to the AP, in an embodiment. The multiple client stations transmit respective OFDM data units, via the particular channel, to the AP **14** as part of the OFDMA transmission from a plurality of client stations **25** to the AP **14**, in this embodiment. Similar to transmission of multiple OFDM downlink data units in a single sub-channel allocated to multiple client stations, transmission of the multiple OFDM uplink data units in a single channel is multiplexed in time among the multiple client stations, in an embodiment. In an embodiment, when a first OFDM data unit and a second OFDM data unit are transmitted from respective client stations in a same sub-channel as part of an OFDMA transmission to the AP, wherein the first OFDM data unit is transmitted in the sub-channel before transmission of the second OFDM data unit is the sub-channel, the AP does not immediately acknowledge receipt of the first OFDM data unit so as not to interfere with transmission of the second OFDM data unit.

FIG. **14**A is a diagram of an example frame exchange **1400** between the AP **14** and a plurality of client stations **25**, according to an embodiment. During a time t**1**, the AP **14** transmits a scheduling frame **1404** to a plurality of client stations **25**. The scheduling frame **1404** includes downlink channel allocation information for the plurality of client stations **25**. The scheduling frame **1404** indicates that a first 20 MHz sub-channel is allocated to a first client stations **25** (STA**1**), a first portion of a second 20 MHz sub-channel is allocated to a second client stations **25** (STA**2**), a second portion of the second 20 MHZ sub-channel is allocated to a fourth client station **25** (STA**4**), and a 40 MHz sub-channel that includes a third 20 MHZ sub-channel and fourth 20 MHz sub-channel is allocated to a third client station **25** (STA**3**). In an embodiment, the scheduling frame **1402** includes the OFDMA downlink scheduling element **700** of FIG. **7**A. In an embodiment, the respective channel subfields corresponding to the AID of STA **2** and AID of STA **4** are set to indicate that the second 20 MHz channel is allocated to each of STA**1** and STA**2**.

During a time t**2** , the AP **14** transmits OFDM data units **1406** as part of an OFDMA transmission **1404**. In an embodiment, a preamble or a header of the OFDM data unit **1406-2**, transmitted in the first portion of the second 20 MHz sub-channel includes an indication that an immediate acknowledgement is not required for the OFDM data unit **1406-2**. For example, an ACK policy field in the PHY preamble or the MAC header of the OFDM data unit **1406-2** indicates that an immediate acknowledgement is not required. On the other hand, a PHY preamble or a MAC header of the OFDM data unit **1406-3**, transmitted in the second portion of the second 20 MHz sub-channel includes an indication that an immediate acknowledgement is required for the OFDM data unit **1406-3**. For example, an ACK policy field in the PHY preamble or the MAC header of the OFDM data unit **1406-3** indicates that an immediate acknowledgement is required.

During a time t**3**, client stations STA**1**, STA**3** and STA**4** transmit respective acknowledgement (ACK) frame **1408** to the AP **14** as part of an OFDMA transmission to the AP **14**, in an embodiment. In an embodiment, ACK frames **1408** are transmitted in the respective sub-channels allocated to the client stations STA**1**, STA**3** and STA**4** indicated in the scheduling frame **1402**. Client station STA**2** does not transmit an ACK frame immediately (e.g., after SIFS) after reception of the OFDM data unit **1406-2**, according to the ACK policy indicated in the data OFDM data unit **1406-2**, so as not to interfere with transmission of the OFDM data unit **1406-3**, in an embodiment.

FIG. **14**B is a diagram of an example frame exchange **1450** between the AP **14** and a plurality of client stations **25**, according to an embodiment. During a time t**1**, the AP **14** transmits a scheduling frame **1452** to a plurality of client stations **25**. The scheduling frame **1452** includes uplink channel allocation information for the plurality of client stations **25**. The scheduling frame **1452** indicates that a first portion of a first 20 MHz sub-channel is allocated to a first client stations **25** (STA**1**), a first portion of a second 20 MHz sub-channel is allocated to a second client stations **25** (STA**2**), a 40 MHZ sub-channel that includes a second portion of the first 20 MHZ sub-channel and a second portion of the second 20 MHz sub-channel is allocated to a fourth client station **25** (STA**4**), and a 40 MHz sub-channel that includes a third 20 MHz-sub-channel and a fourth 20 MHz sub-channel is allocated to a third client station **25** (STA**3**). In an embodiment, the scheduling frame **1452** includes the OFDMA uplink scheduling element **700** of FIG.

7A. In an embodiment, the respective channel subfields corresponding to the AID of STA **1**, AID of STA**2**, and AID of STA **4** are set to indicate portions of the first 20 MHz sub-channel and portions of the second 20 MHz sub-channel are allocated to each of STA**1**, STA**2** and STA**4**.

During a time t**2**, the client stations **25** transmit respective OFDM data unit **1456** to the AP **14**, as part of an uplink OFDM data unit **1454** to the AP **14**, using channel allocation indicated in the scheduling frame **1452**. In an embodiment, each the data units **1456-1** and **1456-2** includes an indication (e.g., ACK policy indication) in a preamble or a header of the data unit that an immediate acknowledgement is not required for the data unit. During a time t**3**, the AP **14** transits respective ACK frames **1458** to acknowledge successful receipt of the data units **1456-3** and **1456-4**. In an embodiment, the respective ACK frames **1458** are transmitted in the respective sub-channels allocated to the client stations STA**3** and STA**4** indicated in the scheduling frame **1452**.

In some embodiment, the AP **14** is configured to obtain information regarding uplink traffic characteristics from a plurality of client stations **25**, and to schedule uplink OFDMA transmissions from the client stations **25** based on the uplink traffic characteristics obtained from the client stations **25**. For example, in an embodiment, each client station **25** of the plurality of client stations **25** transmits a suitable control frame that indicates uplink traffic characteristics for the client station **25** to the AP **14**. In another embodiment, the AP **14** obtains information regarding uplink traffic characteristics from a plurality of client stations **25** in another suitable manner. In various embodiments, uplink traffic characteristics that the AP **14** obtains from each client statin **25** includes one or more of (i) a service interval proposed by the client station **25**, (ii) data rate proposed by the client station **25** for each access category (AC) of traffic at the client station **25**, (iii) proposed time or amount of burst of traffic that the client station **25** can transmit during a service interval, etc.

In an embodiment, the AP **14** schedules uplink OFDMA transmissions by the client stations **25** based on the uplink traffic characteristics obtained from the client stations **25**. For example, the AP **14** forms one or more OFDMA groups of client stations **25** by grouping client stations **25** having similar uplink traffic characteristics into an OFDMA group. In an embodiment, the AP **14** determines a suitable duration and/or a suitable time interval for communications between the AP and the client stations **25** of each of the one or more OFDMA groups of client stations **25**. In an embodiment, the AP **14** signals to the client stations **25** the determined uplink OFDMA parameters for the client stations **25**. For example, the AP **14** transits one or more suitable control frames to the client stations **25** to signal the determined uplink OFDMA parameters to the client stations **25**. The determined uplink OFDMA parameters that the AP **14** provides to the client stations **25** include, for example, indications of and OFDMA group (e.g. group number) to which each client station **25** belongs, start time of a service period for the OFDMA group, duration of a service period for the OFDMA group, service period interval for the OFDMA group, etc.

In another embodiment, the AP **14** considers downlink traffic characteristics for client stations **25**, in addition to or instead of uplink traffic characteristics of the client stations **25**, when forming OFDMA groups of client stations **25** and/or scheduling OFDMA communications with the client stations **25**. For example, the AP **14** forms and OFDMA group of client stations **25** having similar downlink traffic characteristics and similar uplink traffic characteristics, in an embodiment. The AP **14** then defines a scheduling period and a scheduling interval for the OFDMA group, wherein the scheduling period includes both downlink OFDMA transmissions to the client stations **25** in the OFDMA group and uplink OFDMA transmissions from the client stations **25** in the OFDMA group, in an embodiment. In yet another embodiment, the AP **14** defines a scheduling period and a scheduling interval for a downlink OFDMA group, wherein the scheduling period includes only downlink transmissions to the client stations **25** in the OFDMA group.

FIG. **15** is a diagram illustrating example uplink OFDMA parameters **1500** for an OFDMA group of client stations **25**, and communications between the AP **14** and client stations **25** of the OFDMA group that occur during time periods defined by the OFDMA parameters **1500**, according to an embodiment. The example uplink OFDMA parameters **1500** in FIG. **15** include a start time parameter **1502** that indicates a start of communications between the AP **14** and the client stations **25** of the OFDMA group, a service period **1504** that defines a time duration of communications between the AP **14** and the client stations **25** of the OFDMA group, and a scheduling interval **1506** that defines an interval between two consecutive service periods for communications between the AP **14** and the client stations **25** of the OFDMA group. In the embodiment of FIG. **15**, the service period **1504** includes a frame exchange between the AP **14** and the client stations **25** in the OFDMA group, in which an uplink OFDMA data unit is transmitted from the client stations **25** in the OFDMA group to the AP **14**. For example, the service period **1504** includes the frame exchange **900** of FIG. **9**, in an embodiment. As another example, in another embodiment, the service period **1504** includes the frame exchange **1000** of FIG. **10**A or the frame exchange **1030** of FIG. **10**B. As yet another example, the service period **1504** includes the frame exchange **1300** of FIG. **13**A. As yet another example, the service period **1504** includes the frame exchange **1400** of FIG. **14**B.

In another embodiment, the service period **1504** includes both uplink and downlink data transmissions between the AP **14** and the client stations **25** in the OFDMA group. For example, the service period **1504** includes the frame exchange **1100** of FIG. **11**A, the frame exchange **1130** of FIG. **11**B, or the frame exchange **1150** of FIG. **11**C, in some embodiments. As another example, in another embodiment, the service period **1504** includes the frame exchange **1200** of FIG. **12**. In yet another embodiment, the service period **1504** is a downlink OFDMA service period that includes transmission of data in only the downlink direction from the AP **14** to client stations **25**. For example, the service period **1504** includes the frame exchange **600** of FIG. **6** or the frame exchange **800** of FIG. **8**, in some embodiments. The service period **1504** includes other suitable frame exchanges between the AP **14** and the client stations **25** of the OFDMA group for which the service period **1504** is defined by the AP **14**, in other embodiments.

FIG. **16** is a diagram of an example frame exchange **1600** between the AP **14** and a plurality of client stations **25**, according to an embodiment. In the embodiment of FIG. **16**, during a time t**1**, the AP transmits a first scheduling frame **1602** to a plurality of client stations **25**. The first scheduling frame **1602** identifies the plurality of the client stations **25** and provides uplink channel allocation information for the plurality of client stations **25**. In particular, the first scheduling frame **1602** identifies three client stations **25** (STA**1**, STA**3** and STA**3**), and provides channel allocation for the three client stations **25**, in the illustrated embodiment. During a time t**2**, the AP **14** receives respective OFDM data units **1606** as parts of an OFDMA transmission from some but not

all client stations **25** of the plurality the client stations **25**. In particular, the AP **14** receives respective OFDM data units **1606** from STA**2** and STA**3**, but does not receive an OFDM data nit from STA**1** , in the illustrated embodiment.

During a time t**3**, the AP **14** transmits respective ACK frames **1610** to the client stations from which the AP **14** received OFDM data units **1602**. During a time t**4** , the AP **14** transmits a second scheduling frame **1610** that identifies the client stations **25** from which the AP **14** received OFDM data units **1606** during the time interval t**2** , and does not identify client stations **25** from which the AP **14** did not receive OFDM data units **1606** during the time t**2**. The second scheduling frame **1610** is transmitted in each of the sub-channels except for the sub-channel previously allocated to the client stations **25** from which the AP **14** did not receive an OFDM data unit during the time t**2**, in an embodiment. During a time t**5**, receives respective OFDM data units **1612** from the client stations **25** indicated in the scheduling frame **1610**. During a time t**6**, the AP **14** transmits respective ACK frames **1616** to the client **25** from which the AP **14** received OFDM data units **1614** during the time t**5**, in an embodiment.

FIG. **17** is a diagram of an example frame exchange **1700** between the AP **14** and a plurality of client stations **25**, according to an embodiment. During a time t**1**, the AP transmits a scheduling frame **1702** to a plurality of client stations **25**. The scheduling frame **1702** provides uplink channel allocation information to the plurality of client stations **25**. During a time t**2**, the AP **14** receives an OFDMA transmission that includes an OFDM data unit **1806** from one of the client stations **25** of the plurality of client stations **25**. During a time t**3**, the AP **14** transmits an ACK frame **1708** to the one client station **25** from which the AP **14** received the OFDM data unit **1706**.

Because the AP **14** receives an OFDM data unit from only one of the client stations **25**, the AP **14** determines only the sub-channel allocated to the one of the client stations **25** is currently available for transmission by the one of the client stations **25**, and that the sub-channels allocated to the other client stations **25** are currently not available for transmission by the other client stations **25**, in an embodiment. The AP **14** decides to terminate the TXOP, in an embodiment. During a time t**4**, to signal termination of the TXOP, the AP **14** transmits a contention free end (CF-end) frame **1710** to the one client station **25** from which the AP **14** received the OFDM data unit **1706** to indicate termination of the contention free TXOP to the one client station **25**. During a time t**5**, the AP **14** conducts a CSMA/CA procedure with a new contention window backoff, in an embodiment, in an embodiment.

FIG. **18**A is a diagram of an example frame exchange **1800** between the AP **14** and a plurality of client stations **25**, according to an embodiment. During a time t**1**, the AP transmits a scheduling frame **1802** to a plurality of client stations **25**. The scheduling frame **1802** provides downlink channel allocation information to the plurality of client stations **25**. During a time t**2**, the AP **14** transmits an OFDMA data unit **1804** that includes respective OFDM data units **1806** directed to the client stations **25** of the plurality of client stations **25**. The AP **14** does not receive any ACK frames from the client stations **25** in a time period during which ACK frames are expected to be received from the client stations **25**, in the illustrated embodiment. Because the AP **14** does not receive any ACK frames, the AP **14** terminates the contention free TXOP. During a time t**3**, the AP **14** conducts a CSMA/CA procedure with a new contention window backoff, in an embodiment, in an embodiment.

FIG. **18**B is a diagram of an example frame exchange **1850** between the AP **14** and a plurality of client stations **25**, according to an embodiment. The frame exchange **1850** is similar to the frame exchange **1800** of FIG. **8**A, except that in the frame exchange **1850**, the AP **14** transmits a CF-Free frame **1858** during a time t**3**, prior to conducting a CSMA/CA procedure with a new contention window backoff during a time, in the illustrated embodiment.

FIG. **19**A is a diagram of an example frame exchange **1900** between the AP **14** and a plurality of client stations **25**, according to an embodiment. During a time t**1**, the AP transmits a scheduling frame **1902** to a plurality of client stations **25**. The scheduling frame **1902** provides uplink channel allocation information to the plurality of client stations **25**. However, the AP **14** does not receive any OFDM data unit from the client stations **25** in the time during which the OFDM data units are expected to be received from the client stations **25**. Because the AP **14** does not receive any OFDM data units from the client stations **25**, the AP **14** terminates the contention free TXOP. During a time t**2**, the AP **14** conducts a CSMA/CA procedure with a new contention window backoff, in an embodiment, in an embodiment.

FIG. **19**B is a diagram of an example frame exchange **1950** between the AP **14** and a plurality of client stations **25**, according to an embodiment. The frame exchange **1950** is similar to the frame exchange **1900** of FIG. **19**A, except that in the frame exchange **1950**, the AP **14** transmits a CF-End frame **1954** during a time t**2**, prior to conducting a CSMA/CA procedure with a new contention window backoff during a time t**3**, in the illustrated embodiment.

In various frame changes described above with respect to FIG. **6** and FIGS. **8-19**, the time t**1** generally at the beginning of a TXOP obtained by (e.g., based on a suitable channel assessment procedure, such as CSMA/CA) or scheduled by the AP **14**, in at least some embodiments. Subsequent times, such as time t**2**, time t**3**, time t**4**, etc. during which certain frames or data units are transmitted the AP **14** or the client stations **25**, generally begin upon expiration of a predetermined time interval, such as a time interval corresponding to a short inter-frame space (SIFS), after completion of transmission or reception of the previous frame or data unit transmitted in the frame exchange, in at least some embodiments. Accordingly, consecutive frames and data units in the described frame exchanges are generally separated, in time, by certain predetermined time intervals, in such embodiments.

Further, in some embodiments, a predetermined time period that is greater than SIFS is defined, and at least some of the consecutive frames and data units in the described frame exchanges are separated by the predetermined interval greater than SIFs. For example, a predetermined time period that is greater than SIFS and less than PIFS is defined. For example, the greater predetermined time interval may provide sufficient time for the client stations **25** to decode a scheduling frame that includes uplink scheduling information, and to prepare for uplink transmission based on the uplink scheduling information provided by the scheduling frame **902**, in at least some embodiments. Additionally or alternatively, certain scheduling frames, such as scheduling frames that include uplink scheduling information, include padding at the end of the scheduling frames to provide sufficient time for the client stations to prepare for uplink transmission based on the uplink scheduling information provided by the scheduling frame, in some embodiments. For example, a MAC header included in a scheduling frame indicates a length of a valid payload, wherein the one or more padding bits follow the valid payload, in an embodi-

ment. Further, a signal field of a PHY preamble of the scheduling frame includes an indication of the entire length of the scheduling frame, which includes the one or more padding bits at the end of the scheduling frame, in an embodiment.

In various embodiments described above with respect to FIGS. **8-19**, transmission of various downlink OFDMA data units is triggered by including scheduling information (e.g., downlink channel allocation) for the downlink OFDMA transmission in a signal field (e.g., in the HEW-SIGA field) of the OFDMA transmission rather by transmission of a scheduling frame, which includes such scheduling information, prior to the downlink OFDMA transmission. For example, various downlink OFDMA data units (e.g., the OFDMA data unit **1104** of FIGS. **4**A and **4**C, the OFDMA data unit **1134** of FIG. **4**B, the OFDMA data unit **1204** of FIG. **12**, the OFDMA data unit **1454** of FIG. **14**B, etc.) include downlink scheduling information in a signal field of the OFDMA data unit, the same as or similar to the OFDMA data unit **602** of FIG. **6**. In at least some such embodiments, transmission of a scheduling frame that includes downlink scheduling information prior to transmission of the downlink OFDMA data unit is omitted from the corresponding frame exchange.

In at least some embodiment, TXOPs scheduled or obtained by the AP **14** for downlink and/or uplink OFDMA transmissions between the AP **14** and a plurality of client stations **25** are protected from transmissions by other client stations **25**. In some embodiments, the AP **14** broadcasts OFDMA parameter to client stations **25**, for example by including OFDMA parameters, defined for one or more OFDMA groups, in a broadcast frame transmitted by the AP **14**, such as a beacon frame or another broadcast frame transmitted by the AP **14**. For example, the broadcast frame, such, as the beacon frame, indicates service information corresponding to each of one or more OFDMA groups. In an embodiment, to indicate service information for a particular OFDMA group, the broadcast frame includes one or more of (i) an indication of an offset of a start time of a service period for the OFDMA group with respect to the start or end of the broadcast frame, (ii) an indication of a length of the service period for the OFDMA group, (iii) an indication of a scheduling interval between two consecutive service periods for the OFDMA group, etc. The broadcast frame serves to protect a service period scheduled for a particular OFDMA group from transmissions by other client stations that are not members of the OFDMA group, in an embodiment. For example, the service periods indicated by the broadcast frame for particular OFDMA groups are treated by the client stations **25** as restricted access windows (RAW) intended for access by only the client stations **25** that are members of the corresponding OFDMA groups.

In another embodiment, a request to send (RTS) frame and/or a clear to send (CTS) frame is used at the beginning of a service period reserved for a particular OFDMA group or immediately before the beginning of the scheduled period to protect the duration of the service period from transmissions by client stations **25** that do not belong to the OFDMA group. For example, in an embodiment, the AP **14** transmits a request to send frame to each of one or more of the client stations **25** that belong to the OFDMA group, signaling to the client stations **25** that are members of the OFDMA group that the client stations **25** are allowed to transmit and/or receive in the upcoming service period, while indicating to other client stations **25** that are not members of the OFDMA group that the client stations **25** are not allowed to transmit frames in the upcoming service period. In response to receiving the RTS frame from the AP **14**, each of the one or more client stations **25** transmits a CTS frame to the AP **14**. In an embodiment, the RTS/CTS frames are transmitted in each sub-channel intended to be used during the service period scheduled for the OFDMA group. In an embodiment, the RTS/CTS indicate a length or duration of the service period scheduled for the OFDMA group. In an embodiment, client stations **25** that receive an RTS and/or a CTS frame and that are not members of the OFDMA group being protected by the RTS and/or the CTS frame refrain from accessing the medium for the duration determined based on the RTS and/or the CTS frame. For example, client stations **25** that receive an RTS and/or a CTS frame set network access allocation (NAV) timers based on NAV duration indication included in the RTS and/or the CTS frame. Client stations **25** that are not members of the OFDMA group being protected by the RTS and/or the CTS frame refrain from accessing the medium until expirations of their NAV timers, in an embodiment. The client stations **25** that belong to the OFDMA group being protected by the RTS and/or the CTS frame, on the other hand, ignore their NAV timers and instead receive and/or transit according to scheduling for the OFDMA group, in an embodiment.

In some embodiment, APs of neighboring basic service sets (BSSs) jointly schedule OFDMA transmissions within the BSSs such that the scheduled OFDMA transmissions in one BSS do not overlap with scheduled OFDMA transmissions in one or more neighboring BSSs. For example, the AP **14** signals to APs of one or more neighboring BSSs the time of a scheduled OFDMA TXOP scheduled by the AP **14**.

In some embodiment, the AP **14** and one or more of the client stations **25** are configured to support sub-channel selective transmissions (SST). In an embodiment, the AP **14** signals its support for SST in a control frame or a management frame, such as a beacon frame. In an embodiment, each of the one or more client stations **25** that support SST signals its support for SST in a control frame or a management frame, such as an association frame. In some such embodiments, the AP **14** indicates, to the client stations **25** that support SST, respective sub-channels that will be used for downlink transmissions to the client stations **25** and/or respective sub-channels to be used for uplink transmissions by the client stations. The respective sub-channels that will be used for downlink transmissions to the client stations **25** and/or respective sub-channels to be used for uplink transmissions by the client stations are indicated for use during certain periods, such as a time period between two consecutive control or management frames, such as beacon frames, that announce respective sub-channel allocation. In such embodiment, the AP **14** and the client stations **25** can transmit and receive OFDMA data units using the channels sub-allocated to the client stations by SST sub-channel indications. In at least some such embodiments, the AP **14** need not transmit a scheduling frame to indicate sub-channels for downlink and/or for uplink OFDMA transmissions. In some embodiment, the AP **14** transmits scheduling frames to a plurality of client stations **25** in respective SST sub-channels allocated to the client stations **25**, wherein different scheduling frames transmitted to the different client stations **25** include different, user-specific, information for the different client stations **25**, in some embodiments.

FIG. **20**A is a flow diagram of an example method **2000** for simultaneously communicating with multiple communication devices in a WLAN, according to an embodiment. In an embodiment, the method **2000** is implemented by an AP in the WLAN, according to an embodiment. With reference to FIG. **1**, the method **2000** is implemented by the host

processor **15** of the AP **14**. For example, the method **2000** is implemented by the MAC processing unit **18** and/or by the PHY processing unit **20** of the host processor **15**, in an embodiment. In other embodiments, the method **2000** is implemented by other components of the AP **14**, or is implemented by a suitable communication device other than the AP **14**.

At block **2002**, respective sub-channels of an OFDM channel are allocated to two or more client devices for uplink OFDMA transmission from the two or more client devices. At block **2004**, indications of the respective two or more sub-channels allocated to the two or more client devices are provided to the two or more client devices. For example, a scheduling frame that includes indications of the respective sub-channels is transmitted to the two or more client devices, in an embodiment. In other embodiments, indications of the respective sub-channels are provided to the two or more client devices in other suitable manners.

At block **2004**, an OFDMA data unit is received. In an embodiment, the OFDMA data unit includes at least a first OFDM data unit from a first client device of the two or more client devices a second OFDM data unit from a second client device of the two or more client devices. In an embodiment, the first OFDM data unit is transmitted by the first client device at least substantially simultaneously with transmission of the second OFDM data unit by the second client device. In an embodiment, the first OFDM data unit is transmitted by the first client device in the sub-channel allocated at block **2002** to the first client device and the second OFDM data unit is transmitted by the second client device in the sub-channel allocated at block **2002** to the second client device.

FIG. **20**B is a flow diagram of an example method **2500** for simultaneously communicating with multiple communication devices in a WLAN, according to another embodiment. In an embodiment, the method **2500** is implemented by an AP in the WLAN, according to an embodiment. With reference to FIG. **1**, the method **2500** is implemented by the host processor **15** of the AP **14**. For example, the method **2500** is implemented by the MAC processing unit **18** and/or by the PHY processing unit **20** of the host processor **15**, in an embodiment. In other embodiments, the method **2500** is implemented by other components of the AP **14**, or is implemented by a suitable communication device other than the AP **14**.

At block **2502**, respective sub-channels of an OFDM channel are allocated to two or more client devices for downlink OFDMA transmission to the two or more client devices. At block **2504**, a signal field is generated. The signal field includes indications of the respective sub-channels allocated, at block **2502**, for downlink transmission to the two or more client devices. At block **2506**, an OFDMA data unit is generated to include (i) the signal field generated at block **2504**, (ii) a first OFDM data unit directed to the first one of the two or more second communication devices and (iii) a second OFDM data unit directed to the second one of the two or more second communication devices, wherein the first OFDM data unit is to be transmitted to the first sub-channel and the second OFDM data unit is to be transmitted in the second sub-channel. In an embodiment, the OFDMA data unit **600** of FIG. **6** is generated. In another embodiment, another suitable OFDMA data unit is generated. At block **2508**, the OFDMA data unit is transmitted to the two or more client devices.

In an embodiment, a method for simultaneously communication with multiple communication devices in a wireless local area network includes allocating, by a first communication device, respective sub-channels of an orthogonal frequency division multiplexing (OFDM) channel to two or more second communication devices for uplink orthogonal frequency division multiple access (OFDMA) transmission from the two or more second communication devices, including allocating a first sub-channel to a first one of the two or more second communication devices and a second sub-channel to a second one of the two or more second communication devices. The method further includes providing, from the first communication device to the two or more second communication devices, indications of the respective sub-channels allocated for uplink OFDMA transmission from the two or more second communication devices. The method additionally includes receiving, at the first communication device, an uplink OFDMA data unit that includes at least a first OFDM data unit from the first one of the two or more second communication devices and a second OFDM data unit from the second one of the two or more second communication devices, wherein the first OFDM data unit is transmitted from the first one of the two or more second communication devices via the first sub-channel allocated to the first one of the two or more second communication devices and the second OFDM data unit is transmitted from the second one of the two or more second communication devices via the second sub-channel allocated to the second one of the two or more second communication devices.

In other embodiments, the method includes any suitable combination of one or more of the following features.

The method further includes transmitting a scheduling frame to trigger transmission of the uplink OFDMA data unit, wherein the scheduling frame includes the respective indications of the respective sub-channels allocated to the two or more second communication devices.

The method further includes comprising conducting, by the first communication device, a channel assessment procedure to obtain a transmit opportunity for OFDMA communication between the first communication device and the two or more second communication devices, wherein transmitting the scheduling frame comprises transmitting the scheduling frame at a beginning of the obtained transmit opportunity.

Transmitting the scheduling frame comprises transmitting the scheduling frame at a beginning of a scheduled transmit opportunity for OFDMA communication between the first communication device and the two or more second communication devices.

The method further includes determining a length for the uplink OFDMA data unit, and wherein the scheduling frame further includes an indication of the length determined for the uplink OFDMA data unit.

Determining the length for the uplink OFDMA data unit comprises requesting, by the first communication device from the two or more second communication devices, respective indications of each of one or both of (i) amount of data buffered for uplink transmission and (ii) requested medium time for uplink transmission, receiving, at the first communication device, the requested indications from the two or more second communication devices, and determining, by the first communication device, the length for the uplink OFDMA data unit based at least in part on the respective indications received from the two or more second communication devices.

Requesting respective indications by the first communication device from the two or more second communication

devices comprises including a request for transmission of the indications in the scheduling frame transmitted by the first communication device.

The scheduling frame further includes a repeat usage indication, wherein the repeat usage indication indicates that the sub-channels allocated for uplink OFDMA transmission from the two or more second communication devices are to be used for multiple consecutive uplink transmissions by the two or more second communication devices.

Allocating respective sub-channels of the OFDM channel for uplink OFDMA transmission from the two or more second communication devices includes allocating a third sub-channel to both (i) a third one of second communication devices and (ii) a fourth one of second communication devices, and wherein the method further comprises indicating, to the fourth one of the second communication devices, a time at which to begin transmitting an uplink OFDM data unit in the third sub-channel, wherein the indicated time begins after an end of transmission of an OFDM data unit in the third-sub-channel by the third one of the second communication devices.

The method further includes indicating, to the third one of the second communication devices that an immediate acknowledgment is not required for the OFDM data unit transmitted in the third-sub-channel by the third one of the second communication device.

Allocating respective sub-channels of the OFDM channel to two or more second communication devices for uplink OFDMA transmission from the two or more second communication devices includes skipping a particular sub-channel of the OFDM channel if the particular sub-channel is determined to be unavailable for transmission.

After receiving the uplink OFDMA data unit, transmitting one or more acknowledgement frames to the two or more second communication devices, wherein the one or more acknowledgement frames are transmitted simultaneously to the two or more second communication devices.

Transmitting the one or more acknowledgement frames comprises transmitting respective acknowledgement frames to the two or more second communication devices as parts of an OFDMA transmission to the two or more second communication devices, wherein the respective acknowledgement frames are transmitted in the respective sub-channels allocated to the two or more second communication devices.

Transmitting the one or more acknowledgement frames comprises transmitting a broadcast acknowledgement frame to the two or more second communication devices, wherein the broadcast acknowledgement frame includes respective acknowledgements for the two or more second communication devices.

The method further includes allocating respective sub-channels of the OFDMA channel for downlink OFDMA transmission to the two or more second communication devices.

The method further includes providing, to the two or more second communication devices, indications of respective sub-channels allocated for downlink OFDMA transmission to the two or more communication devices.

The method further includes transmitting a downlink OFDMA data unit to the two or more second communication devices, wherein the downlink OFDMA data unit includes respective OFDM data units directed to the two or more communication devices transmitted in the respective OFDM data units in the respective sub-channels allocated for downlink OFDMA transmission to the two or more second communication devices.

Receiving the uplink OFDMA data unit and transmitting the downlink OFDMA data unit occur during a same transmission opportunity for OFDMA communication between the first communication device and the two or more second communication devices.

Providing, to the two or more second communication devices, indications of respective sub-channels allocated for downlink OFDMA transmission to the two or more communication devices comprises including the indications in the scheduling frame.

The method further includes receiving, at the first communication device, respective acknowledgement frames from the two or more second communication devices, wherein the acknowledgement frames are transmitted simultaneously by the two or more second communication devices as part of an OFDMA transmission from the two or more second communication devices, wherein the respective acknowledgement frames are transmitted in the respective sub-channels allocated for downlink OFDMA transmission to the two or more second communication devices.

The method further includes allocating respective sub-channels of the OFDMA channel for downlink OFDMA transmission to the two or more second communication devices.

The method further includes generating a downlink OFDMA data unit to include, in a physical layer (PHY) signal field of the downlink OFDMA data unit, indications of the respective sub-channels for downlink OFDMA transmission to the two or more second communication devices.

The method further includes transmitting the downlink OFDMA data unit to the two or more second communication devices, wherein the downlink OFDMA data unit includes respective OFDM data units directed to the two or more client communication transmitted in the respective OFDM data units in the respective sub-channels allocated for downlink OFDMA transmission to the two or more second communication devices.

In another embodiment, a first communication device comprises a network interface configured to allocate respective sub-channels of an orthogonal frequency division multiplexing (OFDM) channel to two or more second communication devices for uplink orthogonal frequency division multiple access (OFDMA) transmission from the two or more second communication devices, including allocating a first sub-channel to a first one of the two or more second communication devices and a second sub-channel to a second one of the two or more communication devices. The network interface is also configured to provide, to the two or more second communication devices, indications of the respective sub-channels allocated for uplink transmission from the two or more second communication devices. The network interface is additionally configured to receive an uplink OFDMA data unit that includes at least a first OFDM data unit from the first one of the two or more second communication devices and a second OFDM data unit from the second one of the two or more second communication devices, wherein the first OFDM data unit is transmitted from the first one of the two or more second communication devices via the first sub-channel allocated to the first of the two or more second communication devices and the second OFDM data unit is transmitted from the second one of the two or more second communication devices via the second sub-channel allocated to the second one of the two or more second communication devices.

In other embodiments, the first communication device includes any suitable combination of one or more of the following features.

The network interface is configured transmit a scheduling frame to trigger transmission of the uplink OFDMA data unit, wherein the scheduling frame provides the respective indications of the respective sub-channels allocated to the two or more second communication devices.

The network interface is further configured to conduct a channel assessment procedure to obtain a transmit opportunity for OFDMA communication between the first communication device and the two or more second communication devices, and transmit the scheduling frame at a beginning of the obtained transmit opportunity.

The network interface is configured to transmit the scheduling frame at a beginning of a scheduled transmit opportunity for OFDMA communication between the first communication device and the two or more second communication devices.

The network interface is further configured to determine a length for the uplink OFDMA data unit, and include, in the scheduling frame, an indication of the length determined for the uplink OFDMA data unit.

The network interface is configured to request, from the two or more second communication devices, respective indications of each of one or both of (i) amount of data buffered for uplink transmission and (ii) requested medium time for uplink transmission, receive the requested indications from the two or more second communication devices, and determine the length for the uplink OFDMA data unit based at least in part on the respective indications received from the two or more second communication devices.

The network interface is configured to request the indications from the two or more second communication devices at least by including a request for transmission of the indications in the scheduling frame.

The network interface is further configured to include, in the scheduling frame, a repeat usage indication, wherein the repeat usage indications indicates that the sub-channels allocated for uplink transmission by the two or more second communication devices are to be used for multiple consecutive uplink transmissions by the two or more second communication devices.

The network interface is further configured to allocate a third sub-channel to both (i) a third one of the second communication devices and (ii) a fourth one of the second communication devices, and indicate, to the fourth one of the second communication devices, a time at which to begin transmitting an uplink OFDM data unit in the third sub-channel, wherein the indicated time begins after an end of an OFDM data unit transmitted in the third-sub-channel by the third one of the second communication devices.

The network interface is further configured to indicate to the third one of the second communication devices that an immediate acknowledgment is not required for the OFDM data unit transmitted in the third-sub-channel by the third one of the second communication devices.

The network interface is configured to, when allocating respective sub-channels of the OFDM channel to the two or more second communication devices for uplink OFDMA transmission from the two or more second communication devices, skip a particular sub-channel of the OFDM channel if the particular sub-channel is determined to be unavailable for transmission.

The network interface is further configured to, after receiving the uplink OFDMA data unit, transmit one or more acknowledgement frames to the two or more second communication devices, wherein the one or more acknowledgement frames are transmitted simultaneously to the two or more second communication devices.

The network interface is configured to transmit respective acknowledgement frames to the two or more second communication devices as parts of an OFDMA transmission to the two or more second communication devices, wherein the respective acknowledgement frames are transmitted in the respective sub-channels allocated to the two or more second communication devices.

The network interface is configured to transmit a broadcast acknowledgement frame to the two or more second communication devices, wherein the broadcast acknowledgement frame includes respective acknowledgements for the two or more second communication devices.

The network interface is further configured to allocate respective sub-channels of the OFDMA channel for downlink OFDMA transmission to the two or more second communication devices.

The network interface is further configured to provide, to the two or more second communication devices, indications of respective sub-channels allocated for downlink OFDMA transmission to the two or more communication devices.

The network interface is further configured to transmit a downlink OFDMA data unit to the two or more second communication devices, wherein the downlink OFDMA data unit includes respective OFDM data units directed to the two or more communication devices transmitted in the respective OFDM data units in the respective sub-channels allocated for downlink OFDMA transmission to the two or more second communication devices.

The network interface is further configured to receive the uplink OFDMA data unit and transmit the downlink OFDMA data unit during a same transmission opportunity for OFDMA communication between the first communication device and the two or more second communication devices.

The network interface is configured to provide, to the two or more second communication devices, indications of respective sub-channels allocated for downlink OFDMA transmission to the two or more communication devices at least by including the indications in the scheduling frame.

The network interface is further configured to receive respective acknowledgement frames from the two or more second communication devices, wherein the acknowledgement frames are transmitted simultaneously by the two or more second communication devices as part of an OFDMA transmission from the two or more second communication devices, wherein the respective acknowledgement frames are transmitted in the respective sub-channels allocated for downlink OFDMA transmission to the two or more second communication devices.

The network interface is further configured to allocate respective sub-channels of the OFDMA channel for downlink OFDMA transmission to the two or more second communication devices.

The network interface is further configured to generate a downlink OFDMA data unit to include, in a physical layer (PHY) signal field of the downlink OFDMA data unit, indications of the respective sub-channels for downlink OFDMA transmission to the two or more second communication devices.

The network interface is further configured to transmit the downlink OFDMA data unit to the two or more second communication devices, wherein the downlink OFDMA data unit includes respective OFDM data units directed to the two or more client communication transmitted in the respective OFDM data units in the respective sub-channels allocated for downlink OFDMA transmission to the two or more second communication devices.

In yet another embodiment, a method for simultaneously communication with multiple communication devices in a wireless local area network includes allocating, by a first communication device, respective sub-channels of an orthogonal frequency division multiplexing (OFDM) channel to two or more second communication devices for downlink orthogonal frequency division multiple access (OFDMA) transmission to the two or more second communication devices, including allocating a first sub-channel to a first one of the two or more second communication devices and a second sub-channel to a second one of the two or more communication devices. The method further includes generating a signal field of an OFDMA data unit to include indications of the respective sub-channels allocated for downlink OFDMA transmission from the two or more second communication devices. The method further still includes generating an OFDMA data unit to include (i) the signal field, (ii) a first OFDM data unit directed to the first one of the two or more second communication devices and (iii) a second OFDM data unit directed to the second one of the two or more second communication devices, wherein the first OFDM data unit is to be transmitted to the first sub-channel and the second OFDM data unit is to be transmitted in the second sub-channel. The method additionally includes transmitting the OFDMA data unit to the two or more second communication devices.

In other embodiments, the method includes any suitable combination of one or more of the following features.

The method further includes receiving respective acknowledgement frames from the two or more second communication devices.

The acknowledgement frames are transmitted simultaneously by the two or more second communication devices as part of an OFDMA transmission from the two or more second communication devices, wherein the respective acknowledgement frames are transmitted in the respective sub-channels allocated for downlink OFDMA transmission to the two or more second communication devices.

In still another embodiment, a first communication device comprises a network interface configured to allocate respective sub-channels of an orthogonal frequency division multiplexing (OFDM) channel to two or more second communication devices for downlink orthogonal frequency division multiple access (OFDMA) transmission to the two or more second communication devices, including allocating a first sub-channel to a first one of the two or more second communication devices and a second sub-channel to a second one of the two or more communication devices. The network interface is further configured to generate a signal field of an OFDMA data unit to include indications of the respective sub-channels allocated for downlink OFDMA transmission from the two or more second communication devices. The network interface is further still configured to generate an OFDMA data unit to include (i) the signal field, (ii) a first OFDM data unit directed to the first one of the two or more second communication devices and (iii) a second OFDM data unit directed to the second one of the two or more second communication devices, wherein the first OFDM data unit is to be transmitted to the first sub-channel and the second OFDM data unit is to be transmitted in the second sub-channel. The network interface is additionally configured to transmit the OFDMA data unit to the two or more second communication devices.

In other embodiments, the first communication device includes any suitable combination of one or more of the following features.

The network interface is further configured to receive respective acknowledgement frames from the two or more second communication devices.

The acknowledgement frames are transmitted simultaneously by the two or more second communication devices as part of an OFDMA transmission from the two or more second communication devices, wherein the respective acknowledgement frames are transmitted in the respective sub-channels allocated for downlink OFDMA transmission to the two or more second communication devices.

At least some of the various blocks, operations, and techniques described above may be implemented utilizing hardware, a processor executing firmware instructions, a processor executing software instructions, or any combination thereof. When implemented utilizing a processor executing software or firmware instructions, the software or firmware instructions may be stored in any computer readable memory such as on a magnetic disk, an optical disk, or other storage medium, in a RAM or ROM or flash memory, processor, hard disk drive, optical disk drive, tape drive, etc. Likewise, the software or firmware instructions may be delivered to a user or a system via any known or desired delivery method including, for example, on a computer readable disk or other transportable computer storage mechanism or via communication media. Communication media typically embodies computer readable instructions, data structures, program modules or other data in a modulated data signal such as a carrier wave or other transport mechanism. The term "modulated data signal" means a signal that has one or more of its characteristics set or changed in such a manner as to encode information in the signal. By way of example, and not limitation, communication media includes wired media such as a wired network or direct-wired connection, and wireless media such as acoustic, radio frequency, infrared and other wireless media. Thus, the software or firmware instructions may be delivered to a user or a system via a communication channel such as a telephone line, a DSL line, a cable television line, a fiber optics line, a wireless communication channel, the Internet, etc. (which are viewed as being the same as or interchangeable with providing such software via a transportable storage medium). The software or firmware instructions may include machine readable instructions that, when executed by the processor, cause the processor to perform various acts.

When implemented in hardware, the hardware may comprise one or more of discrete components, an integrated circuit, an application-specific integrated circuit (ASIC), etc.

While the present invention has been described with reference to specific examples, which are intended to be illustrative only and not to be limiting of the invention, changes, additions and/or deletions may be made to the disclosed embodiments without departing from the scope of the invention.

What is claimed is:

1. A method for simultaneously communication with multiple communication devices in a wireless local area network, the method comprising:

allocating, by a first communication device, respective sub-channels of an orthogonal frequency division multiplexing (OFDM) channel to two or more second communication devices for uplink orthogonal frequency division multiple access (OFDMA) transmission from the two or more second communication devices, including: (i) allocating non-contiguous sub-channels by skipping a particular sub-channel of the OFDM channel, when the particular sub-channel is

determined to be unavailable for transmission, and (ii) allocating a first sub-channel to a first one of the two or more second communication devices and a second sub-channel to a second one of the two or more second communication devices;

providing, from the first communication device to the two or more second communication devices, i) indications of the respective sub-channels allocated for uplink OFDMA transmission from the two or more second communication devices, including indications of the non-contiguous sub-channel allocation, and ii) an indication of a length of the uplink OFDMA transmission from the two or more second communication devices; and

receiving, at the first communication device, an uplink OFDMA data unit that includes at least a first OFDM data unit from the first one of the two or more second communication devices and a second OFDM data unit from the second one of the two or more second communication devices, wherein the first OFDM data unit i) has a duration in accordance with the indication of the length provided by the first communication device and ii) is transmitted from the first one of the two or more second communication devices via the first sub-channel allocated to the first one of the two or more second communication devices and the second OFDM data unit i) has the duration in accordance with the indication of the length provided by the first communication device and ii) is transmitted from the second one of the two or more second communication devices via the second sub-channel allocated to the second one of the two or more second communication devices.

2. The method of claim **1**, further comprising transmitting a scheduling frame to trigger transmission of the uplink OFDMA data unit, wherein the scheduling frame includes the respective indications of the respective sub-channels allocated to the two or more second communication devices.

3. The method of claim **2**, further comprising conducting, by the first communication device, a channel assessment procedure to obtain a transmit opportunity for OFDMA communication between the first communication device and the two or more second communication devices, wherein transmitting the scheduling frame comprises transmitting the scheduling frame at a beginning of the obtained transmit opportunity.

4. The method of claim **2**, wherein transmitting the scheduling frame comprises transmitting the scheduling frame at a beginning of a scheduled transmit opportunity for OFDMA communication between the first communication device and the two or more second communication devices.

5. The method of claim **2**, further comprising determining, at the first communication device, the length of the uplink OFDMA transmission, and wherein the scheduling frame further includes the indication of the length of the uplink OFDMA transmission.

6. The method of claim **5**, wherein determining the length of the uplink OFDMA transmission comprises:

requesting, by the first communication device from the two or more second communication devices, respective indications of each of one or both of (i) amount of data buffered for uplink transmission and (ii) requested medium time for uplink transmission,

receiving, at the first communication device, the requested indications from the two or more second communication devices, and

determining, by the first communication device, the length for the uplink OFDMA transmission based at least in part on the respective indications received from the two or more second communication devices.

7. The method of claim **6**, wherein requesting respective indications by the first communication device from the two or more second communication devices comprises including a request for transmission of the indications in the scheduling frame transmitted by the first communication device.

8. The method of claim **2**, wherein the scheduling frame further includes a repeat usage indication, wherein the repeat usage indication indicates that the sub-channels allocated for uplink OFDMA transmission from the two or more second communication devices are to be used for multiple consecutive uplink transmissions by the two or more second communication devices.

9. The method of claim **1**, wherein allocating respective sub-channels of the OFDM channel for uplink OFDMA transmission from the two or more second communication devices includes allocating a third sub-channel to both (i) a third one of second communication devices and (ii) a fourth one of second communication devices, and wherein the method further comprises indicating, to the fourth one of the second communication devices, a time at which to begin transmitting an uplink OFDM data unit in the third sub-channel, wherein the indicated time begins after an end of transmission of an OFDM data unit in the third-sub-channel by the third one of the second communication devices.

10. The method of claim **9**, further comprising indicating, to the third one of the second communication devices, that an immediate acknowledgment is not required for the OFDM data unit transmitted in the third-sub-channel by the third one of the second communication device.

11. The method of claim **1**, wherein allocating respective sub-channels of the OFDM channel to two or more second communication devices for uplink OFDMA transmission from the two or more second communication devices includes skipping a particular sub-channel of the OFDM channel if the particular sub-channel is determined to be unavailable for transmission.

12. The method of claim **1**, further comprising, after receiving the uplink OFDMA data unit, transmitting one or more acknowledgement frames to the two or more second communication devices, wherein the one or more acknowledgement frames are transmitted simultaneously to the two or more second communication devices.

13. The method of claim **12**, wherein transmitting the one or more acknowledgement frames comprises transmitting respective acknowledgement frames to the two or more second communication devices as parts of an OFDMA transmission to the two or more second communication devices, wherein the respective acknowledgement frames are transmitted in the respective sub-channels allocated to the two or more second communication devices.

14. The method of claim **12**, wherein transmitting the one or more acknowledgement frames comprises transmitting a broadcast acknowledgement frame to the two or more second communication devices, wherein the broadcast acknowledgement frame includes respective acknowledgements for the two or more second communication devices.

15. The method of claim **2**, further comprising:

allocating respective sub-channels of the OFDM channel for downlink OFDMA transmission to the two or more second communication devices,

providing, to the two or more second communication devices, indications of the respective sub-channels allocated for downlink OFDMA transmission to the two or more second communication devices, and

transmitting a downlink OFDMA data unit to the two or more second communication devices, wherein the downlink OFDMA data unit includes respective OFDM data units directed to the two or more second communication devices transmitted in the respective OFDM data units in the respective sub-channels allocated for downlink OFDMA transmission to the two or more second communication devices.

16. The method of claim **15**, wherein receiving the uplink OFDMA data unit and transmitting the downlink OFDMA data unit occur during a same transmission opportunity for OFDMA communication between the first communication device and the two or more second communication devices.

17. The method of claim **15**, wherein providing, to the two or more second communication devices, indications of respective sub-channels allocated for downlink OFDMA transmission to the two or more second communication devices comprises including the indications in the scheduling frame.

18. The method of claim **15**, further comprising receiving, at the first communication device, respective acknowledgement frames from the two or more second communication devices, wherein the acknowledgement frames are transmitted simultaneously by the two or more second communication devices as part of an OFDMA transmission from the two or more second communication devices, wherein the respective acknowledgement frames are transmitted in the respective sub-channels allocated for downlink OFDMA transmission to the two or more second communication devices.

19. The method of claim **1**, further comprising:

allocating respective sub-channels of the OFDM channel for downlink OFDMA transmission to the two or more second communication devices,

generating a downlink OFDMA data unit to include, in a physical layer (PHY) signal field of the downlink OFDMA data unit, indications of the respective sub-channels for downlink OFDMA transmission to the two or more second communication devices, and

transmitting the downlink OFDMA data unit to the two or more second communication devices, wherein the downlink OFDMA data unit includes respective OFDM data units directed to the two or more second communication devices transmitted in the respective OFDM data units in the respective sub-channels allocated for downlink OFDMA transmission to the two or more second communication devices.

20. A first communication device, comprising:

a network interface configured to:

allocate respective sub-channels of an orthogonal frequency division multiplexing (OFDM) channel to two or more second communication devices for uplink orthogonal frequency division multiple access (OFDMA) transmission from the two or more second communication devices, including: (i) allocating non-contiguous sub-channels by skipping a particular sub-channel of the OFDM channel, when the particular sub-channel is determined to be unavailable for transmission, and (ii) allocating a first sub-channel to a first one of the two or more second communication devices and a second sub-channel to a second one of the two or more communication devices;

provide, to the two or more second communication devices, i) indications of the respective sub-channels allocated for uplink transmission from the two or more second communication devices, including indications of the non-contiguous sub-channel allocation, and ii) an indication of a length of the uplink OFDMA transmission from the two or more second communication devices; and

receive an uplink OFDMA data unit that includes at least a first OFDM data unit from the first one of the two or more second communication devices and a second OFDM data unit from the second one of the two or more second communication devices, wherein the first OFDM data unit i) has a duration in accordance with the indication of the length provided by the first communication device and ii) is transmitted from the first one of the two or more second communication devices via the first sub-channel allocated to the first one of the two or more second communication devices and the second OFDM data unit i) has the duration in accordance with the indication of the length provided by the first communication device and ii) is transmitted from the second one of the two or more second communication devices via the second sub-channel allocated to the second one of the two or more second communication devices.

21. The first communication device of claim **20**, wherein the network interface is configured transmit a scheduling frame to trigger transmission of the uplink OFDMA data unit, wherein the scheduling frame provides the respective indications of the respective sub-channels allocated to the two or more second communication devices.

22. The first communication device of claim **21**, wherein the network interface is further configured to

conduct a channel assessment procedure to obtain a transmit opportunity for OFDMA communication between the first communication device and the two or more second communication devices, and

transmit the scheduling frame at a beginning of the obtained transmit opportunity.

23. The first communication device of claim **21**, wherein the network interface is configured to transmit the scheduling frame at a beginning of a scheduled transmit opportunity for OFDMA communication between the first communication device and the two or more second communication devices.

24. The first communication device of claim **21**, wherein the network interface is further configured to:

determine the length of the uplink OFDMA transmission, and

include, in the scheduling frame, the indication of the length of the uplink OFDMA transmission.

25. The first communication device of claim **24**, wherein the network interface is configured to:

request, from the two or more second communication devices, respective indications of each of one or both of (i) amount of data buffered for uplink transmission and (ii) requested medium time for uplink transmission,

receive the requested indications from the two or more second communication devices, and

determine the length of the uplink OFDMA transmission based at least in part on the respective indications received from the two or more second communication devices.

26. The first communication device of claim **25**, wherein the network interface is configured to request the indications from the two or more second communication devices at least by including a request for transmission of the indications in the scheduling frame.

27. The first communication device of claim **21**, wherein the network interface is further configured to include, in the

scheduling frame, a repeat usage indication, wherein the repeat usage indications indicates that the sub-channels allocated for uplink transmission by the two or more second communication devices are to be used for multiple consecutive uplink transmissions by the two or more second communication devices.

28. The first communication device of claim **20**, wherein the network interface is further configured to:

allocate a third sub-channel to both (i) a third one of the second communication devices and (ii) a fourth one of the second communication devices, and

indicate, to the fourth one of the second communication devices, a time at which to begin transmitting an uplink OFDM data unit in the third sub-channel, wherein the indicated time begins after an end of an OFDM data unit transmitted in the third-sub-channel by the third one of the second communication devices.

29. The first communication device of claim **28**, wherein the network interface is further configured to indicate to the third one of the second communication devices that an immediate acknowledgment is not required for the OFDM data unit transmitted in the third-sub-channel by the third one of the second communication devices.

30. The first communication device of claim **20**, wherein the network interface is configured to, when allocating respective sub-channels of the OFDM channel to the two or more second communication devices for uplink OFDMA transmission from the two or more second communication devices, skip a particular sub-channel of the OFDM channel if the particular sub-channel is determined to be unavailable for transmission.

31. The first communication device of claim **20**, wherein the network interface is further configured to, after receiving the uplink OFDMA data unit, transmit one or more acknowledgement frames to the two or more second communication devices, wherein the one or more acknowledgement frames are transmitted simultaneously to the two or more second communication devices.

32. The first communication device of claim **31**, wherein the network interface is configured to transmit respective acknowledgement frames to the two or more second communication devices as parts of an OFDMA transmission to the two or more second communication devices, wherein the respective acknowledgement frames are transmitted in the respective sub-channels allocated to the two or more second communication devices.

33. The first communication device of claim **31**, wherein the network interface is configured to transmit a broadcast acknowledgement frame to the two or more second communication devices, wherein the broadcast acknowledgement frame includes respective acknowledgements for the two or more second communication devices.

34. The first communication device of claim **21**, wherein the network interface is further configured to:

allocate respective sub-channels of the OFDM channel for downlink OFDMA transmission to the two or more second communication devices,

provide, to the two or more second communication devices, indications of respective sub-channels allocated for downlink OFDMA transmission to the two or more communication devices, and

transmit a downlink OFDMA data unit to the two or more second communication devices, wherein the downlink OFDMA data unit includes respective OFDM data units directed to the two or more second communication devices transmitted in the respective OFDM data units in the respective sub-channels allocated for downlink OFDMA transmission to the two or more second communication devices.

35. The first communication device of claim **34**, wherein the network interface is further configured to receive the uplink OFDMA data unit and transmit the downlink OFDMA data unit during a same transmission opportunity for OFDMA communication between the first communication device and the two or more second communication devices.

36. The first communication device of claim **34**, wherein the network interface is configured to provide, to the two or more second communication devices, indications of respective sub-channels allocated for downlink OFDMA transmission to the two or more second communication devices at least by including the indications in the scheduling frame.

37. The first communication device of claim **34**, wherein the network interface is further configured to receive respective acknowledgement frames from the two or more second communication devices, wherein the acknowledgement frames are transmitted simultaneously by the two or more second communication devices as part of an OFDMA transmission from the two or more second communication devices, wherein the respective acknowledgement frames are transmitted in the respective sub-channels allocated for downlink OFDMA transmission to the two or more second communication devices.

38. The first communication device of claim **20**, wherein the network interface is further configured to:

allocate respective sub-channels of the OFDM channel for downlink OFDMA transmission to the two or more second communication devices,

generate a downlink OFDMA data unit to include, in a physical layer (PHY) signal field of the downlink OFDMA data unit, indications of the respective sub-channels for downlink OFDMA transmission to the two or more second communication devices, and

transmit the downlink OFDMA data unit to the two or more second communication devices, wherein the downlink OFDMA data unit includes respective OFDM data units directed to the two or more second communication devices transmitted in the respective OFDM data units in the respective sub-channels allocated for downlink OFDMA transmission to the two or more second communication devices.

39. A method for simultaneously communication with multiple communication devices in a wireless local area network, the method comprising:

allocating, by a first communication device, respective sub-channels of an orthogonal frequency division multiplexing (OFDM) channel to two or more second communication devices for downlink orthogonal frequency division multiple access (OFDMA) transmission to the two or more second communication devices, including: (i) allocating non-contiguous sub-channels by skipping a particular sub-channel of the OFDM channel, when the particular sub-channel is determined to be unavailable for transmission, and (ii) allocating a first sub-channel to a first one of the two or more second communication devices and a second sub-channel to a second one of the two or more communication devices;

generating a signal field of an OFDMA data unit to include indications of the respective sub-channels allocated for downlink OFDMA transmission to the two or more second communication devices, including indications of the non-contiguous sub-channel allocation;

generating the OFDMA data unit to include (i) the signal field, (ii) a first OFDM data unit directed to the first one of the two or more second communication devices and (iii) a second OFDM data unit directed to the second one of the two or more second communication devices, wherein the first OFDM data unit is to be transmitted in the first sub-channel and the second OFDM data unit is to be transmitted in the second sub-channel; and

transmitting the OFDMA data unit to the two or more second communication devices.

40. The method of claim **39**, further comprising receiving respective acknowledgement frames from the two or more second communication devices, wherein the acknowledgement frames are transmitted simultaneously by the two or more second communication devices as part of an OFDMA transmission from the two or more second communication devices, wherein the respective acknowledgement frames are transmitted in the respective sub-channels allocated for downlink OFDMA transmission to the two or more second communication devices.

41. A first communication device, comprising:

a network interface configured to:

allocate respective sub-channels of an orthogonal frequency division multiplexing (OFDM) channel to two or more second communication devices for downlink orthogonal frequency division multiple access (OFDMA) transmission to the two or more second communication devices, including: (i) allocating non-contiguous sub-channels by skipping a particular sub-channel of the OFDM channel, when the particular sub-channel is determined to be unavailable for transmission, and (ii) allocating a first sub-channel to a first one of the two or more second communication devices and a second sub-channel to a second one of the two or more communication devices;

generate a signal field of an OFDMA data unit to include indications of the respective sub-channels allocated for downlink OFDMA transmission from the two or more second communication devices, including indications of the non-contiguous sub-channel allocation;

generate the OFDMA data unit to include (i) the signal field, (ii) a first OFDM data unit directed to the first one of the two or more second communication devices and (iii) a second OFDM data unit directed to the second one of the two or more second communication devices, wherein the first OFDM data unit is to be transmitted in the first sub-channel and the second OFDM data unit is to be transmitted in the second sub-channel; and

transmit the OFDMA data unit to the two or more second communication devices.

42. The first communication device of claim **41**, wherein the network interface is further configured to receive respective acknowledgement frames from the two or more second communication devices, wherein the acknowledgement frames are transmitted simultaneously by the two or more second communication devices as part of an OFDMA transmission from the two or more second communication devices, wherein the respective acknowledgement frames are transmitted in the respective sub-channels allocated for downlink OFDMA transmission to the two or more second communication devices.

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