IN THE UNITED STATES DISTRICT COURT
FOR THE WESTERN DISTRICT OF TEXAS
WACO DIVISION

ATLAS GLOBAL TECHNOLOGIES LLC, Plaintiff, v. ZYXEL NETWORKS CORPORATION AND ZYXEL COMMUNICATIONS CORPORATION Defendants.	Civil Action No. 6:22-cv-00355-ADA
ATLAS GLOBAL TECHNOLOGIES LLC, Plaintiff, v. D-LINK CORPORATION, Defendant.	Civil Action No. 6:22-cv-00520-ADA

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I. INTRODUCTION

Defendants D-Link Corporation, ZyXEL Networks Corporation, and ZyXEL Communications Corporation (collectively "Defendants") respectfully request the Court to construe the claim terms proposed below. Plaintiff has asserted 130 claims among the nine patents-in-suit against Defendants. Instead of following the basic patent tenets that the claims are construed "as of the *effective filing date* of the patent application" *and* that a patent claim term is determined from the *intrinsic* record (*i.e.*, the claims, patent specification, and the prosecution history), *see Phillips v. AWH Corp.*, 415 F.3d 1303, 1313 (Fed. Cir. 2005) (en banc) (emphasis added), Plaintiff improperly relies on extrinsic evidence to support its proposed plain-and-ordinary claim constructions,[1] many items of which relate to the 802.11ax WiFi standard that *post-dates* the filing of the patents-in-suit and therefore do not fall into the realm of extrinsic evidence available for claim-construction purposes. In contrast, the Defendants' proposed constructions are based on the intrinsic records of the patents-in-suit. Defendants note that this Court previously considered some claim terms of the nine patents-in-suit. However, because Plaintiff relies on *post-filing extrinsic evidence* to support its proposed "plain-and-ordinary" construction—which Plaintiff cannot do—the Court should instead provide specific constructions for the disputed terms. As Defendants faithfully follow the basic patent tenets, while Plaintiff fails to properly engage in the claim-construction process, Defendants' evidence and rationale should guide the Court's decisions and their claim constructions should be adopted.

[1] "[E]xtrinsic evidence in general [is] less reliable than the patent and its prosecution history in determining how to read claim terms . . . [as it] by definition is not part of the patent and does not have the specification's virtue of being created at the time of patent prosecution for the purpose of explaining the patent's scope and meaning . . . [and if] generated at the time of and for the purpose of litigation . . . can suffer from bias that is not present in intrinsic evidence." *Phillips*, 415 F.3d at 1318.

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II. BACKGROUND[2]

A. U.S. Patent No. 9,531,520

U.S. Patent No. 9,531,520 (the "'520 patent") discloses:

> Methods and devices are described that facilitate uplink multi-user acknowledgment transmissions. In particular, acknowledgment information may be located in a media access control (MAC) header of a payload section of a MAC Protocol Data Unit within a downlink multi-user frame. The acknowledgment information may be present in… the downlink multi-user frame to indicate to each corresponding station properties/characteristics of a subsequent acknowledgment transmission.

'520 patent, Abstract. The '520 patent acknowledges that the devices used to implement its disclosed methods were well-known (*e.g.*, under the prior art 802.11 standard, an access point ("AP"—"a functional entity for providing access to a distribution system") may communicate with associated non-AP stations ("non-AP STAs")). *See, e.g.*, '520 patent, 6:21-29; 47-49. For its disclosed methods, the patents direct an AP to generate and transmit a downlink frame containing acknowledgement information (*e.g.*, setting an ACK Policy subfield) for associated non-AP station. *Id.*, 14:15-25.

B. U.S. Patent No. 9,763,259

U.S. Patent No. 9,763,259 (the "'259 patent") acknowledges that for years IEEE 802.11 standards had been directed to improving wireless communication by increasing throughput and that "[r]ecently, a high efficiency (HE) WLAN for enhancing the system throughput . . . is being developed by the IEEE 802.11ax task group." '259 patent, 1:27-42. The '259 patent describes a sounding process involving an AP transmitting a null data packet announcement ("NDPA") to one or more non-AP STAs, and a short interframe space ("SIFS") after the transmission of the NDPA,

[2] Because the technology underlying certain defined terms is explained in more detail during the discussion of another patent, various terms used throughout this Background may be defined later in the Background.

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with the AP transmitting a null data packet ("NDP") frame. *Id.*, 9:15-18. The first STA that receives the NDP frame transmits a feedback frame in response. *Id.*, 9:18-22. After receiving this feedback frame, the AP may "poll" other STAs for feedback frames using a beamforming report poll frame. *Id.*, 9:24-28. After receiving the beamforming report poll frame, the STAs may each respond by transmitting a feedback frame (*id.*, 9:28-30), which may include "subchannel information of a subchannel allocated" to the STA (*id.*, 10:35-40) such as "an average SNR [signal-to-noise ratio] of the subchannel." *Id.*, 10:40-41.

C. U.S. Patent No. 9,825,738

U.S. Patent No. 9,825,738 (the "'738 patent") describes an acknowledgment ("ACK") method in a Wireless Local Area Network. '738 patent, Abstract, 1:16-21. According to the '738 patent, the ACK method begins when an "AP transmits a UL MU-MIMO initiation (ULI) frame to perform UL MU-MIMO with a plurality of stations," with the ULI frame indicating the stations that are to initiate the UL MU-MIMO transmission. *Id.*, 20:48-52. A UL request frame is transmitted to the AP in turn from each of the stations that receive the ULI frame, from which the AP will select "a station for joining in the UL MU-MIMO . . . based on the feedback information carried by the UL req[uest] frame[s], and transmit[] a UL MU-MIMO setup (UL setup) frame to the selected stations." *Id.*, 20:58-20:63.

The UL setup frame transmitted from the AP includes setup information, which may include common information that is common to all stations for joining the UL MU-MIMO transmission, such as the total number of data streams to be transmitted by the STAs and a transmission length of the UL data frame. *Id.*, 22:35-46. The setup information may also include dedicated information that is specific to each station such as identification information of the corresponding station, the number of data streams to be transmitted by the corresponding station,

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a transmission power of the corresponding station, an MCS of the corresponding station, or beam information for the corresponding station. *Id.*, 22:35-38; 22:54-61.

Each of the stations that receive the UL setup frame from the AP transmits a UL data frame, (e.g., a UL MU PPDU) based on the setup information in the UL setup frame. *Id.*, 21:4-6. The acknowledgment method completes when the AP that receives the UL data frame (e.g., UL MU PPDUs) transmits an "ACK frame on the UL MU PPDUs to the stations" from which it received the PPDUs (physical protocol data units). *Id.*, 21:6-8.

D. U.S. Patent No. 9,848,442

U.S. Patent No. 9,848,442 (the "'442 patent") describes "methods for transmitting and receiving a frame in an overlapping basis service set (OBSS) environment." '442 patent, 1:15-18. A basic service set ("BSS") may have multiple WLAN devices. *Id.*, 4:17-29. BSSs may overlap and, with respect to the BSS to which a first station belongs (called "MyBSS"), the other BSSs are considered "OBSSs." *Id.*, 8:54-57. The '442 patent discloses the use of both physical carrier sensing (which "listens" to the communications channel to determine if it is busy with other transmissions), and virtual carrier sensing (which uses information included in a received physical protocol data unit, or "PPDU," to set a timer indicating a time period that the communication channel is expected to be busy). *Id.*, 7:17-42. Stations in the BSSs may transmit frames during windows of time called "transmission opportunities" ("TxOPs"); however, a station may lose its transmission opportunity if another station belonging to an OBSS is transmitting at the same time. *Id.*, 1:56-61.

The '442 patent purports to solve this problem by receiving a PPDU and determining if that PPDU is from the station's own BSS or a different OBSS. *Id.*, 2:4-11. If the PPDU is from an OBSS, it sets virtual carrier sensing by using information included in a preamble of the first PPDU when the received signal strength is higher than a threshold or attempting to obtain a transmission

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opportunity when the received signal strength is lower than that threshold. *Id.*, 2:11-19. The virtual carrier sensing (which may be implemented at the PHY-level or the MAC-level) may be based on information included in the preamble of the first PPDU or in the MAC header of the first PPDU. *Id.*, 9:35-45. The claimed inventions for the '442 patent are directed to a method (independent claim 1) and to a station comprising a processor and memory with instructions to perform that method (independent claim 8).

E. U.S. Patent No. 9,912,513

U.S. Patent No. 9,912,513 (the "'513 patent") discloses a system and method intended to synchronize communications sent to a central AP, from numerous wireless stations to enhance the ability of the AP's ability to properly decode the incoming communications. *Id.*, 2:66-3:16. The AP transmits an initial communication, or trigger frame, to the STAs that allocates resources for responsive communications from the STAs and sets a guard interval length to be used for subsequent uplink transmission by one or more of the STAs. *Id.*, 2:47-65, 3:52-61. The guard interval length is used by the STAs as a timing buffer between symbol transmissions to ensure that they do not interfere with one another. *Id.*, 13:42-47. Upon receiving the trigger frame, the STAs send a responsive communication that uses the guard interval length set by the trigger frame and includes a payload. *Id.*, 3:52-61.

With respect to the claimed invention, some of the claims differ from the process described above in that they involve a "cyclic prefix" length instead of a guard interval length. A POSITA would have understood the direct relationship between the cyclic prefix length and the guard interval length. In fact, the '513 patent discloses embodiments in which the guard interval length is a cyclic prefix. *Id.*, 10:55-57. The guard interval length represents a period of time used to ensure that distinct symbol transmissions do not interfere with each other or overlap. Thus, the recitation of the term "guard interval length" in claim 1 is simply referring to the duration of time for this

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function. And the cyclic prefix is merely a specific way in which the guard interval is used to ensure no mutual interference between successive orthogonal frequency division multiplexing ("OFDM") symbols and is achieved by copying a portion of the tail end of the symbol and pre-pending it.

F. U.S. Patent No. 10,020,919

U.S. Patent No. 10,020,919 (the "'919 patent") discloses performing channel sounding using multi-user multiple-input-multiple-output ("MU-MIMO") and orthogonal frequency division multiple access ("OFDMA") communications in a wireless network. '919 patent, 1:20-24, 2:6-16. The '919 patent mentions that multi-user ("MU") transmissions "are distinguished from other transmissions . . . by the allocation in the MU communication of only a portion of the channel . . . to a particular communication." *Id.*, 1:65-2:5.

The disclosed channel sounding process involves a beamformer (*i.e.*, an AP) transmitting a null data packet announcement ("NDPA") to one or more STA(s) to inform the STA(s) to expect to receive a subsequent null data packet ("NDP") for sounding. *Id.*, 18:19-25. When a single STA is designated for sounding in the NDPA, in response to the NDP, the designated STA measures channel state information ("CSI") and transmits it back to the AP as a single user transmission. *Id.*, 18:58-19:9. When multiple STAs are selected for sounding, to reduce overhead, the uplink transmissions (*i.e.*, STA to AP) may be sent as OFDMA transmissions, MU-MIMO transmissions, or both, in response to a trigger frame transmitted by the AP. *Id.*, 19:10-42. As part of the NDPA, the AP includes a "per-STA information list" to inform the STAs which and how many STAs have been designated for sounding. *Id.*, 21:23-38.

G. U.S. Patent No. 10,756,851

U.S. Patent No. 10,756,851 (the "'851 patent") discloses the use of "acknowledgement messages in response to downlink frames." '851 patent, 1:21-24. To that end, the '851 discloses

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the use of a "control extension," which is an extension to the legacy control field and appended at the end of the field, with the patent specification explaining that

> an AP may use the QoS control field in the MAC header of each MPDU and an extended HT control field (denoted as HE Control Extension (HECE) in the HT control field) in a DL payload to notify a STA (that has a payload in the DL MU frame) about the sub-band that the STA can use to place its ACK or BA frame in the immediately multiplexed-ACK/BA frame.

Id., 30:16-22. That is, the control field extension may be used to inform an STA about the sub-band to be used for a response. As illustrated in Figure 13 below, the "control extension" 1320 is appended to the end of the legacy HT control field 1300.

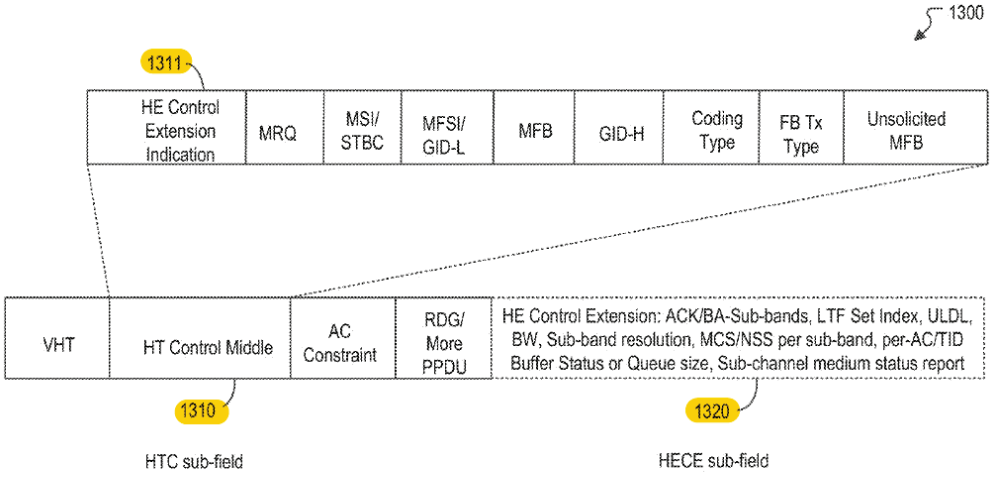


FIG. 13

Id., Fig. 13. Accordingly, although the HE Control Extension Indication (1311) may be encompassed within the legacy HT Control Field, the '851 patent discloses that the HE Control Extension Field (1320) is an extension appended to the end of the HT Control Field, such that the length of the resultant Control Field is longer than a typical legacy HT Control Field.

III. ARGUMENT

A. U.S. Patent No. 9,531,520

1. "[a/the] network device" (claims 1, 6)

Defendants' Proposed Construction	Plaintiff's Proposed Construction
"[an/the] access point"	plain and ordinary meaning

The parties agree that the phrase "[a/the] network device" refers to "[an/the] access point" ("AP"); however, the parties disagree on whether the phrase "network device" as it appears in the '520 patent claims could also refer to a non-AP station. Defendants respectfully submit that the patentee, as the lexicographer, distinguishes "network device" and "station" within claim 1, thereby disclaiming any station from the phrase "network device," and, during prosecution, the patentee explicitly stated that intention to the patent examiner.

Lexicography.

Defendants respectfully request that the Court focus on the plain language of claim 1 as drafted by the patentee, particularly as the subject phrase appears only in the claim context.

- *Limiting Claim Preamble*. The phrase "[a/the] network device" first appears in the claim 1 preamble, which the parties agree is limiting. As the lexicographer, the patentee limits the claim preamble by requiring "a network device" to be capable of "coordinating an uplink multi-user response transmission to a downlink multi-user transmission." As the patentee acknowledges, for example, "an access point may transmit a single downlink (DL) . . . frame that assigns particular resource units (RUs) to separate stations in the wireless system." '520 patent, 1:31-35. Consistent with the Defendants' proposed construction, all disclosed embodiments in the specification specify an access point to coordinate an uplink multi-user response transmission. *See, e.g.*, '520 patent, 4:9-12, 16-18, 22-24, 28-30; FIGs. 5A, 6A, 7A, and 8A (each figure illustrating "a method for coordinating an UL MU acknowledgement/response transmission"). Each of the methods

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illustrated in FIGs. 5A, 6A, 7A, and 8A begins with the step of "generating, by an access point (AP), a downlink (DL) multiuser (MU) frame for a set of target stations (STAs)." As only an access point (*not* a non-AP station) is capable of implementing a downlink transmission method step, the phrase "network device" must mean "access point."

- *Distinguishing Phrases Within Same Limitation of Claim 1*. Additionally, as the lexicographer, the patentee elects to further recite a separate phrase "a plurality of stations" within the very same claim limitation in claim 1 that recites "network device." That is, claim 1 recites and thereby requires "generating, by the *network device*, a downlink multi-user frame addressed to a *plurality of stations*." '520 patent, 30:50-51 (emphases added). As the lexicographer, through the inclusion of both terms within the same claim limitation of claim 1, the patentee unambiguously distinguishes "network device" from "station," thereby mandating the term "network device" to mean something other than the term "station." *Helmsderfer v. Bobrick Washroom Equip., Inc.*, 527 F.3d 1379, 1382 (Fed. Cir. 2008) ("[D]ifferent claim terms are presumed to have different meanings."). The patentee's use of "network device" and "stations" in the very same claim limitation effectively disclaims "network device" from encompassing any "station." Accordingly, the term "[a/the] network device" should be construed consistently with the limiting preamble and the other plain language of claim 1 and the patent specification to mean "[an/the] access point."

Prosecution Estoppel.

"Like the specification, the prosecution history provides evidence of how . . . the inventor understood the patent." *Phillips*, 415 F.3d at 1317. During prosecution, the patentee argued and represented to the USPTO that "Claims 1-20 . . . are directed to . . . transmissions . . . transmitted from respective stations to an Access Point (AP)." July 22, 2016 Amendment, p. 7 (reproduced in part below).

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REMARKS/ARGUMENTS

The claims have been amended as indicated above. No new matter has been added.

Claims 1-20 stand rejected under 35 U.S.C. §103(a) as allegedly unpatentable over US Pub. No. 2013/0301569 to Wang et al. (Wang). Applicants respectfully traverse the rejections.

As discussed with the Examiner at the July 20, 2016 interview, the claims are directed to Up-Link (UL) Multi-User (MU) transmissions, and in particular to UL MU acknowledgement transmissions transmitted in response to a Down-Link (DL) frame. The UL MU transmissions may be simultaneous transmitted from respective stations to an Access Point (AP).

A patentee's statements to the USPTO during prosecution in support of patentability estop the patentee from obtaining protection of the subject matter surrendered by such statements. *Athletic Alternatives, Inc. v. Prince Mfg., Inc.*, 73 F.3d 1573, 1582 (Fed. Cir. 1996) (citing *Kinzenbaw v. Deere & Co.*, 741 F.2d 383, 389 (Fed. Cir. 1984)). Here, the patentee equated "network device" and "AP" when representing that all pending claims involved "transmissions . . . from respective stations to an Access Point (AP)." Accordingly, prosecution estoppel applies here, and in addition to the lexicography reasons discussed above, the term "[a/the] network device" should be construed to mean "[an/the] access point" due to prosecution estoppel.

2. "acknowledgement information" (claims 1, 2, 4, 8, 9, 11, 12, 18, & 19)

Defendants' Proposed Construction	Plaintiff's Proposed Construction
"solicitation for information to be transmitted following receipt of the downlink multi-user frame to acknowledge the downlink multi-user frame"	plain and ordinary meaning

The patentee acted as his/her own lexicographer with the phrase "acknowledgement information." While in a vacuum, the phrase "acknowledgement information" might generally refer to any information that relates to an acknowledgement, such as information that provides an acknowledgment, here, in the '520 patent context, the patentee has used the phrase "acknowledgement information" to refer only to a solicitation for information from a non-AP station to acknowledge an AP's downlink transmission. Specifically, the '520 patent specification defines: "***acknowledgement information that is used for indicating to*** respective ***STAs*** a

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scheme/technique used ***to transmit acknowledgement messages to the AP***." '520 patent, 14:16-18 (emphases added). And Defendants' proposed construction is consistent with the patent's remaining disclosure, for example, the patentee's description of FIGs. 1A and 1B as involving "transmission that solicits . . . acknowledgements from . . . stations." '520 patent, 3:55-60. Accordingly, to properly reflect the patentee's use of the phrase "acknowledgement information" in the '520 patent, Defendants' proposed construction should be adopted.

B. U.S. Patent No. 9,763,259

1. "transmitting to the transmitting device a feedback frame including subchannel information measured on a first subchannel after receiving the NDP frame" (claim 1) / "receiving from each receiving device a feedback frame including subchannel information measured on a subchannel that is allocated to each receiving device among a plurality of subchannels into which a band is divided, after transmitting the NDP frame" (claim 18)

Defendants' Proposed Construction	Plaintiff's Proposed Construction
"in response to receiving the NDP frame, transmitting to the transmitting device a feedback frame including subchannel information measured on a first subchannel one SIFS after receiving the NDP frame" (claim 1) "in response to and one SIFS after the transmitting of the NDP frame, receiving from each receiving device a feedback frame including subchannel information measured on a subchannel that is allocated to each receiving device among a plurality of subchannels into which a band is divided" (claim 18) If not construed as above, the terms are indefinite.	plain and ordinary meaning

The disputed claims phrases are recited in claims 1 and 18 respectively, and each phrase requires a step that depends on the condition "after [receiving/transmitting the NDP frame]." Claims 1 and 18 are reproduced in their entireties below.

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1. A sounding method by a first receiving device, the method comprising:

receiving a null data packet announcement (NDPA) frame from a transmitting device;

receiving a null data packet (NDP) frame from the transmitting device after receiving the NPDA frame; and

transmitting to the transmitting device a feedback frame including subchannel information measured on a first subchannel after receiving the NDP frame, the first subchannel being a subchannel that is allocated to the first receiving device among a plurality of subchannels into which a predetermined band is divided,

wherein transmitting the feedback frame includes:

transmitting the feedback frame to the transmitting device while a second feedback frame including subchannel information measured on the second subchannel is transmitted to the transmitting device by a second receiving device, the second subchannel being a subchannel that is allocated to the second receiving device among the plurality of subchannels.

18. A sounding method by a transmitting device, the method comprising:

transmitting a null data packet announcement (NDPA) frame to a plurality of receiving devices;

transmitting a null data packet (NDP) frame to the plurality of receiving devices after transmitting the NPDA frame; and

receiving from each receiving device a feedback frame including subchannel information measured on a subchannel that is allocated to each receiving device among a plurality of subchannels into which a band is divided, after transmitting the NDP frame,

wherein the plurality of feedback frames from the plurality of receiving devices are received at a same time, and the NDPA frame includes allocation information of the plurality of subchannels.

Defendants request that the Court construe the disputed claim phrases because a POSITA would not have known the scope of the invention with certainty, rendering the disputed claim phrases indefinite under 35 U.S.C. § 112, ¶ 2, as they fail to "inform, with reasonable certainty, those skilled in the art about the scope of the invention." *Nautilus, Inc. v. Biosig Instruments, Inc.*, 572 U.S. 898, 901 (2014). For example, a POSITA would not have known with reasonable certainty whether the disputed claim phrases are related to the immediately preceding step of "receiving/transmitting a null data packet (NDP) frame," or whether the feedback frame could be transmitted/received based on different NDP frames or some other triggers. Also, a POSITA would not have known with reasonable certainty whether the requisite condition of "after [receiving/transmitting the NDP frame]" is the condition for either or both "subchannel information measured on a [first] subchannel" and "transmitting/receiving . . . a feedback frame." In addition, the term "after" might include an open-ended timeline starting from the reception of the NDP until forever.

In view of the foregoing uncertainty, a POSITA would have turned to the patent specification for guidance. The '259 specification discloses the beamformer sends a null data packet announcement ("NDPA") frame and a null data packet ("NDP") frame to multiple receiving

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devices, and receives multiple feedback frames from the receiving devices in response to receipt of the particular NDP frame after a short interframe space ("SIFS") interval. *See, e.g.*, '259 patent, 9:18-22 ("The first beamformee device (e.g., beamformee device 1) among the plurality of beamformee devices receiving the NDP frame feeds a feedback frame back to the beamformer device ***as a response of the NDP frame after a SIFS interval***." (emphasis added)). Defendants' proposed constructions are consistent with the '259 patent specification and should be adopted. Otherwise, without a particular construction in light of particular embodiments disclosed in the specification, these claim phrases are indefinite under 35 U.S.C. § 112, ¶ 2.

2. "wherein the NDPA frame indicates information corresponding to the predetermined length" (claim 6)

Defendants' Proposed Construction	Plaintiff's Proposed Construction
indefinite	plain and ordinary meaning

This claim phrase is indefinite under 35 U.S.C. § 112, ¶ 2 as it fails to "inform, with reasonable certainty, those skilled in the art about the scope of the invention." *Nautilus*, 572 U.S. at 901. Specifically, a POSITA would not have understood what is, and what is not, encompassed within the scope of the phrase "indicates information corresponding to." The only disclosure in the '259 specification is at 2:35-37 that "[t]he NDPA frame or the NDP frame may indicate information corresponding to the predetermined length," which is exactly the same as the claim phrase and fails to provide further information for the claim phrase. As such, the patent specification does not disclose how a frame "indicate[s] information," what that information may be, or how any such information "corresponds to the predetermined length." Notably, the patentee elected not to use the claim phrase "contains information" or "identifies information," both of which may arguably have informed a POSITA that the NDPA frame actually provides information. Instead, the patentee intentionally selected language ("indicates information") that denotes that

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"something" other than actual information is provided without explaining what that "something" may encompass.[3] Hence, a POSITA would not have understood the scope of the subject claim term with reasonable certainty and thus the claim is indefinite. Roy Decl., ¶¶ 29-32.

C. U.S. Patent No. 9,825,738

1. "transmitting the downlink data and the uplink setup information in a single physical downlink frame to a plurality of stations" (claim 1) / "the physical downlink frame comprising: uplink setup information including a first information to be used for uplink multi-user transmission by the station, and downlink data" (claim 9)

Defendants' Proposed Construction	Plaintiff's Proposed Construction
"transmitting the downlink data and the uplink setup information in a single physical downlink frame to a plurality of stations, wherein the uplink setup information is that which would otherwise be in an uplink setup or uplink initiation (ULI) frame, and the downlink data is data other than the uplink setup information" (claim 1) "the physical downlink frame comprising: uplink setup information including a first information to be used for uplink multi-user transmission by the station, and downlink data, wherein the uplink setup information is that which would otherwise be in an uplink setup or uplink initiation (ULI) frame, and the downlink data is data other than the uplink setup" (claim 9)	plain and ordinary meaning

The disputed claim phrases require, *inter alia*, transmitting/receiving "*downlink data*" and "*uplink* setup *information*" in a physical *downlink frame*. From the plain claim language, a POSITA would have understood that "downlink data" is different and distinct from "uplink setup information," and claims 1 and 9 require both "downlink data" and "uplink setup information." Moreover, as the patentee, being the lexicographer, elects both the "downlink" and "uplink"

[3] The claim phrase "corresponding to" only further frustrates any reasonable understanding of the intended scope as it further distances the subject claim language from providing actual information.

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descriptors within the same transmitting/receiving step, the patentee must have imparted a particular meaning to *each* of the disputed claim phrases. Turning to the patent specification for guidance, a POSITA would have recognized that the '738 specification specifies a scenario that may arguably be mapped to the claimed feature. *See* '738 patent, 23:61-67 ("[I]nformation included in a ULI frame [containing the setup information] is piggybacked on an NDPA frame . . . information included in a UL setup frame [containing the setup information] is piggybacked on a DL PPDU. Then, the AP and the stations STA1 and STA2 may omit a procedure for exchanging the ULI frame . . . and the UL setup frame."). Accordingly, a POSITA considering the '738 specification would have understood the "setup information" as the ULI frame (or UL setup frame) and the "downlink data" as the NDPA frame (or DL PPDU), both of which are piggybacked together to form the "single physical downlink frame."

Therefore, based on both the plain claim language and the patentee's lexicography in the '738 patent specification, "downlink data" is different and distinct from "uplink setup information," and the "uplink setup information" is that which would otherwise be in an uplink setup or uplink initiation ("ULI") frame. As Defendants' proposed constructions properly reflect the patentee's lexicography and are consistent with the '738 patent specification, their constructions should be adopted.

2. "the second information is a function of a total number of space time streams to be used to transmit the multiple uplink frames" (claim 1) / "the second information is a function of a total number of space time streams to be used to perform the simultaneous transmission of the uplink frame and the one or more uplink frames from the one or more other stations" (claim 9)

Defendants' Proposed Construction	Plaintiff's Proposed Construction
indefinite	plain and ordinary meaning

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Defendants' Proposed Construction	Plaintiff's Proposed Construction
	Alternatively, "The second information in the common information portion is a value that is related to the total number of space time streams to be used to transmit the multiple uplink frames" (claim 1) / "the second information in the common information portion is a value that depends on the total number of space time streams to be used to simultaneously transmit the multiple uplink frames" (claim 9)

These claim phrases are indefinite under 35 U.S.C. § 112, ¶ 2, as they fail to "inform, with reasonable certainty, those skilled in the art about the scope of the invention." *Nautilus*, 572 U.S. at 901. Specifically, these phrases are indefinite because a POSITA would not have been reasonably informed of the claims' scope with respect to the claimed "second information," as the intrinsic record provides no guidance. *See* Roy Decl., ¶¶ 34-36. First, the claims themselves provide no help in construing these phrases as they fail to provide any information on such "a function." Similarly, the patent specification fails to provide any clarity as neither the phrase "a function of a total number of space time streams" nor the phrase "a total number of space time streams" appears in the patent specification. Instead, the patent specification states:

> When the MIMO or the MU-MIMO is used, the transmitting signal processing unit 100 may use a plurality of interleavers 120 and a plurality of mappers corresponding to the number of N_{SS} of spatial streams.

'738 patent, 8:11-14. And while a POSITA may arguably interpret the abbreviation "N_{SS}" to refer to a number of spatial streams, a POSITA would not understand "N_{SS}" to refer to "a total number of space time streams" as claimed, especially as the abbreviation "N_{STS}" also appears in the patent specification. Similarly, while a POSITA may arguably interpret the abbreviation "N_{STS}" (mentioned *only once* in the patent specification) to refer to a number of space-time streams, the related discussion is not in the context of transmitting or receiving "a total number of space time streams" or any "function" thereof but instead states:

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> The transmitting signal processing unit 100 may further include a space-time block code (STBC) encoder for spreading the constellation points from the N_{SS} spatial streams into N_{STS} space-time streams and a spatial mapper for mapping the space-time streams to transmit chains.

'738 patent, 8:18-23; Roy Decl., ¶ 35. Moreover, a POSITA would not have equated "interleavers" or "mappers" to "a function." Roy Decl., ¶ 35. The concept of a "function" is broad, just requiring a mathematical dependence between quantities. Roy Decl., ¶ 36; Ex. 8, page 468 (definition of "function"); Ex. 9, page 682 (definition of "function"). Given that here only two pieces of data are mathematically related (*i.e.*, the "second information" and the "total number of space time streams"), a POSITA would have been unable to ascertain the bounds of the claimed "function" as it is essentially unbounded. Roy Decl., ¶ 36. As a POSITA would not have been informed of the scope of "the second information" with reasonable certainty, the claim is indefinite. *Nautilus*, 572 U.S. at 901.

D. U.S. Patent No. 9,848,442

1. "a mode that is High Efficiency" / "a mode of a standard previous to a standard defining the High Efficiency mode" (claims 1, 8)

Defendants' Proposed Construction	Plaintiff's Proposed Construction
indefinite	"a mode specified as High Efficiency (HE) by an 802.11 Standard or proposed 802.11 Standard" "a legacy mode specified in a IEEE 802.11 Standard released prior to 802.11ax standard or proposed standard (*e.g.*, a non-HT, a HT, a VHT)

The subject claim phrases do not appear in the patent specification. Other than in the claims, the '442 patent does not reference any "mode" or "high efficiency." Although the '442 patent specification discusses the IEEE 802.11 standard and amendments thereto (*see* '442 patent, 1:29-55), nothing in the patent's disclosure, including the claims, limits the claimed invention only to the 802.11 standard. *See, e.g.*, '442 patent, 4:18-22 ("The WLAN device *may* include a medium

access control (MAC) layer and a physical (PHY) layer according to IEEE (Institute of Electrical and Electronics Engineers) 802.11 standard." (emphasis added)).

Furthermore, the '442 patent does not provide any objective criteria by which to determine whether the efficiency of a PPDU's "mode" (whatever that may be) is *sufficiently* "high" so as to fall within the scope of the claimed "mode of High Efficiency." *Nautilus*, 572 U.S. at 910; *Interval Licensing LLC v. AOL, Inc.*, 766 F.3d 1364, 1371 (Fed. Cir. 2014) ("The claims, when read in light of the specification and the prosecution history, must provide objective boundaries for those of skill in the art."). Because no objective criteria for determining the efficiency of various WLAN "modes" exists in the '442 patent specification, much less for determining whether such efficiency is sufficiently "high" to fall within the patent's claims, the subject claim phrases are indefinite.

Plaintiff attempts to preserve the validity of these claims by incorporating into the claims not only limitations directed to 802.11 standards disclosed in the patent specification but also limitations directed to standards that *were not yet contemplated* as of the time of the patent's purported invention. However, it is well established that claims must be construed "as of the effective filing date for the patent application." *Phillips,* 415 F.3d at 1313; *see also PC Connector Sols. LLC v. SmartDisk Corp.*, 406 F.3d 1359, 1363 (Fed. Cir. 2005) ("A claim cannot have different meanings at different times; its meaning must be interpreted as of its effective filing date."). And courts have repeatedly limited claims directed to standards to those versions of the standard that existed at the time of the effective filing date. *See, e.g., BillJCo, LLC, v. Cisco Systems, Inc.*, No. 2:21-CV-00181-JRG, 2022 WL 782740, at *5 (E.D. Tex. Mar. 14, 2022); *ACQIS LLC v. Samsung Elecs. Co.*, No. 2:20-cv-00295-JRG (ECF No. 92), at 32–33 (E.D. Tex. Sept. 26, 2021); *Uniloc USA, Inc. v. Apple, Inc.*, No. 19-cv-01692-EJD (VKD), 2021 WL 432183, at *8 (N.D. Cal. Jan. 15, 2021); *Fundamental Innovation Sys. Int'l LLC v. Samsung Elecs. Co.*,

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No. 2:17-cv-145-JRG-RSP, 2018 WL 647734, at *11 (E.D. Tex. Jan. 31, 2018). Moreover, in these cases, the claimed standard was recited within the disputed claim itself. Here, however, the '442 claim phrases make no reference to *any* 802.11 standard, and the Court should reject Plaintiff's improper attempt to incorporate such limitations into the plain language of the claim.[4]

2. "when the BSS of the first PPDU is the BSS to which the first station does not belong, a received signal strength of the first PPDU is higher than a first threshold, and the first PPDU is a frame having a mode that is High Efficiency and having a PHY header that includes duration information for setting a virtual carrier sensing…; when… the received signal strength of the first PPDU is higher than the first threshold, the first PPDU is a frame having a mode of a standard previous to a standard defining the High Efficiency mode, and the first PPDU is a frame having a PHY header that does not include duration information for setting the virtual carrier sensing…; and when… the received signal strength of the first PPDU is lower than the first threshold" (Claims 1, 8)

Defendants' Proposed Construction	Plaintiff's Proposed Construction
indefinite If not indefinite, the Court must determine whether only one of the claimed steps with mutually exclusive conditions, or all three of the claimed steps with mutually exclusive conditions, are required to occur for purposes of meeting the claim limitations.	plain and ordinary meaning

The '442 patent has one independent method claim (claim 1) and one independent apparatus claim (claim 8). Both claims require the claimed station belonging to a particular basic service set ("BSS"), upon determining from a received first PPDU that the PPDU is from a different BSS, to take different actions depending on certain conditions, referred to below in the

[4] Should the Court adopt Plaintiff's construction despite the imported limitations from the IEEE 802.11 standard, the Court should nevertheless reject the parenthetical portion of the construction providing non-limiting examples, as it not definitional and would not be helpful to a jury.

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subject claim language for ease of briefing as Conditions A, B, and C; the Conditions appear in red text below, with the actions taken on their respective occurrences appearing in blue text.

> . . . when the BSS of the first PPDU is the BSS to which the first station does not belong, ***[A]*** a received signal strength of the first PPDU is higher than a first threshold, and the first PPDU is a frame having a mode that is High Efficiency and having a PHY header that includes duration information for setting a virtual carrier sensing, setting a PHY-level virtual carrier sensing, wherein setting the PHY-level virtual carrier sensing includes setting a virtual carrier sensing by using the duration information included in a PHY header of the first PPDU;
>
> when the BSS of the first PPDU is the BSS to which the first station does not belong, ***[B]*** the received signal strength of the first PPDU is higher than the first threshold, the first PPDU is a frame having a mode of a standard previous to a standard defining the High Efficiency mode, and the first PPDU is a frame having a PHY header that does not include duration information for setting the virtual carrier sensing, setting a medium access control (MAC)-level virtual carrier sensing, wherein setting the MAC-level virtual carrier sensing includes setting the virtual carrier sensing by using duration information included in a MAC header of the first PPDU; and
>
> when the BSS of the first PPDU is the BSS to which the first station does not belong and ***[C]*** the received signal strength of the first PPDU is lower than the first threshold, attempting to obtain a transmission opportunity.

'442 patent, claims 1, 8.

Both Condition A and Condition B have three components, the first of which they have in common; that is, they both occur "when a received signal strength of the first PPDU is higher than a first threshold." However, Condition A also requires that "the first PPDU is a frame having a *mode that is High Efficiency* and having a *PHY header that includes duration information* for setting a virtual carrier sensing" while Condition B requires instead "that the first PPDU is a frame having a *mode of a standard previous to a standard defining the High Efficiency mode*, and the first PPDU is a frame having a *PHY header that does not include duration information* for setting the virtual carrier sensing." (emphases added). Condition C has only one component, which differs from the first components of Condition A and Condition B in that Condition C occurs when "the received signal strength of the first PPDU is lower than the first threshold." Notably, the three Conditions A, B, and C are *mutually exclusive* for a given PPDU. That is, no single received PPDU

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can meet more than one of these Conditions. And importantly, if the claimed station is in an environment with no overlap in basic service sets ("BSSs"), none of the three Conditions would ever occur because "the BSS of the first PPDU" would never be "the BSS to which the first station does not belong."

Turning to claim construction, the subject claim phrase is indefinite because a POSITA would be unable to determine if the claim has or *has not yet* been infringed. For example, with respect to method claim 1, is the claim infringed: (1) at the time when none of the conditions have occurred, and none of the corresponding actions are performed; (2) at the time when one condition has occurred and only one corresponding action has been performed, or (3) at the time when all three conditions have occurred and all three corresponding actions have been performed? *See Cybersettle, Inc. v. Nat'l Arbitration Forum, Inc.*, 243 F. App'x 603, 606-07 (Fed. Cir. 2007) ("A patented method is a series of steps, each of which must be performed for infringement to occur. *It is not enough that a claimed step be 'capable' of being performed.* A party that does not perform a claimed step does not infringe a method claim merely because it is capable of doing so." (emphasis added) (citation omitted)). Similarly, with respect to apparatus claim 8, it is unclear whether, for example, an apparatus that is programmed to practice only one of the corresponding actions can nevertheless practice the claim if used in an environment where only that action's condition (or none of the three conditions) occurs.

In *Cybersettle*, the Federal Circuit stated that "[i]f the condition for performing a contingent step is not satisfied, the performance recited by the step need not be carried out in order for the claimed method to be performed." *Cybersettle*, 243 F. App'x at 607[5]; *see also Ex Parte*

[5] In *Hytera Commc'ns Co. v. Motorola Sols., Inc.*, 841 F. App'x 210, 216 (Fed. Cir. 2021), the Court referred to this statement as dictum.

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Schulhauser, Appeal No. 2013-007847, at 10 (PTAB Apr. 28, 2016) (precedential) (citing *Cybersettle*); *Marvell Semiconductor v. Uniloc 2017*, IPR2019-01350, Paper 24, at 36-39 (P.T.A.B. Feb. 1, 2021). However, the Federal Circuit has also held that where a conditional or contingent limitation modifies a step of a method claim, the method requires performance of each alternative under each given condition, not just one. *Lincoln Nat'l Life Ins. Co. v. Transamerica Life Ins. Co.*, 609 F.3d 1364, 1370 (Fed. Cir. 2010) (holding that the plaintiff failed to prove that the defendant performed the conditional step (e) of the asserted method claim); *see also Hytera Commc'n*, 841 F. App'x at 218 ("Ultimately, our binding precedent in *Lincoln* supports the Board's conclusion that . . . the prior art must teach each step of the claim, including the response to each condition in the 'selecting' step."); *In re Certain Televisions, Remote Controls, and Components Thereof*, Inv. No. 337-TA-1263, USITC Order No. 30, at 7–13 (Jan. 14, 2022) (finding that, in a scenario where the condition of step c) was not met, "it would be unclear to a person of ordinary skill in the art what the outcome of step c) would be").

With respect to the existing Federal Circuit guidance, this Court may follow the Federal Circuit's holding in *Cybersettle* to find that a station that meets none or only one of these conditions clauses is sufficient to practice the claim (in which case, the applicant-admitted prior art invalidates the independent claims of the '442 patent), or the Court may follow the Federal Circuit's holding in *Lincoln* to find that all the steps must be performed when the conditions are met (in which case, the claims remain indefinite as discussed above).

The Court should find the subject claim phrases to be indefinite for the reason discussed above. However, if the Court finds that these phrases are definite, it must issue a determination as to whether *all three* corresponding actions (in blue text above) must actually be performed in order

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to practice the subject claim phrases, or if performing *only one of the three* corresponding actions (or none, if the conditions do not occur) is sufficient to practice the subject claim phrases.

E. U.S. Patent No. 9,912,513

1. "wherein at least a portion of the payload of the uplink frame is associated with the first guard interval length" (claim 1) / "wherein at least a portion of the payload of the uplink frame is associated with the first CP length" (claim 9) / "wherein at least a portion of the legacy header is associated with a second CP length" (claim 10) / "wherein at least a portion of the respective non-legacy header is associated with the first guard interval" (claim 16)

Defendants' Proposed Construction	Plaintiff's Proposed Construction
indefinite	plain and ordinary meaning

Each of the subject claim phrases requires an undefined "portion" of something (*i.e.*, the uplink frame, the legacy header, or the respective non-legacy header) to be "associated with" something else (*i.e.*, a guard interval or CP length) rendering claims 1, 9, 10, and 16 indefinite because a POSITA would not have been reasonably informed of the bounds of the claims with respect to the "portion" of the claimed header and claimed payload and the level to which they must be "associated with" the guard interval or CP length.

Each of the subject claim phrases includes two separate "terms of degree" (*i.e.*, "portion" and "associated with") which, while not inherently indefinite, must "provide[] enough certainty to one of skill in the art when read in the context of the invention" to be considered definite. *Biosig Instruments, Inc. v. Nautilus, Inc.*, 783 F.3d 1374, 1378 (Fed. Cir. 2015) (quoting *Interval Licensing*, 783 F.3d at 1370); *see also Advanced Aerospace Techs., Inc. v. U.S.*, 124 Fed. Cl. 282, 293-94 (Fed. Cl. 2015) (finding "outboard portion" indefinite because "the intrinsic evidence contains no guidance that would informs skilled artisan, with reasonable certainty, as to where the 'outboard portion' begins and ends"). Thus, for the subject claims to be considered definite,

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the ’513 patent must disclose “some standard for measuring” the bounds of the claim terms “portion” and “associated with.” *Biosig Instruments*, 783 F.3d at 1378; *see also Berkheimer v. HP Inc.*, 881 F.3d 1360, 1363 (Fed. Cir. 2018).

Turning first to the language of the claims for guidance in determining the boundaries of these terms, according to the claims, an indication of the guard interval or cyclic prefix (“CP”) is transmitted as part of the downlink transmission “to be used by each of a plurality of stations . . . associated with the UL MU transmission.” ’513 patent, 21:27-35, 22:13-20. Thereafter, “at least a portion of” the uplink frame is “associated with” the guard interval or cyclic prefix. *Id.*, 21:42-44, 22:26-27. However, the claims provide no details as to what “portion” of the uplink frame must be “associated with” the guard interval or cyclic prefix.

The specification also fails to provide any guidance on the objective boundaries for these limitations, with the only references to the guard interval in the context of the uplink frame being that the guard interval may be “used” by the stations in transmitting the uplink frames. *Id.*, 12:64-13:3 (“[T]he participating stations use the predetermined guard interval duration . . . for the first *parts* . . . of their respective frames . . . .” (emphasis added)), 13:48-65 (guard intervals are “utilized by the first part . . . of the downlink frame”), 14:47-63, 15:12-20, 16:22-30, 17:28-38. And Figures 5-8 show only that the guard interval may be pre-pended to the uplink frame but provide no objective guidance on the boundaries of the claimed “portion” of the frame and how it is “associated with” the guard interval. *Id.*, Figs. 5-8.

And given the lack of guidance from the intrinsic record as discussed above, Plaintiff’s “plain and ordinary meaning” construction (which is to be determined from review of the *intrinsic* evidence) is deficient on its face as it fails to specify *any* objective boundary and cannot rely on the patent disclosure or prosecution history for support, as the intrinsic record is silent on this issue.

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Further, Plaintiff's alternative construction should also be rejected because the phrasing "some or all" fails to remedy the indefinite issues. Notably, a "portion" of something, by its plain language, cannot include "all" of it, and the word "some" is no less indefinite than the claim term "portion." As a POSITA would not have been reasonably certain as to the amount of the "portion" of the payload and the extent of which it is to be "associated with" the guard interval, these claim terms (and the corresponding claims) are indefinite.

F. U.S. Patent No. 10,020,919

1. "determining exactly a number of the one or more station information fields in the NDPA…in response to determining that the number of the one or more station information fields in the NDPA is one, transmitting first Channel State Information (CSI) feedback in response to receiving the NDP" (claim 1) / "when the number of the one or more station information fields in the NDPA is greater than one… transmitting the first CSI feedback in response to receiving the first trigger frame" (claim 2) / "when the number of one or more station information fields in the NDPA is greater than one… transmitting second CSI feedback in response to receiving the second trigger frame" (claim 8) / "when a number of the one or more station information fields in the NDPA is one, receiving first Channel State Information (CSI) feedback transmitted in response to the NDP having only one station information field" (claim 11) / "when the number of the one or more station information fields in the NDPA is greater than one… receiving the first CSI feedback in response to transmitting the first trigger frame" (claim 12) / "when the number of one or more station information fields in the NDPA is greater than one… receiving second CSI feedback in response to transmitting the second trigger frame" (claim 19)

Defendants' Proposed Construction	Plaintiff's Proposed Construction
Indefinite. If not indefinite, the claims should be construed as set forth below. Claim 1: determining an exact value of a number of one or more station information fields in the NDPA; …. in response to (i) determining that the value of the number is one, which indicates that there is only one station information field in the NDPA and (ii)	plain and ordinary meaning

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Defendants' Proposed Construction	Plaintiff's Proposed Construction
receiving the NDP, transmitting first Channel State Information (CSI) feedback to an access point Claim 2: when the value of the number is two or more, which indicates that there are two or more station information fields in the NDPA, … transmitting the first CSI feedback to the access point in response to receiving the first trigger frame Claim 8: when the value of the number is two or more, which indicates that there are two or more station information fields in the NDPA, … transmitting second CSI feedback to the access point in response to receiving the second trigger frame Claim 11: when a station determines that the value of a number of the one or more station information fields is one, which indicates that there is only one station information field in the NDPA, receiving first Channel State Information (CSI) feedback transmitted in response to the NDP having only one station information field Claim 12: when the station determines that the value of the number is two or more, which indicates that there are two or more station information fields in the NDPA, … receiving the first CSI feedback in response to transmitting the first trigger frame Claim 19: when the station determines that the value of the number is two or more, which indicates that there are two or more station information fields in the NDPA, … receiving second CSI feedback in response to transmitting the second trigger frame	

Claims 1, 2, 11, and 12 are reproduced in their entireties below.

1. A method performed by a wireless device, the method comprising:

receiving a Null Data Packet Announcement (NDPA), the NDPA including one or more station information fields;

determining exactly a number of the one or more station information fields in the NDPA;

receiving a Null Data Packet (NDP); and

in response to determining that the number of the one or more station information fields in the NDPA is one, transmitting first Channel State Information (CSI) feedback in response to receiving the NDP,

wherein the number of the one or more station information fields in the NDPA is the cardinality of the one or more station information fields in the NDPA.

11. A method performed by a wireless device, the method comprising:

transmitting a Null Data Packet Announcement (NDPA), the NDPA including one or more station information fields;

transmitting a Null Data Packet (NDP); and

when a number of the one or more station information fields in the NDPA is one, receiving first Channel State Information (CSI) feedback transmitted in response to the NDP having only one station information field,

wherein the number of the one or more station information fields in the NDPA is exactly the cardinality of the one or more station information fields in the NDPA.

2. The method of claim **1**, further comprising:
when the number of the one or more station information fields in the NDPA is greater than one:
receiving a first trigger frame; and
transmitting the first CSI feedback in response to receiving the first trigger frame.

12. The method of claim **11**, further comprising:
when the number of the one or more station information fields in the NDPA is greater than one:
transmitting a first trigger frame; and
receiving the first CSI feedback in response to transmitting the first trigger frame.

Independent claim 1 requires, *inter alia*, "determining *exactly a number*" and "determining that the number of the one or more station information fields in the NDPA is one." '919 patent, 33:1-5 (emphasis added). Similarly, claim 11 requires, *inter alia*, "*a number* of the one or more station information fields in the NDPA is one." *Id.*, 34:5-6 (emphasis added). However, the dependent claims 2, 8, 12, and 19 (depending from claim 1 or claim 11) further require "when the number of one or more station information fields in the NDPA is *greater than one*" (*i.e.*, two or more). *See id.*, 33:12-13, 33:41-42, 34:12-13, 34:46-47 (emphasis added). When the independent claims 1 and 11 are practiced (*i.e.*, when the "number . . . is one"), it would be *impossible* to practice dependent claims 2, 8, 12, and 19 (requiring "the number . . . is greater than one"). Conversely, if dependent claims 2, 8, 12, and 19 were practiced, independent claims 1 and 11 would not be practiced. This mutually exclusive relationship between the independent and dependent claims renders the dependent claims 2, 8, 12, and 19 indefinite. That is, where, as here, the dependent claims are "nonsensical and require an impossibility," the Court should find them indefinite. *Synchronoss Techs., Inc. v. Dropbox, Inc.*, 987 F.3d 1358, 1366-67 (Fed. Cir. 2021) (finding asserted claims indefinite where they "are nonsensical and require an impossibility"); *Trustees of Columbia Univ. in City of New York v. Symantec Corp.*, 811 F.3d 1359, 1367 (Fed. Cir. 2016) (holding claims that nonsensically "describe[d] the step of extracting machine code instructions from something that does not have machine code instructions" were indefinite for being "nonsensical").

Alternatively, or in addition, the dependent claims are indefinite in view of the well-established tenet that independent claims must be broader than dependent claims. *See, e.g.*, *Alcon Rsch., Ltd. v. Apotex Inc.*, 687 F.3d 1362, 1367 (Fed. Cir. 2012) ("It is axiomatic that a dependent claim cannot be broader than the claim from which it depends."); *Intamin Ltd. v. Magnetar Techs., Corp.*, 483 F.3d 1328, 1335 (Fed. Cir. 2007) ("An independent claim impliedly embraces more subject matter than its narrower dependent claim."). Plaintiff's plain-and-ordinary construction violates this tenet. If Plaintiff's construction is adopted, the dependent claims would not narrow the independent claims but instead would be *broader* than the independent claims, allowing "greater than one" station information field in dependent claims 2, 8, 12, and 19 with only a single station information field allowed by independent claims 1 and 11. Accordingly, the Court should find the disputed claim phrases indefinite. *See Synchronoss Techs., Inc.*, 987 F.3d at 1366.

Should the disputed claim phrases be found not to be indefinite, the disputed claim phrases at least need specific constructions. Setting aside the limitation of "[determining *exactly*] *a number* . . . is one," each of independent claims 1 and 11 still requires multiple conditions within the same limitation. Independent claim 1 requires, *inter alia*, "***in response to*** determining that the number of the one or more station information fields in the NDPA is one, transmitting first Channel State Information (CSI) feedback ***in response to*** receiving the NDP." '919 patent, 33:4-7 (emphases added). Similarly, claim 11 requires, *inter alia*, "***when*** a number of the one or more station information fields in the NDPA is one, receiving first Channel State Information (CSI) feedback transmitted ***in response to*** the NDP having only one station information field." *Id.*, 34:5-8 (emphases added). As such, it is unclear to a POSITA whether the CSI feedback is transmitted in response to a station's analysis of station information fields ***only***, or in response to ***both*** that analysis and receipt of an NDP. Turning to the specification for guidance, the '919 specification

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describes the CSI feedback process. *See* '919 patent, 18:58-22:56. In each of the disclosed embodiments, CSI feedback is only transmitted in response to *both* a station's analysis of station information fields and receipt of an NDP. *See, e.g.*, *id*, 18:23-25 ("In response to the NDPA transmission and the NDP, a beamformee (such as a station) transmits CSI feedback to the beamformer."); 19:4-8 ("When the first station STA1 determines that the first sounding procedure for CSI feedback is being used, then in response to the NDP 806, the first station STA1 transmits its CSI feedback after a SIFS has elapsed from the end of the NDP 806."). Accordingly, if the disputed claim phrases are found not to be indefinite, Defendants' proposed alternative constructions are consistent with the '919 patent specification and should be adopted.

2. "wherein the number of the one or more station information fields in the NDPA is the cardinality of the one or more station information fields in the NDPA" (claims 1, 11)

Defendants' Proposed Construction	Plaintiff's Proposed Construction
plain meaning: wherein the number of the one or more station information fields in the NDPA is the number of the one or more station information fields in the NDPA This plain meaning renders the claims indefinite.	plain and ordinary meaning Alternatively, "wherein the number of the one or more station information fields in the NDPA is the number of elements in the set of station information fields"

Independent claims 1 and 11 require "determining *exactly a number*" and "determining that the number of the one or more station information fields in the NDPA is one." In other words, claims 1 and 11 explicitly recite that the number of the "one or more station information fields" is "one," resulting in this claim limitation being nonsensical (essentially meaning "one is one"). To the extent Plaintiff attempts to ascribe any meaning other than "one is one" to the subject claim phrase in view of the other claim 1 and claim 11 language, the claims are indefinite.

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G. U.S. Patent No. 10,756,851

1. "scheduling extension" (claims 1, 2, 7, 8)

Defendants' Proposed Construction	Plaintiff's Proposed Construction
"an extension appended to the control field that is dedicated to including scheduling information"	plain and ordinary meaning: "an extension to the control field that includes scheduling information"

The subject claim phrase should be construed as proposed by Defendants due at least to prosecution-history estoppel. Prosecution-history estoppel prevents a patentee from recapturing subject matter surrendered during prosecution from the literal scope of a claim. *See Hoganas AB v. Dresser Indus., Inc.*, 9 F.3d 948, 950 n.6 (Fed. Cir. 1993). Here, the subject claim term only appears in the claims and was introduced by the patentee in an amendment by replacing "an extension" with "a scheduling extension." *See* March 25, 2020 Amendment (reproduced in part below). This amendment effectively excludes "an extension" (i.e., excludes just any type of extension) from the claimed phrase "scheduling extension." Accordingly, Defendants propose that the phrase means "an extension . . . that is dedicated to including scheduling information."

1. (Currently Amended) A station for facilitating multi-user communication in a wireless network, the station comprising:

one or more memories; and

one or more processors coupled to the one or more memories, the one or more processors configured to cause:

receiving a first frame of a downlink transmission for a plurality of stations;

obtaining ~~scheduling information~~a control extension indication from a control field included in the first frame;

determining whether [[a]] the control extension indication ~~field~~ included in the first frame indicates whether the control field includes [[an]] a scheduling extension;

obtaining ~~additional~~ scheduling information from the control field when the control extension indication ~~field~~ indicates that the control field includes the scheduling extension;

generating a second frame for a multi-user uplink transmission with the plurality of stations based on the scheduling information ~~and~~ included in the ~~additional~~ scheduling ~~information~~extension; and

transmitting the second frame as part of the multi-user uplink transmission with the plurality of stations.

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Further, the claim language as amended explains that the scheduling extension is associated with the control field ("the control field includes the scheduling extension") and includes "scheduling information" ("the scheduling information included in the scheduling extension"). Defendants' construction reflects each of these concepts. Moreover, although the '851 patent specification does not use the term "scheduling extension," it does discuss an HE Control Extension ("HECE"). *See* '851 patent, 30:11-33:52, 40:11-44, Fig. 13. And consistent with the language of the claims, the patent specification explains that a HE control extension indicator ("HECEI") field indicates whether or not the HECE field "exists." *Id.*, 30:40-42 ("[I]f the HECEI field is set to one, then the HECE subfield 1320 exists; otherwise the HECE does not exist."); *see also, e.g.*, claim 1 ("determining whether the control extension indication . . . indicates whether the control field includes a scheduling extension"). When in existence, the HECE is an extension to the legacy HT Control Field. *Id.*, 30:11-15, 40:28-32. "The structure of the HT Control (HTC) field and its ***possible extension*** is shown in FIG. 13." *Id.*, 40:28-29 (emphasis added), Fig. 13 (annotated below).

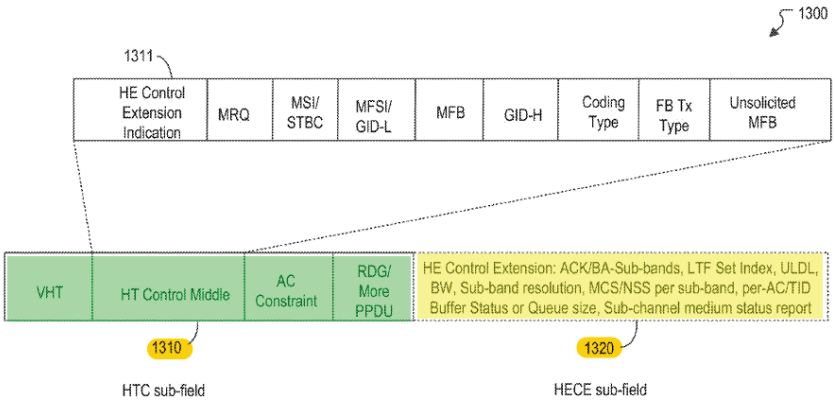


FIG. 13

In Figure 13 above, the legacy HT Control Field (highlighted yellow) is designated by numeral 1310, with the HECE subfield, designated by numeral 1320, appended to the right end. In this

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respect, even Plaintiff's cited extrinsic evidence accords with the appending of the "scheduling extension" to the HT control field. *See, e.g.*, ATLAS-00033174 (dictionary excerpt defining "extension" as "a part that is *added to something* to enlarge or prolong it" (emphasis added)). Accordingly, Defendants propose that the claim phrase "scheduling extension" be construed to mean "an extension appended to the control field that is dedicated to including scheduling information," and the Court should adopt Defendants' construction as it comports with both the intrinsic record, including prosecution estoppel, and the extrinsic evidence.

IV. CONCLUSION

For the reasons set forth above, the Court should adopt Defendants' proposed constructions.

Date: February 9, 2023

Respectfully submitted,

/s/ Mark D. Strachan

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CERTIFICATE OF SERVICE

The undersigned certifies that on February 9, 2023, all counsel of record who are deemed to have consented to electronic service are being served with a copy of this document through the Court's CM/ECF system.

*/s/ Mark D. Strachan*____
Mark D. Strachan

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IN THE UNITED STATES DISTRICT COURT
FOR THE WESTERN DISTRICT OF TEXAS
WACO DIVISION

ATLAS GLOBAL TECHNOLOGIES LLC, Plaintiff, v. ZYXEL NETWORKS CORPORATION AND ZYXEL COMMUNICATIONS CORPORATION Defendants.	Civil Action No. 6:22-cv-00355-ADA
D-LINK CORPORATION, Defendant.	Civil Action No. 6:22-cv-00520-ADA

DECLARATION OF DR. SUMIT ROY IN SUPPORT OF THE OPENING CLAIM CONSTRUCTION BRIEF OF DEFENDANTS ZYXEL NETWORKS CORPORATION, ZYXEL COMMUNICATIONS CORPORATION, AND D-LINK CORPORATION

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A. U.S. Patent No. 9,763,259 6

1. "wherein the NDPA frame indicates information corresponding to the predetermined length" (claim 6) 6

B. U.S. Patent No. 9,825,738 8

1.. "the second information is a function of a total number of space time streams to be used to transmit the multiple uplink frames" (claim 1) 8

2.. "the second information is a function of a total number of space time streams to be used to perform the simultaneous transmission of the uplink frame and the one or more uplink frames from the one or more other stations" (claim 9) 8

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I, Sumit Roy, hereby declare:

1. My name is Sumit Roy, Program Lead at Innovate Beyond 5G. I am over eighteen years of age and I could competently testify as to the matters set forth herein if I am called upon to do so.

2. I am a technical expert in the subject matter areas relevant to the patents-in-suit including the area of wireless communication systems and methods. I am qualified to reach the opinions and conclusions stated in this Declaration.

3. My opinions expressed herein are based on my review of the patents-in-suit, their prosecution histories, extrinsic evidence relating to the technology of the patents-in-suit, and other evidence cited in this declaration. My opinions are also based on my technical experience, knowledge, and expertise in the area of wireless communications systems and methods.

4. I am being compensated for my work on this case at my standard hourly rate of $800 per hour. No part of my compensation is dependent upon the outcome of this case or any issue in it.

I. EDUCATION AND EXPERIENCE

5. I am an expert in the field of wireless networks. I have studied, taught, practiced, and researched this field for over thirty years. I have summarized in this section my educational background, work experience, and other relevant qualifications.

6. I earned my Bachelor of Technology degree in Electrical Engineering from Indian Institute of Technology in Kanpur in 1983. In 1985, I earned my Master of Science degree in Electrical Engineering from University of California in Santa Barbara. I earned a Doctor of Philosophy in Electrical Engineering and Master of Arts in Statistics & Applied Probability from University of California in Santa Barbara in 1988, with my dissertation being on "Estimation Strategies for a Network of Distributed Sensors."

7. While a graduate student, from 1983 through 1988, I worked on various projects related to networked wireless communication and radar systems using a mix of analytical modeling and computer simulation.

8. In July of 1988, I joined the faculty of the University of Pennsylvania as an Assistant Professor in the Department of Electrical Engineering, where I taught upper level undergraduate course called "Communication Systems" and graduate level courses, "Advanced Digital Signal Processing" and "Digital Communications."

9. In January of 1995, I became a tenured Associate Professor in the Division of Engineering at the University of Texas at San Antonio, in San Antonio, Texas. In April of 1998, I transferred to a tenured Associate Professor in the Department of Electrical Engineering in the University of Washington ("UW") in Seattle, Washington and was promoted to Professor in September of 2002. As a faculty member at UW, I have taught courses and directed research in networking and telecommunications, including 802.11 WLAN and cellular technologies. From September 2014 to September of 2019, I received Integrated Systems Term Professorship at the UW in recognition of my leadership and national stature in this area.

10. I took full-time leave from UW to serve as a Senior Staff Researcher at Intel Labs, Hillsboro, OR from September 2001 to December 2003, where I served as Wireless Systems Architect researching IEEE 802.15.3a Ultra-Wideband PHY layer for Wireless Personal Area Networks and nascent pre-802.11n (MIMO WiFi) technology, with responsibility for representing Intel at IEEE Standards meetings and coordination with other industry partners. My research resulted in several patents relating to the above, including design implementation of MIMO WiFi transceivers.

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11. As a result of my academic teaching, research, and industry experience, I have significant knowledge of wireless networking technologies. Since 1988, I have received over ten million dollars in funding from various national and international organizations to support my work on wireless networking.

12. In addition to advising and mentoring students at UW, I have served as external dissertation reviewer for several reputed international universities, such as McGill Univ., Montreal, National University of Singapore, University of Victoria, and Australia National University. At UW and U. Penn., I have advised and supervised over 20 Ph.D students and visiting scholars.

13. In addition to my academic work, I have remained active in the communication industry through my consulting work. I consulted for Mathworks, a vendor of WLAN toolbox products for design, on current 802.11 designs including MIMO systems. I am also the named inventor on U.S. Patent Nos. 7,782,970 and 8,289,836 titled "An Apparatus and Associated Methods to Introduce Diversity in a Multi Carrier Channel," among others, which are listed in my curriculum vitae.

14. I have authored and co-authored over 200 journal publications, conference proceedings, technical papers, book chapters, and technical presentations in a broad array of communications-related technologies, including networking and wireless communication. I have also developed and taught over 10 courses related to communications and computer systems, including several courses on signals and systems, wireless communication, communications systems. These courses included introductory courses on communication systems, as well as more advanced courses on wireless communications. A complete list of my publications and the courses I have developed and/or taught is also contained in my curriculum vitae.

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15. My professional affiliations include serving in various professional organizations and as a reviewer for a number of technical publications, journals, and conferences. I have also received multiple awards and recognitions, most notably, elevation to IEEE Fellow in 2007 for "contributions to multi-user communications theory and cross-layer design of wireless networking standards." By IEEE bylaws, only 0.1% of IEEE membership is elevated to Fellow annually. *See* https://www/ieee.org/membership/fellows/steps.html. In addition, I was selected as IEEE Communications Society's Distinguished Lecturer (2014-15, 2017-18), and appointed by Shanghai JiaoTung University as High-end Foreign Expert award (1 month/year, 2014-16), which are listed in my curriculum vitae.

17. I am not now and have never been an employee of Defendants.

II. LEGAL STANDARDS

18. I am not a legal expert and offer no opinions on the law. However, I have been informed by counsel of the legal standards that apply with respect to claim construction, and I have applied them in arriving at my conclusions.

19. I understand that claim terms in a patent should be interpreted from the vantage point of a person of ordinary skill in the art ("POSITA") at the time of the invention.

20. I am familiar with patents and with the legal framework by which claim terms in patents are to be interpreted. I understand that a claim term must be given the meaning it would have had to one of skill in the art at the time of the invention after reviewing the intrinsic record.

21. With respect to construing the patent claims, I understand that one must first consider the intrinsic evidence, which includes the claim language, the specification, and the prosecution history of the asserted patent. I further understand that one may also consider extrinsic evidence to ensure that a claim construction is not inconsistent with clearly expressed and widely held understandings in the pertinent technical field, particularly for technical terms. Such extrinsic

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evidence may take the form of expert testimony, dictionaries, textbooks, technical treatises, and articles. I further understand that one may not rely on extrinsic evidence to contradict or vary the clear meaning of claims provided by the intrinsic evidence of record.

22. I understand that a claim is indefinite if one skilled in the art would not understand what is claimed even after the claim is read in light of the specification. Specifically, a claim is indefinite if a person of ordinary skill in the art would not understand the scope of the claim with reasonable certainty. I understand that a claim is indefinite if its full scope is not reasonably certain to a POSITA, even if a POSITA would be able to discern particular embodiments that are within the scope of the claim.

23. I further understand that if a claim attempts to cover both an apparatus and a method of use of that apparatus, the claim is indefinite. Similarly, I understand that if a claim does not inform with reasonable certainty one skilled in the art of when, as a matter of timing, the claim would be infringed, then the claim is indefinite.

III. THE PATENTS-IN-SUIT

A. The Effective Filing Date of U.S. Patent Nos. 9,763,259 & 9,825,738

24. For purposes of this declaration, I have been instructed to use the following dates as the effectives filing date of U.S. Patent Nos. 9,763,259 and 9,825,738.

Patent	Priority Date of Asserted Claims
9,763,259	September 15, 2014
9,825,738	April 4, 2015

25. My opinions in this declaration were formed from the perspective of a person of ordinary skill in the art as of the dates listed above.

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IV. CLAIM TERMS

26. I understand that the parties dispute the meaning of certain claim terms of the following U.S. Patent Nos. 9,763,259 ("259 Patent") and 9,825,738 ("738 Patent)[1]. The disputed claim terms I have been asked to address are:

a. "wherein the NDPA frame indicates information corresponding to the predetermined length" (259 patent, claim 6)

b. "the second information is a function of a total number of space time streams to be used to transmit the multiple uplink frames" (738 patent, claim 1)

c. "the second information is a function of a total number of space time streams to be used to perform the simultaneous transmission of the uplink frame and the one or more uplink frames from the one or more other stations" (738 patent, claim 9)

27. I have been asked to address each of these claim terms from the perspective of a person of ordinary skill in the art at the time of the invention.

V. ANALYSIS

A. U.S. Patent No. 9,763,259

1. "wherein the NDPA frame indicates information corresponding to the predetermined length" (claim 6)

Defendants' Proposed Construction	Atlas' Proposed Construction
Indefinite	Plain and ordinary meaning

28. The above limitation is included in claim 6 of the 259 patent. I have been asked to provide the perspective of a person of ordinary skill in the art regarding the meaning of the above limitation in the context of the 259 patent.

[1] The patents-in-suit are attached as Ex. 2 ("259 patent"), and Ex. 3 ("738 patent").

29. In particular, I find that a POSITA would not have been informed, with reasonable certainty, of the scope of the phrase "indicates information corresponding to."

30. The specification provides no guidance as to the bounds of the phrase "indicates information corresponding to" besides noting that "[t]he NDPA frame or the NDP frame may indicate information corresponding to the predetermined length. Ex. 2, 2:35-37. The specification contains no disclosure on how a frame is to "indicate[] information" or how that indicated information is to "correspond[] to the predetermined length." I note that this phrase is different than if patentee had chosen the phrase "contains information" or "identifies." If patentee had chosen those phrases, a POSITA would have recognized that this limitation would require that the NDPA frame *contains* or *identifies* information corresponding to the predetermined length. Instead, patentee's choice of vague words are further complicated by the requirement that the indicated information must be "corresponding to" the predetermined length.

31. The "predetermined length" in the context of this claim is the length against which the data is compared to determine whether pad bits are to be added to the frame. '259 patent, 2:28-31. If the data is shorter than the "predetermined length," pad bits are added to the frame. *Id*. If it is longer than the "predetermined length," the data is partitioned into a plurality of fragments and "any one of the fragments" is inserted into the data field of the feedback frame. *Id*. at 2:31-34.

32. A POSITA would have been unable to ascertain the bounds of which the indicated information is to "correspond to" the predetermined length nor what that "information" entails and to what level suffices for it to be indicated.

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B. U.S. Patent No. 9,825,738

1. "the second information is a function of a total number of space time streams to be used to transmit the multiple uplink frames" (claim 1)

2. "the second information is a function of a total number of space time streams to be used to perform the simultaneous transmission of the uplink frame and the one or more uplink frames from the one or more other stations" (claim 9)

Defendants' Proposed Construction	Atlas' Proposed Construction
Indefinite	Plain and ordinary meaning

33. The above limitations are included in claims 1 and 9 of the '738 patent. I have been asked to provide the perspective of a person of ordinary skill in the art regarding the meaning of the above limitations in the context of the '738 patent.

34. I opine that these claim limitations are indefinite because a POSITA would not be reasonably apprised of the claims' bounds with respect to the limits of "the second information" that is claimed.

35. First, the claims themselves provide no help in ascertaining any objective meaning of these terms and the phrase "a function of a total number of space time streams" or "a total number of space time streams" does not appear in the specification. Rather, the Specification states "[w]hen the MIMO or the MU-MIMO is used, the transmitting signal processing unit 100 may use a plurality of interleavers 120 and a plurality of mappers corresponding to the number of N_{SS} of spatial streams." '738 patent, 8:11-14. At most, a POSITA would understand the abbreviation "N_{SS}" to refer to a number of spatial streams, not "a total number of space time streams" which is a wholly different concept. While a POSITA may recognize that N_{STS} refers to a number of space-time streams, this disclosure does not discuss anything related to a "function" of the space time streams being used to transmit the uplink frame. *Id.*, 8:18-25. What's more,

"interleavers" and "mappers" are not "functions," they are devices. *Id*. at 8:4-10, Fig. 8. Thus, this disclosure is in no way teaching anything related to a "function" of space time streams. It merely discloses the actions performed by various devices such as mapping and interleaving of signals as part of the transmitting signal processing unit.

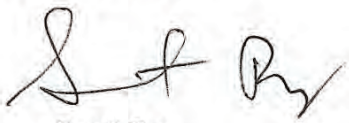
36. "Function" is a broad term. It is defined as "[w]hen a mathematical quality u depends on a variable quantity x so that to each value of x (within the interval of definition) there correspond one or more values of u, then u is a function of x written u." Ex. 8, page 468 (IEEE dictionary – function). As required by the claims, the "second information" is an information that is "common to all of the plurality of stations to receive the uplink setup information." '738 patent, 25:3-8, 26:9-14. Thus, these claims entail a "second information" that is mathematically dependent on a total number of number of space time streams to be a "function" of it. But, as there are only two pieces of data included in the mathematical relation (and they are supposed to share a relation between each other), these claims are unbounded. A POSITA would have understood that these claim limitations have no objective boundaries because every "second information" will be a "function" of the total number of space time streams as there will always be some sort of mathematical relation between the two data.

37. As such, a POSITA would have understood that this claim limitation is indefinite because a POSITA would not have been able to understand any objective boundaries.

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Executed on the 8th day of February, 2022, in Bothell, WA.

I declare under penalty of perjury that the foregoing is true and correct.



Sumit Roy

EXHIBIT LIST

Exhibit No.	Description
1	U.S. Patent No. 9,531,520 (ATLAS-00000001 - ATLAS-00000033)
1A	Partial File History of U.S. Patent No. 9,531,520 FH, July 22, 2016 Amendment (ATLAS-00004051 - ATLAS-00004060)
2	U.S. Patent No. 9,763,259 (ATLAS-00004620 - ATLAS-00004658)
3	U.S. Patent No. 9,825,738 (ATLAS-00008981 - ATLAS-00009022)
4	U.S. Patent No. 9,848,442 (ATLAS-00013900 - ATLAS-00013919)
5	U.S. Patent No. 9,912,513 (ATLAS-00014189 - ATLAS-00014213)
6	U.S. Patent No. 10,020,919 (ATLAS-00018964 - ATLAS-00018995)
7	U.S. Patent No. 10,756,851 (ATLAS-00020345 - ATLAS-00020388)
7A	Partial File History of U.S. Patent No. 10,756,851, March 25, 2020 Amendment (ATLAS-00020530 - ATLAS-00020541)
8	IEEE 100: The Authoritative Dictionary of IEEE Standards Terms (7th ed. 2000), page 468
9	Definition of "Function" from New Oxford American Dictionary (2nd Ed. 2005), page 682 (ATLAS-00033191 - ATLAS-00033195)

APPENDIX

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EXHIBIT 1

U 8146575

THE UNITED STATES OF AMERICA

TO ALL TO WHOM THESE PRESENTS SHALL COME:

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office

August 23, 2021

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U.S. PATENT: *9,531,520*
ISSUE DATE: *December 27, 2016*

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(12) **United States Patent**
Kwon et al.

(10) **Patent No.: US 9,531,520 B2**
(45) **Date of Patent: Dec. 27, 2016**

(54) **APPARATUS AND METHOD FOR DOWNLINK AND UPLINK MULTI-USER TRANSMISSIONS**

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Related U.S. Application Data

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(51) **Int. Cl.**

H04L 5/00	(2006.01)
H04W 72/12	(2009.01)
H04W 72/04	(2009.01)

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

CPC ***H04L 5/0055*** (2013.01); ***H04W 72/042*** (2013.01); ***H04W 72/0446*** (2013.01); ***H04W 72/1268*** (2013.01)

(58) **Field of Classification Search**

CPC H04L 1/1621; H04L 1/1685; H04L 1/1854; H04L 1/1864; H04L 1/1887; H04L 1/1896; H04L 5/0055; H04L 1/00; H04L 1/12; H04L 1/16; H04L 1/1614; H04L 1/1861; H04L 27/2601; H04L 27/2628; H04W 4/06; H04W 28/044; H04W 84/12; H04W 72/042; H04W 72/0406; H04W 72/0446; H04W 72/1268; H04B 7/0452; H04J 11/00

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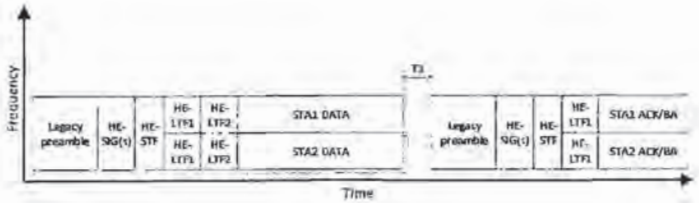
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Primary Examiner — Tri H Phan

(57) **ABSTRACT**

Methods and devices are described that facilitate uplink multi-user acknowledgment transmissions. In particular, acknowledgment information may be located in a media access control (MAC) header of a payload section of a MAC Protocol Data Unit within a downlink multi-user frame. The acknowledgment information may be present in each resource unit of the downlink multi-user frame to indicate to each corresponding station properties/characteristics of a subsequent acknowledgment transmission. The properties may include one or more of (1) whether the acknowledgement transmission is multi-user or single user, (2) whether the acknowledgement transmission is transmitted immediately following receipt of the downlink multi-user frame or upon receipt of a multi-user block acknowledgement request frame, and (3) resource scheduling information for an uplink multi-user acknowledgement transmission.

20 Claims, 13 Drawing Sheets



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(58) **Field of Classification Search**
USPC 370/310–350
See application file for complete search history.

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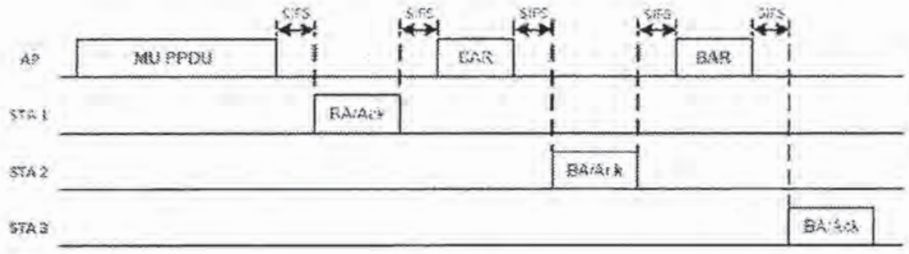


FIG. 1A

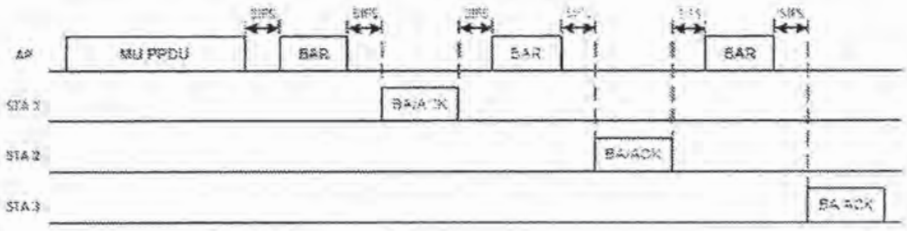


FIG. 1B

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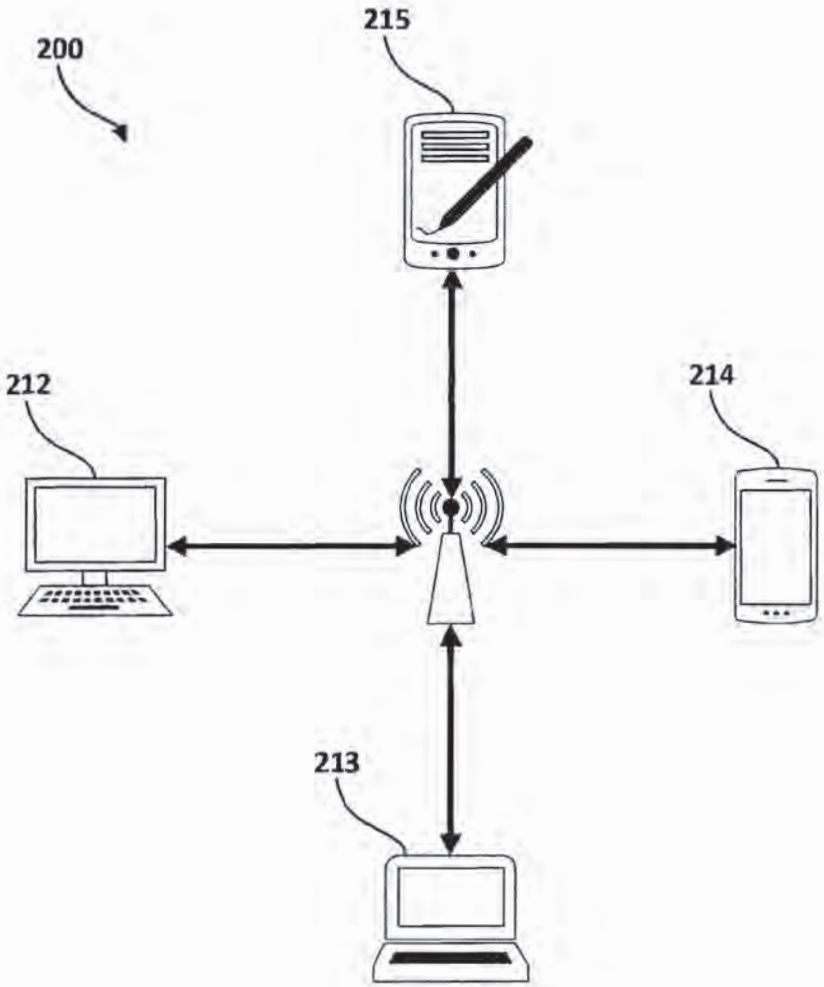


FIG. 2

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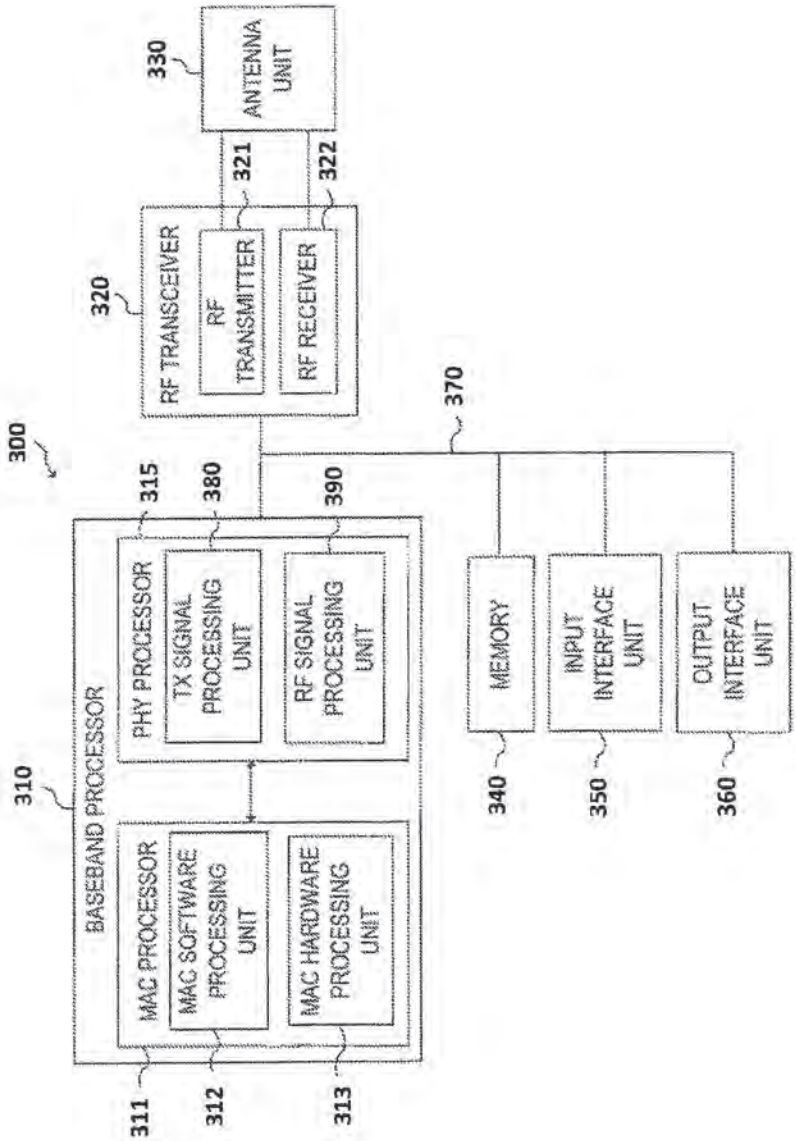


FIG. 3

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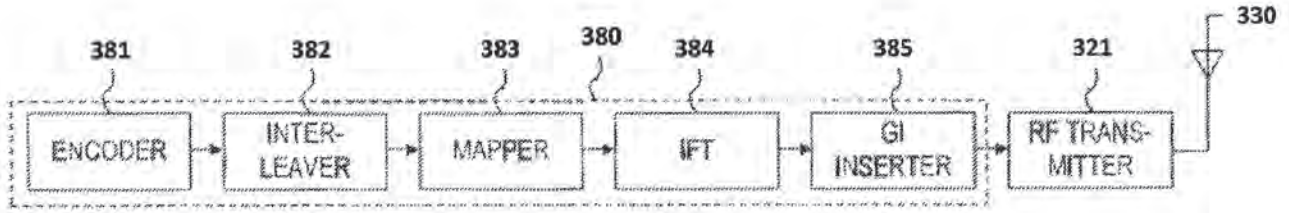


FIG. 4A

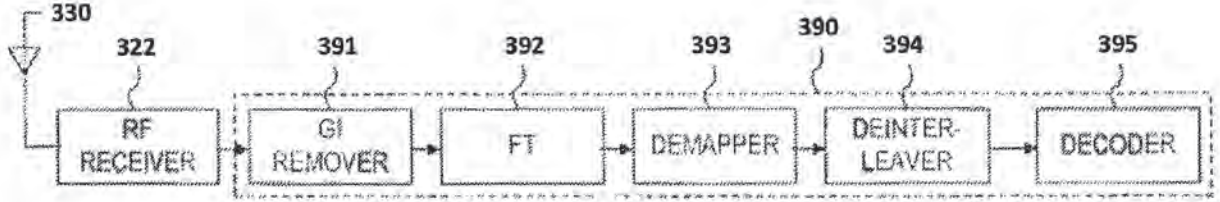


FIG. 4B

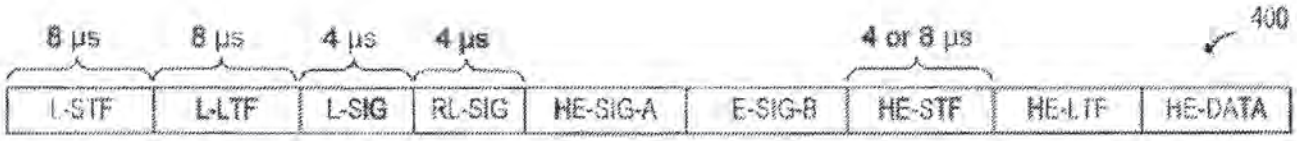


FIG. 4C

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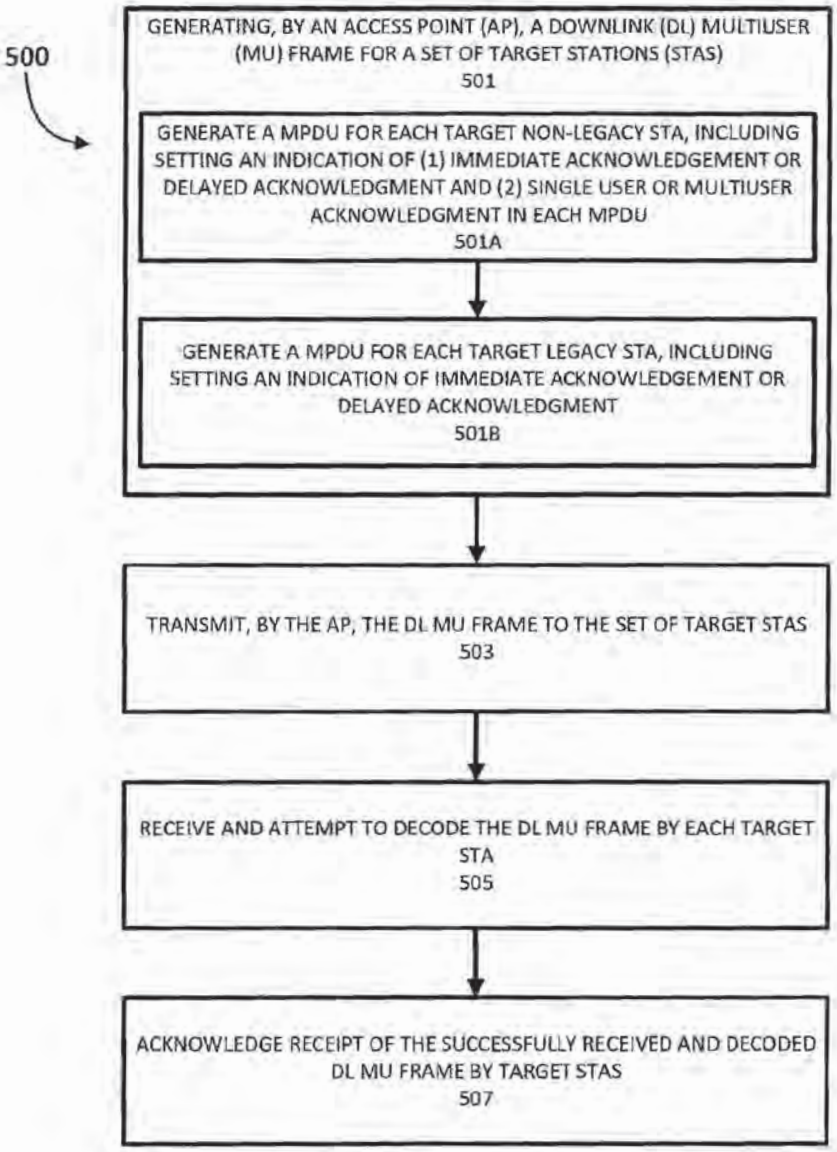


FIG. 5A

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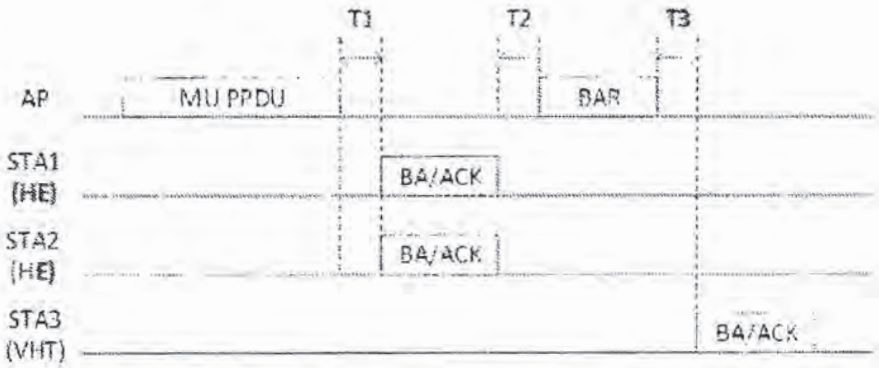


FIG. 5B

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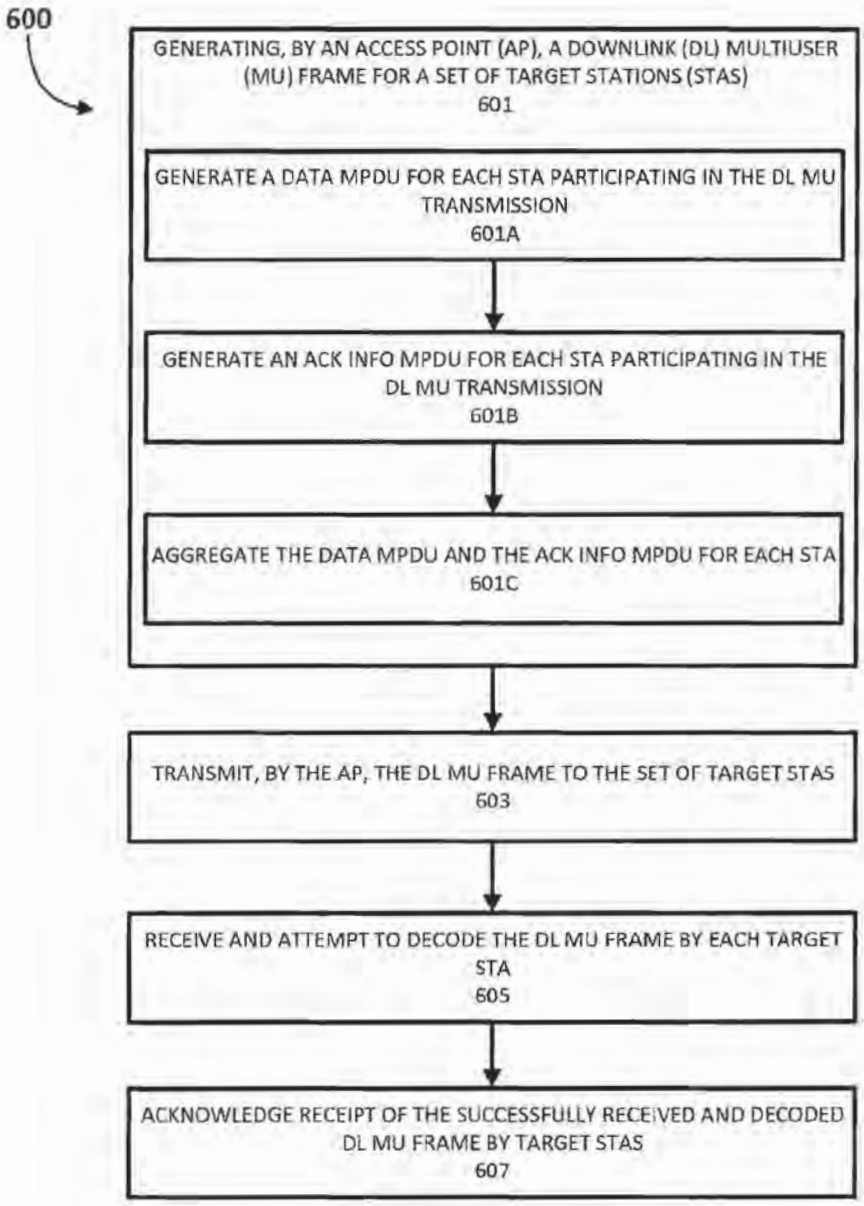


FIG. 6A

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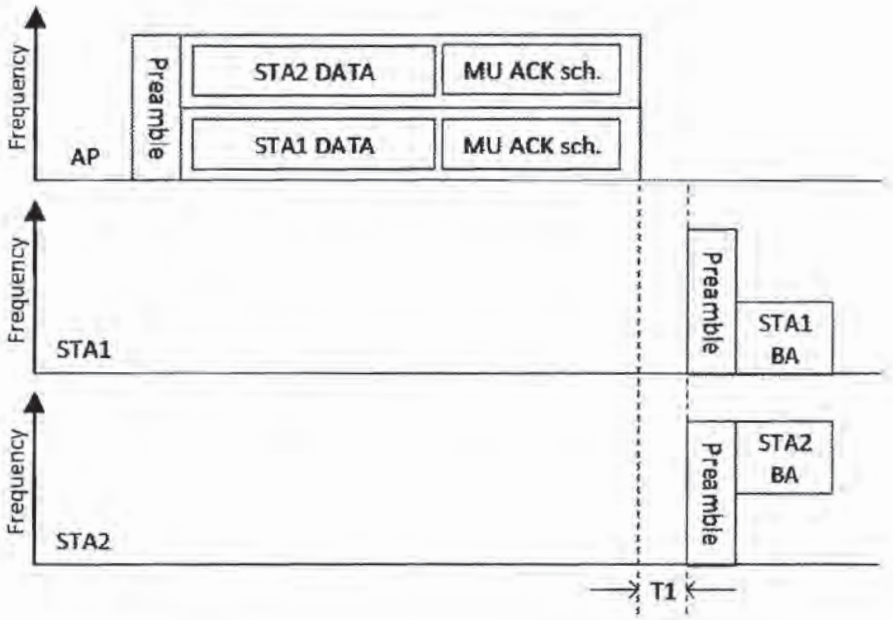


FIG. 6B

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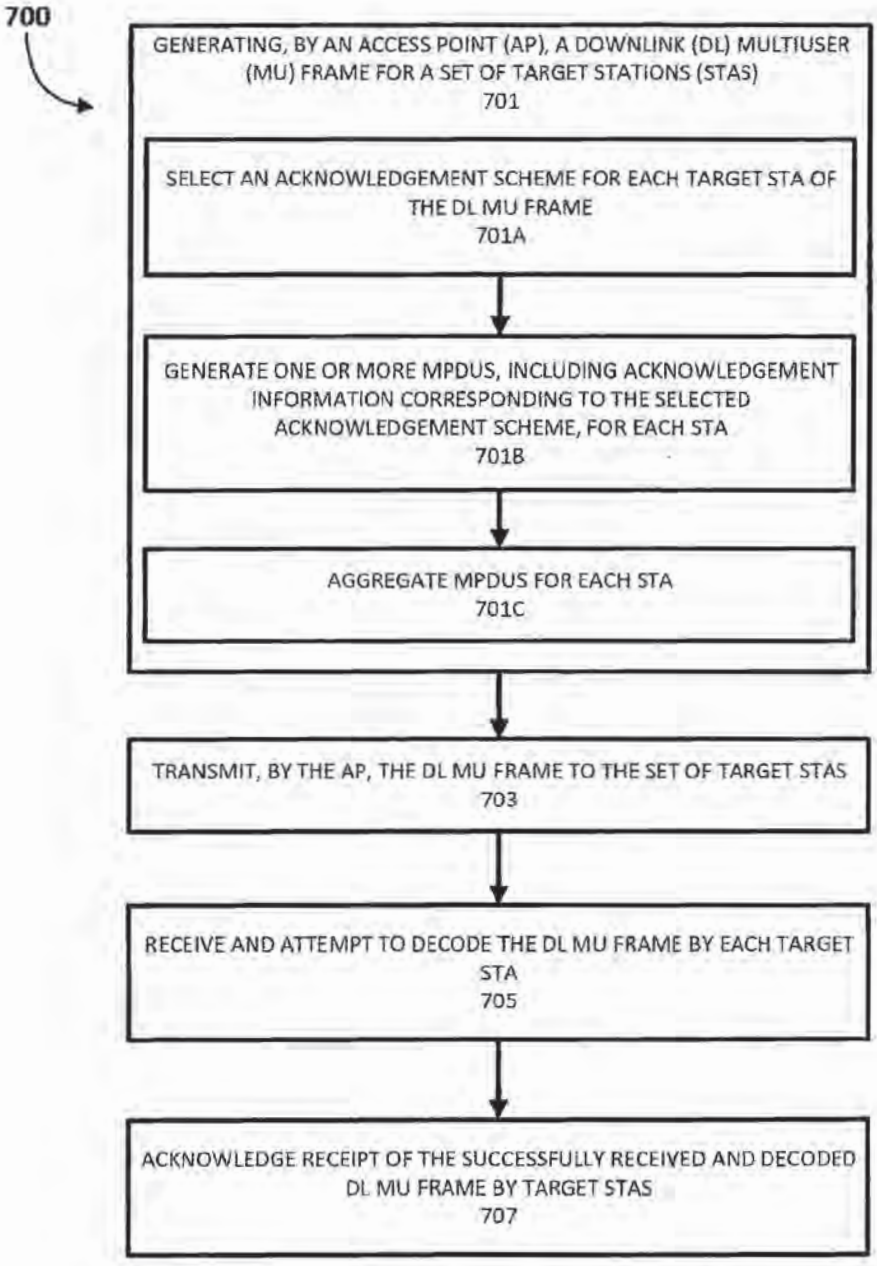


FIG. 7A

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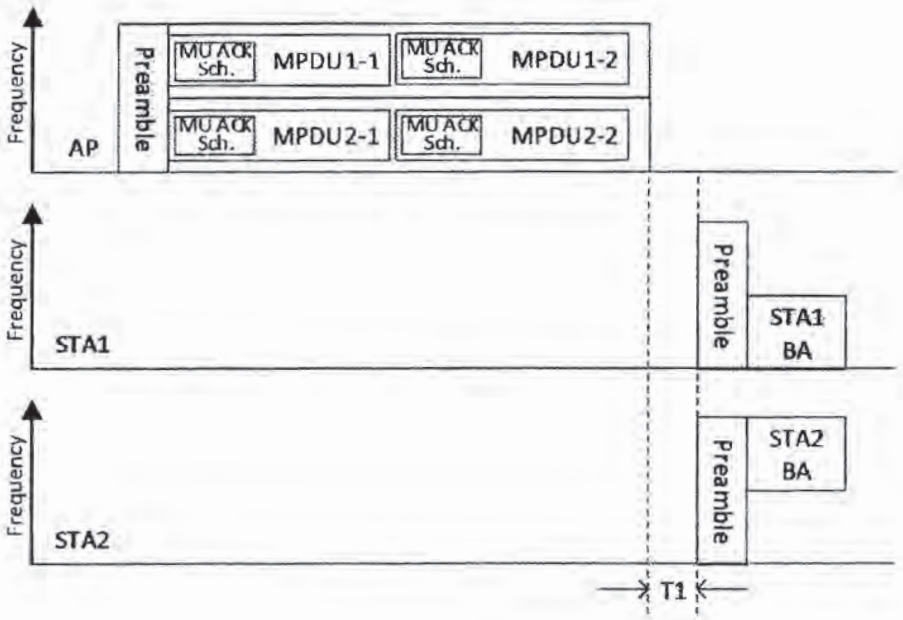


FIG. 7B

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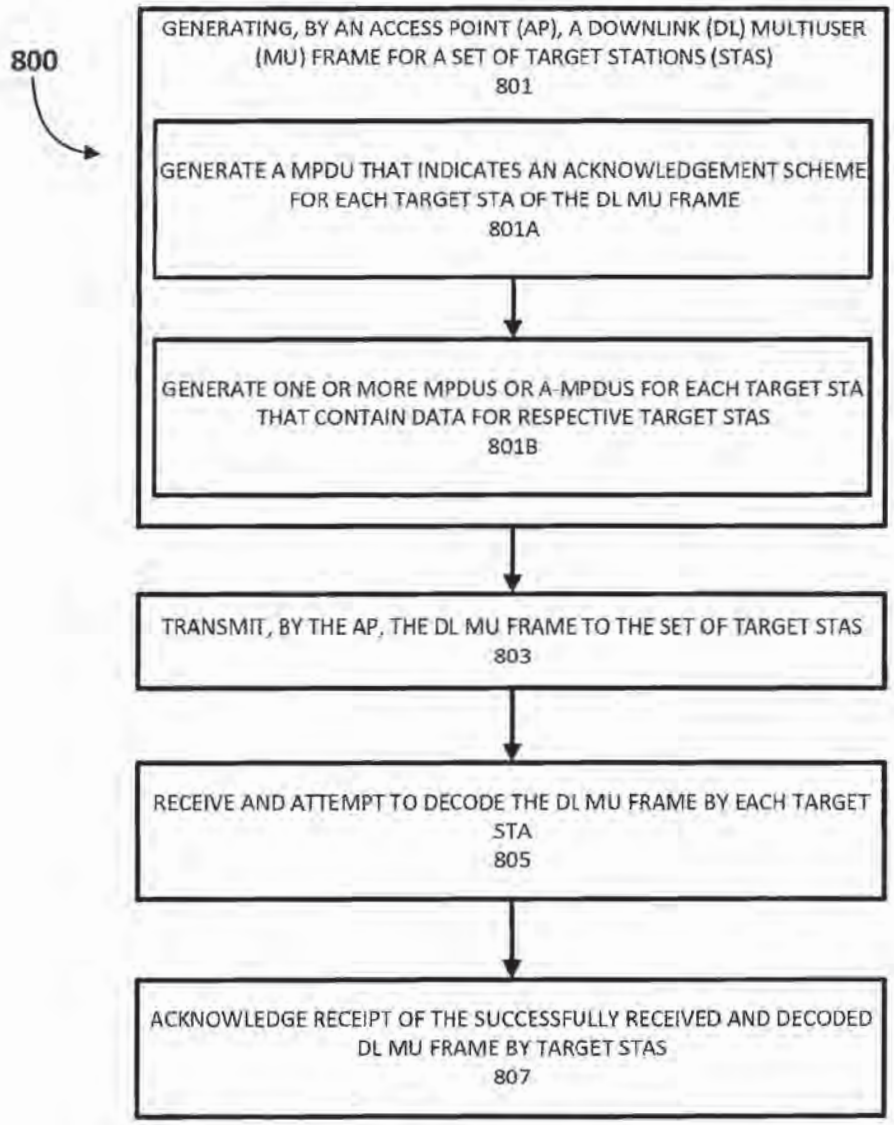


FIG. 8A

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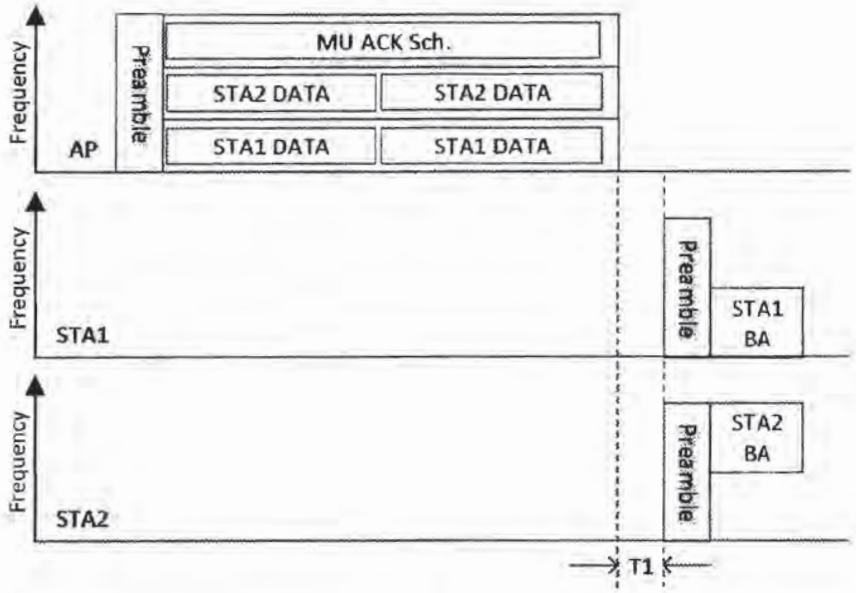


FIG. 8B

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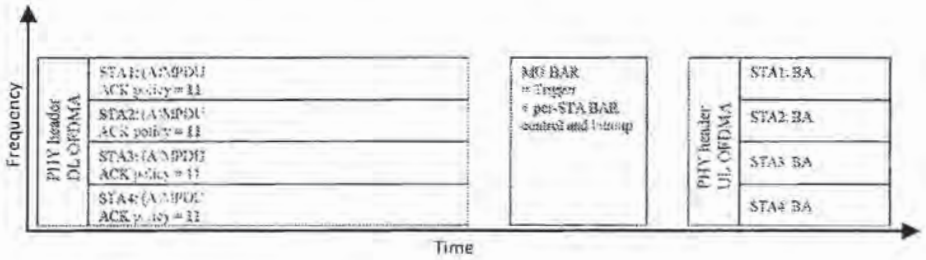


FIG. 9

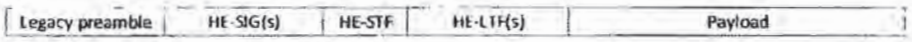


FIG. 10

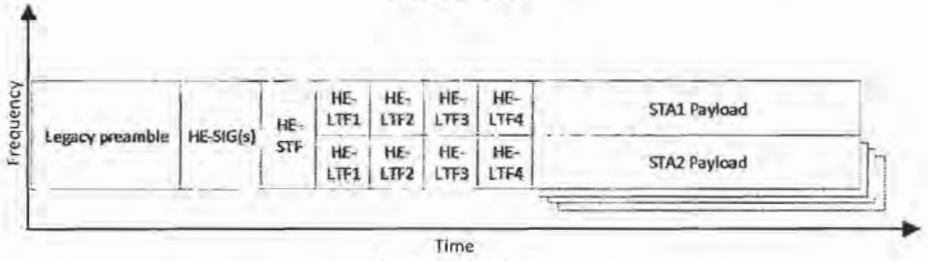


FIG. 11

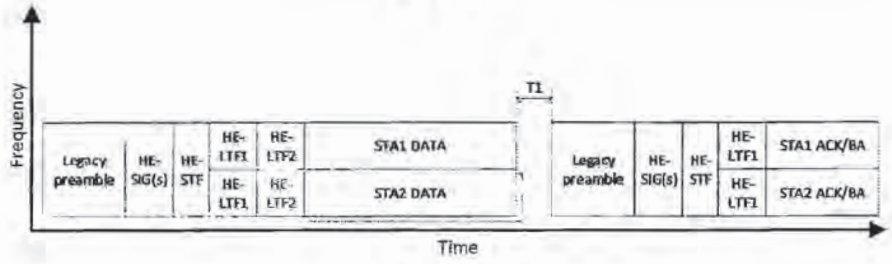


FIG. 12

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APPARATUS AND METHOD FOR DOWNLINK AND UPLINK MULTI-USER TRANSMISSIONS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of priority from U.S. Provisional Application No. 62/137,138, entitled "APPARATUS AND METHODS FOR DOWNLINK MULTI-USER TRANSMISSION," filed Mar. 23, 2015 and U.S. Provisional Application No. 62/140,349, entitled "APPARATUS AND METHODS FOR TRANSMITTING RESPONSE FRAMES," filed Mar. 30, 2015, which are incorporated herein by reference in its entirety.

TECHNICAL FIELD

The present description relates in general to wireless communication systems and methods, and more particularly to, for example, without limitation, systems and methods for multi-user transmission of response frames.

BACKGROUND

Wireless local area network (WLAN) devices are deployed in diverse environments. These environments are generally characterized by the existence of access points and non-access point stations. In some systems, stations may utilize multi-user (MU) transmissions to more efficiently communicate data. In particular, an access point may transmit a single downlink (DL) Orthogonal Frequency Division Multiple Access (OFDMA) frame that assigns particular resource units (RUs) to separate stations in the wireless system. Each RU may include data and/or control information that is intended for a single station or a set of stations.

Although described in relation to OFDMA, MU transmissions may be implemented through the use of Multiple-Input and Multiple-Output (MIMO) techniques. MU-MIMO techniques utilize multiple transmit and receive antennas to exploit multipath propagation. MIMO may be used separately or jointly with OFDMA to transmit data and control information in both the downlink and uplink directions.

The description provided in the background section should not be assumed to be prior art merely because it is mentioned in or associated with the background section. The background section may include information that describes one or more aspects of the subject technology.

SUMMARY

A method, implemented by a network device in a wireless network, for coordinating an uplink multi-user response transmission to a downlink multi-user transmission is described herein. The method may comprise: generating, by the network device, a downlink multi-user frame addressed to a plurality of stations operating in the wireless network, the downlink multi-user frame including a plurality of resource units that are each assigned to a station in the plurality of stations, wherein generating the downlink multi-user frame comprises: including a set of MAC Protocol Data Units (MPDUs) in each resource unit of the plurality of resource units, wherein one or more MPDUs in each of the resource units in the downlink multi-user frame includes acknowledgement information for indicating properties of a multi-user acknowledgement transmission transmitted by each respective station in the plurality of stations to acknowledge the downlink multi-user frame; and transmitting the downlink multi-user frame to the plurality of stations over a wireless channel.

In one embodiment, generating the downlink multi-user frame further comprises: including the acknowledgement information, for indicating properties of the multi-user acknowledgement transmission transmitted by each respective station in the plurality of stations to acknowledge the downlink multi-user frame, in a header of the one or more MPDUs. In one embodiment, the header is a MAC header of the one or more MPDUs.

In one embodiment, one of the one or more MPDUs in each of the resource units in the downlink multi-user frame is a unicast trigger frame that contains the acknowledgement information for the respective station in the plurality of stations. In one embodiment, the trigger frame instigates each respective station in the plurality of stations to transmit the multi-user acknowledgement transmission after an inter-frame spacing period following receipt of the downlink multi-user frame.

In one embodiment, the method further comprises: generating, by the network device, a multi-user block acknowledgement request frame to solicit acknowledgements from two or more stations of the plurality of stations; and transmitting the multi-user block acknowledgment request frame following transmission of the downlink multi-user frame.

In one embodiment, the acknowledgement information includes one or more of: (1) whether the acknowledgement transmission is multi-user or single user, (2) whether the acknowledgment transmission is immediate or non-immediate, and (3) resource scheduling information for the multi-user acknowledgement transmission.

A method, implemented by a first station in a wireless network, for transmitting an uplink acknowledgment is also described here. The method comprises: receiving a downlink multi-user frame addressed to a plurality of stations, including the first station, and received from an access point in the wireless network; processing a first MAC Protocol Data Units (MPDU) in the downlink multi-user frame to determine acknowledgement information for indicating properties of a first multi-user acknowledgement frame to acknowledge the downlink multi-user frame by two or more stations; generating the first multi-user acknowledgment frame based on the acknowledgement information; and transmitting the first multi-user acknowledgement frame to the access point based on the acknowledgement information.

In one embodiment, the first MPDU is located in a first resource unit of the downlink multi-user frame allocated to the first station, wherein the downlink multi-user frame includes a second resource unit that contains a second MPDU with acknowledgement information for a second station to transmit a second multi-user acknowledgement frame. In one embodiment, the first multi-user acknowledgement frame and the second multi-user acknowledgement frame together form a multi-user acknowledgement frame for acknowledging the downlink multi-user frame.

In one embodiment, processing the first MPDU comprises: extracting the acknowledgement information, for indicating properties of the first multi-user acknowledgement frame, in a header of the first MPDU. In one embodiment, the header is a MAC header of the first MPDU.

In one embodiment, processing the MPDU comprises: extracting the acknowledgement information, for indicating properties of the first multi-user acknowledgement frame transmission, from a payload of the first MPDU, wherein the first MPDU is a unicast trigger frame. In one embodiment, the method further comprises: processing a second MPDU

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in a same resource unit as the first MPDU, wherein the second MPDU includes data intended for the first station. In one embodiment, the trigger frame instigates the first station to transmit the first multi-user acknowledgement after an interframe spacing period following receipt of the downlink multi-user frame.

In one embodiment, the method further comprises: receiving a multi-user block acknowledgement request frame that solicits acknowledgements from two or more stations, wherein the first multi-user acknowledgement frame is transmitted after receipt of and in response to the multi-user block acknowledgement request frame.

In one embodiment, the acknowledgement information includes one or more of: (1) whether the first multi-user acknowledgement frame is part of multi-user or single user transmission, (2) whether the first multi-user acknowledgement frame is transmitted immediately following receipt of the downlink multi-user frame or upon receipt of a multi-user block acknowledgement request frame, and (3) resource scheduling information for an uplink multi-user acknowledgement transmission.

A method, implemented by a first station in a wireless network, for transmitting an uplink acknowledgment is described herein. In one embodiment, the method comprises: receiving a downlink multi-user frame addressed to a plurality of stations, including the first station, wherein the downlink multi-user frame is received from an access point in the wireless network; receiving a multi-user block acknowledgement request frame that solicits acknowledgements from two or more stations, wherein the multi-user block acknowledgement request frame includes acknowledgement information for indicating properties of a first multi-user acknowledgement frame that acknowledges receipt of the downlink multi-user frame by the first station; generating the first multi-user acknowledgment frame based on the acknowledgement information; and transmitting the first multi-user acknowledgement frame to the access point based on the acknowledgement information.

In one embodiment, the acknowledgement information includes one or more of: (1) whether the first multi-user acknowledgement frame is part of a multi-user or single user transmission and (2) resource scheduling information for the first multi-user acknowledgement transmission. In one embodiment, the acknowledgment scheduling information includes properties of a second multi-user acknowledgement frame generated and transmitted by a second station, wherein the first multi-user acknowledgement frame and the second multi-user acknowledgement together form a multi-user transmission.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1A** depicts a multi-user (MU) transmission that solicits an immediate acknowledgement from one target station and delayed acknowledgements from other target stations according to one embodiment.

FIG. **1B** depicts a MU transmission that solicits delayed acknowledgements from all target stations according to one embodiment.

FIG. **2** illustrates a schematic diagram of an example of a wireless communication network according to one embodiment.

FIG. **3** illustrates a schematic diagram of an example of a wireless communication device according to one embodiment.

FIG. **4A** illustrates a schematic block diagram of an example of a transmitting signal processor in a wireless communication device according to one embodiment.

FIG. **4B** illustrates a schematic block diagram of an example of a receiving signal processor in a wireless communication device according to one embodiment.

FIG. **4C** illustrates an example of a high efficiency (HE) frame according to one embodiment.

FIG. **5A** illustrates a method for coordinating an uplink (UL) MU acknowledgement/response transmission to a downlink (DL) MU transmission according to a first embodiment.

FIG. **5B** illustrates a transmission diagram for coordinating an UL MU acknowledgement/response transmission according to the first embodiment.

FIG. **6A** illustrates a method for coordinating an UL MU acknowledgement/response transmission to a DL MU transmission according to a second embodiment.

FIG. **6B** illustrates a transmission diagram for coordinating an UL MU acknowledgement/response transmission according to the second embodiment.

FIG. **7A** illustrates a method for coordinating an UL MU acknowledgement/response transmission to a DL MU transmission according to a third embodiment.

FIG. **7B** illustrates a transmission diagram for coordinating an UL MU acknowledgement/response transmission according to the third embodiment.

FIG. **8A** illustrates a method for coordinating an UL MU acknowledgement/response transmission to a DL MU transmission according to a fourth embodiment.

FIG. **8B** illustrates a transmission diagram for coordinating an UL MU acknowledgement/response transmission according to the fourth embodiment.

FIG. **9** illustrates a trigger frame for coordinating an UL MU acknowledgement/response transmission to a DL MU transmission according to an embodiment.

FIG. **10** illustrates an example of a HE frame according to one embodiment.

FIG. **11** illustrates an example of coordinating the number of HE long training fields (HE-LTF) in an UL MU transmission according to one embodiment.

FIG. **12** illustrates an example of coordinating the number of HE-LTF in an UL MU transmission according to another embodiment.

In one or more implementations, not all of the depicted components in each figure may be required, and one or more implementations may include additional components not shown in a figure. Variations in the arrangement and type of the components may be made without departing from the scope of the subject disclosure. Additional components, different components, or fewer components may be utilized within the scope of the subject disclosure.

DETAILED DESCRIPTION

The detailed description set forth below is intended as a description of various implementations and is not intended to represent the only implementations in which the subject technology may be practiced. As those skilled in the art would realize, the described implementations may be modified in various different ways, all without departing from the scope of the present disclosure. Accordingly, the drawings and description are to be regarded as illustrative in nature and not restrictive.

During the standardization activities of the Institute of Electrical and Electronics Engineers (IEEE) 802.11, multi-user (MU) simultaneous transmission techniques such as

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Orthogonal Frequency Division Multiple Access (OFDMA) and Multi-User Multiple Input Multiple Output (MU-MIMO) are considered to improve network efficiency. For example, FIG. **1**A depicts an MU transmission that solicits an immediate acknowledgement from a station while FIG. **1**B depicts an MU transmission that does not solicit an immediate response from any of the participating/target stations.

In particular, as shown in FIG. **1**A, an access point (AP) transmits a downlink (DL) MU physical layer convergence procedure (PLCP) protocol data unit (PPDU) to a set of stations (STAs) (i.e., addressed, target, or receiving STAs) on a shared wireless channel. The PPDU may identify a particular STA in the set of addressed STAs to send back an immediate acknowledgement on the shared wireless channel or a portion of the shared wireless channel (i.e., an implicit block acknowledgment request (BAR)). As used herein, an "immediate" response or acknowledgement refers to a transmission that is the next transmission on the shared wireless channel or a portion of the shared wireless channel after the DL PPDU. Accordingly, the immediate acknowledgment/response and the preceding transmission may be separated by a period during which no activity/transmission is occurring on the shared channel or a designated portion of the shared channel. For examples, as shown in FIG. **1**A, the period between the DL PPDU/frame and the immediate acknowledgment may be a short interframe space (SIFS) period. However, in other embodiments, other IFS periods may be used. After receiving the acknowledgement frame from the specific STA for which an immediate response was requested, the AP polls acknowledgement frames from every other STA that the AP has sent the DL MU PPDU using a set of BAR frames (i.e., explicit BARs). Response to each corresponding BAR frame, as shown in the FIG. **1**A, occur after an inactivity period on the channel and therefore would be considered immediate responses to the corresponding BAR frame.

Similarly, a DL MU transmission with no request for an immediate acknowledgement (i.e., no implicit BAR indication is present in the DL MU PPDU) requires the AP to poll each STA in the DL MU transmission for an acknowledgement that the DL MU PPDU was successfully received/processed. In particular, the AP may set an ACK Policy to be a block acknowledgement for every STA. As shown in FIG. **1**B, after sending the DL MU PPDU, the AP polls acknowledgement frames from each STA addressed by the MU PPDU using corresponding BAR frames.

Therefore, for both of the mechanisms described above and shown in FIG. **1**A and FIG. **1**B, even though DL data frames are sent in parallel in the spatial domain (e.g., using OFDMA or MIMO techniques), the acknowledgement frames from multiple STAs are transmitted and received in a serial (i.e., SU) manner. In particular, one or more BAR frames must be transmitted from the AP to one or more respective STAs such that each STA may sequentially send a corresponding acknowledgement or block acknowledgment back to the AP. This serial acknowledgement scheme consumes/requires a considerable amount of overhead (e.g., the time the shared wireless channel is devoted to acknowledgement transmissions) and reduces the overall gain/efficiency of DL MU transmissions. This inefficient serial acknowledgement mechanism is unavoidable in wireless systems in which MU uplink (UL) transmissions are prohibited or otherwise are not supported. However, several techniques are presented herein that facilitate a MU UL transmission scheme for acknowledgements to reduce or eliminate the inefficiencies of serial acknowledgements.

As used herein and where appropriate, acknowledgment frames/PPDUs/messages may either be individual acknowledgments (ACKs) or block acknowledgements (BAs). As defined in IEEE 802.11e, BAs acknowledge the receipt of multiple MAC Protocol Data Units (MPDUs) whereas ACKs acknowledge receipt of a single MPDU.

FIG. **2** illustrates a schematic diagram of an example of a wireless communication network **200** in which one or more of the methods, systems, and apparatuses described herein may operate or otherwise be implemented within. In the wireless communication network **200**, such as a wireless local area network (WLAN), a basic service set (BSS) includes a plurality of wireless communication devices (e.g., WLAN devices). In one aspect, a BSS refers to a set of STAs that can communicate in synchronization, rather than a concept indicating a particular area. In the example, the wireless communication network **200** includes wireless communication devices **211-215**, which may be referred to as stations (STAs).

Each of the wireless communication devices **211-215** may include a media access control (MAC) layer and a physical (PHY) layer according to an IEEE 802.11 standard or a modification of an IEEE 802.11 standard. In the example network **200**, at least one wireless communication device (e.g., device **211**) is an access point (AP). An AP may be referred to as an AP STA, an AP device, or a central station. The other wireless communication devices (e.g., devices **212-215**) may be non-AP STAs. Alternatively, all of the wireless communication devices **211-215** may be non-AP STAs in an Ad-hoc networking environment.

An AP STA and a non-AP STA may be collectively called STAs. However, for simplicity of description, in some aspects, only a non-AP STA may be referred to as a STA. An AP may be, for example, a centralized controller, a base station (BS), a node-B, a base transceiver system (BTS), a site controller, a network adapter, a network interface card (NIC), a router, or the like. A non-AP STA (e.g., a client device operable by a user) may be, for example, a device with wireless communication capability, a terminal, a wireless transmit/receive unit (WTRU), a user equipment (UE), a mobile station (MS), a mobile terminal, a mobile subscriber unit, a laptop, a non-mobile computing device (e.g., a desktop computer with wireless communication capability) or the like. In one or more aspects, a non-AP STA may act as an AP (e.g., a wireless hotspot).

In one aspect, an AP is a functional entity for providing access to a distribution system, by way of a wireless medium, for an associated STA. For example, an AP may provide access to the Internet for one or more STAs that are wirelessly and communicatively connected to the AP. In FIG. **2**, wireless communications between non-AP STAs **212-215** are made by way of the AP **211**. However, when a direct link is established between two or more non-AP STAs **212-215**, the connected STAs **212-215** can communicate directly with each other (without using the AP **211**).

In one or more implementations, OFDMA-based 802.11 technologies are utilized, and for the sake of brevity, a STA refers to a non-AP high efficiency (HE) STA, and an AP refers to an HE AP. In one or more aspects, a STA may act as an AP.

FIG. **3** illustrates a schematic diagram of an example of a wireless communication device **300**. The wireless communication device **300** includes a baseband processor **310**, a radio frequency (RF) transceiver **320**, an antenna unit **330**, a memory **340**, an input interface unit **350**, an output interface unit **360**, and a bus **370**, or subsets and variations

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thereof. The wireless communication device **300** can be, or can be a part of, any of the wireless communication devices **211-215**.

In the example shown in FIG. **3**, the baseband processor **310** performs baseband signal processing, and includes a medium access control (MAC) processor **311** and a PHY processor **315**. The memory **340** may store software (such as MAC software) including at least some functions of the MAC layer. The memory **340** may further store an operating system and applications.

In the illustration, the MAC processor **311** includes a MAC software processing unit **312** and a MAC hardware processing unit **313**. The MAC software processing unit **312** executes the MAC software to implement some functions of the MAC layer, and the MAC hardware processing unit **313** may implement remaining functions of the MAC layer as hardware (MAC hardware). However, the MAC processor **311** may vary in functionality depending on implementation. The PHY processor **315** includes a transmitting (TX) signal processing unit **380** and a receiving (RX) signal processing unit **390**. The term TX may refer to transmitting, transmit, transmitted, transmitter or the like. The term RX may refer to receiving, receive, received, receiver or the like.

The PHY processor **315** interfaces to the MAC processor **311** through, among others, transmit vector (TXVECTOR) and receive vector (RXVECTOR) parameters. In one or more aspects, the MAC processor **311** generates and provides TXVECTOR parameters to the PHY processor **315** to supply per-packet transmit parameters. In one or more aspects, the PHY processor **315** generates and provides RXVECTOR parameters to the MAC processor **311** to inform the MAC processor **311** of the received packet parameters.

In some aspects, the wireless communication device **300** includes a read-only memory (ROM) (not shown) or registers (not shown) that store instructions that are needed by one or more of the MAC processor **311**, the PHY processor **315** and/or other components of the wireless communication device **300**.

In one or more implementations, the wireless communication device **300** includes a permanent storage device (not shown) configured as a read-and-write memory device. The permanent storage device may be a non-volatile memory unit that stores instructions even when the wireless communication device **300** is off. The ROM, registers, and the permanent storage device may be part of the baseband processor **310** or be a part of the memory **340**. Each of the ROM, registers, the permanent storage device, and the memory **340** may be an example of a memory or a computer-readable medium. A memory may be one or more memories.

The memory **340** may be a read-and-write memory, a read-only memory, a volatile memory, a non-volatile memory, or a combination of some or all of the foregoing. The memory **340** may store instructions that one or more of the MAC processor **311**, the PHY processor **315**, and/or another component may need at runtime.

The RF transceiver **320** includes an RF transmitter **321** and an RF receiver **322**. The input interface unit **350** receives information from a user, and the output interface unit **360** outputs information to the user. The antenna unit **330** includes one or more antennas. When multi-input multi-output (MIMO) or multi-user MIMO (MU-MIMO) is used, the antenna unit **330** may include more than one antenna.

The bus **370** collectively represents all system, peripheral, and chipset buses that communicatively connect the numerous internal components of the wireless communication device **300**. In one or more implementations, the bus **370** communicatively connects the baseband processor **310** with the memory **340**. From the memory **340**, the baseband processor **310** may retrieve instructions to execute and data to process in order to execute the processes of the subject disclosure. The baseband processor **310** can be a single processor, multiple processors, or a multi-core processor in different implementations. The baseband processor **310**, the memory **340**, the input interface unit **350**, and the output interface unit **360** may communicate with each other via the bus **370**.

The bus **370** also connects to the input interface unit **350** and the output interface unit **360**. The input interface unit **350** enables a user to communicate information and select commands to the wireless communication device **300**. Input devices that may be used with the input interface unit **350** may include any acoustic, speech, visual, touch, tactile and/or sensory input device (e.g., a keyboard, a pointing device, a microphone, or a touchscreen). The output interface unit **360** may enable, for example, the display or output of videos, images, audio, and data generated by the wireless communication device **300**. Output devices that may be used with the output interface unit **360** may include any visual, auditory, tactile, and/or sensory output device (e.g., printers and display devices or any other device for outputting information). One or more implementations may include devices that function as both input and output devices, such as a touchscreen.

One or more implementations can be realized in part or in whole using a computer-readable medium. In one aspect, a computer-readable medium includes one or more media. In one or more aspects, a computer-readable medium is a tangible computer-readable medium, a computer-readable storage medium, a non-transitory computer-readable medium, a machine-readable medium, a memory, or some combination of the foregoing (e.g., a tangible computer-readable storage medium, or a non-transitory machine-readable storage medium). In one aspect, a computer is a machine. In one aspect, a computer-implemented method is a machine-implemented method.

A computer-readable medium may include storage integrated into a processor and/or storage external to a processor. A computer-readable medium may be a volatile, non-volatile, solid state, optical, magnetic, and/or other suitable storage device (e.g., RAM, ROM, PROM, EPROM, flash memory, registers, a hard disk, removable memory, or a remote storage device).

In one aspect, a computer-readable medium includes/comprises instructions stored therein. In one aspect, a computer-readable medium is encoded with instructions. In one aspect, instructions are executable by one or more processors (e.g., **310**, **311**, **312**, **313**, **315**, **380**, **390**) to perform one or more operations or a method. Instructions may include, for example, programs, routines, subroutines, data, data structures, objects, sequences, commands, operations, modules, applications, and/or functions. Those skilled in the art would recognize how to implement the instructions.

A processor (e.g., **310**, **311**, **312**, **313**, **315**, **380**, **390**) may be coupled to one or more memories (e.g., one or more external memories such as the memory **340**, one or more memories internal to the processor, one or more registers internal or external to the processor, or one or more remote memories outside of the device **300**), for example, via one or more wired and/or wireless connections. The coupling may be direct or indirect. In one aspect, a processor includes one or more processors. A processor, including a processing circuitry capable of executing instructions, may read, write, or access a computer-readable medium. A processor may be.

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for example, an application specific integrated circuit (ASIC), a digital signal processor (DSP), or a field programmable gate array (FPGA).

In one aspect, a processor (e.g., **310**, **311**, **312**, **313**, **315**, **380**, **390**) is configured to cause one or more operations of the subject disclosure to occur. In one aspect, a processor is configured to cause an apparatus (e.g., a wireless communication device **300**) to perform operations or a method of the subject disclosure. In one or more implementations, a processor configuration involves having a processor coupled to one or more memories. A memory may be internal or external to the processor. Instructions may be in a form of software, hardware or a combination thereof. Software instructions (including data) may be stored in a memory. Hardware instructions may be part of the hardware circuitry components of a processor. When the instructions are executed or processed by one or more processors, (e.g., **310**, **311**, **312**, **313**, **315**, **380**, **390**), the one or more processors cause one or more operations of the subject disclosure to occur or cause an apparatus (e.g., a wireless communication device **300**) to perform operations or a method of the subject disclosure.

FIG. **4**A illustrates a schematic block diagram of an example of a transmitting signal processing unit **380** in a wireless communication device **300**. The transmitting signal processing unit **380** of the PHY processor **315** includes an encoder **381**, an interleaver **382**, a mapper **383**, an inverse Fourier transformer (IFT) **384**, and a guard interval (GI) inserter **385**.

The encoder **381** encodes input data. For example, the encoder **381** may be a forward error correction (FEC) encoder. The FEC encoder may include a binary convolutional code (BCC) encoder followed by a puncturing device, or may include a low-density parity-check (LDPC) encoder. The interleaver **382** interleaves the bits of each stream output from the encoder **381** to change the order of bits. In one aspect, interleaving may be applied only when BCC encoding is employed. The mapper **383** maps the sequence of bits output from the interleaver **382** into constellation points.

When MIMO or MU-MIMO is employed, the transmitting signal processing unit **380** may use multiple instances of the interleaver **382** and multiple instances of the mapper **383** corresponding to the number of spatial streams (N_{SS}). In the example, the transmitting signal processing unit **380** may further include a stream parser for dividing outputs of the BCC encoders or the LDPC encoder into blocks that are sent to different interleavers **382** or mappers **383**. The transmitting signal processing unit **380** may further include a space-time block code (STBC) encoder for spreading the constellation points from the number of spatial streams into a number of space-time streams (N_{STS}) and a spatial mapper for mapping the space-time streams to transmit chains. The spatial mapper may use direct mapping, spatial expansion, or beamforming depending on implementation. When MU-MIMO is employed, one or more of the blocks before reaching the spatial mapper may be provided for each user.

The IFT **384** converts a block of the constellation points output from the mapper **383** or the spatial mapper into a time domain block (e.g., a symbol) by using an inverse discrete Fourier transform (IDFT) or an inverse fast Fourier transform (IFFT). If the STBC encoder and the spatial mapper are employed, the IFT **384** may be provided for each transmit chain.

When MIMO or MU-MIMO is employed, the transmitting signal processing unit **380** may insert cyclic shift diversities (CSDs) to prevent unintentional beamforming. The CSD insertion may occur before or after the inverse Fourier transform operation. The CSD may be specified per transmit chain or may be specified per space-time stream. Alternatively, the CSD may be applied as a part of the spatial mapper.

The GI inserter **385** prepends a GI to the symbol. The transmitting signal processing unit **380** may optionally perform windowing to smooth edges of each symbol after inserting the GI. The RF transmitter **321** converts the symbols into an RF signal and transmits the RF signal via the antenna unit **330**. When MIMO or MU-MIMO is employed, the GI inserter **385** and the RF transmitter **321** may be provided for each transmit chain.

FIG. **4**B illustrates a schematic block diagram of an example of a receiving signal processing unit **390** in a wireless communication device. The receiving signal processing unit **390** of the PHY processor **315** includes a GI remover **391**, a Fourier transformer (FT) **392**, a demapper **393**, a deinterleaver **394**, and a decoder **395**.

The RF receiver **322** receives an RF signal via the antenna unit **330** and converts the RF signal into one or more symbols. In some aspects, the GI remover **391** removes the GI from the symbol. When MIMO or MU-MIMO is employed, the RF receiver **322** and the GI remover **391** may be provided for each receive chain.

The FT **392** converts the symbol (e.g., the time domain block) into a block of the constellation points by using a discrete Fourier transform (DFT) or a fast Fourier transform (FFT) depending on implementation. In one or more implementations, the FT **392** is provided for each receive chain.

When MIMO or MU-MIMO is employed, the receiving signal processing unit **390** may be a spatial demapper for converting the Fourier transformed receiver chains to constellation points of the space-time streams, and a STBC decoder (not shown) for despreading the constellation points from the space-time streams into the spatial streams.

The demapper **393** demaps the constellation points output from the FT **392** or the STBC decoder to the bit streams. If the LDPC encoding is used, the demapper **393** may further perform LDPC tone demapping before the constellation demapping. The deinterleaver **394** deinterleaves the bits of each stream output from the demapper **393**. In one or more implementations, deinterleaving may be applied only when BCC encoding is used.

When MIMO or MU-MIMO is employed, the receiving signal processing unit **390** may use multiple instances on the demapper **393** and multiple instances of the deinterleaver **394** corresponding to the number of spatial streams. In the example, the receiving signal processing unit **390** may further include a stream deparser for combining the streams output from the deinterleavers **394**.

The decoder **395** decodes the streams output from the deinterleaver **394** and/or the stream deparser. For example, the decoder **395** may be an FEC decoder. The FEC decoder may include a BCC decoder or an LDPC decoder.

FIG. **4**C illustrates an example of a high efficiency (HE) frame **400**. The HE frame **400** is a physical layer convergence procedure (PLCP) protocol data unit (or PPDU) format. An HE frame may be referred to as an OFDMA frame, a PPDU, a PPDU format, an OFDMA PPDU, an MU PPDU, another similar term, or vice versa. An HE frame may be simply referred to as a frame for convenience. In one or more implementations, an AP may transmit a frame for downlink (DL) using a frame format shown in this figure or a variation thereof (e.g., without any or some portions of an HE header). A STA may transmit a frame for uplink (UL)

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using a frame format shown in this figure or a variation thereof (e.g., without any or some portions of an HE header).

Referring to FIG. **4C**, the HE frame **400** contains a header and a data field. The header includes a legacy header comprised of a legacy short training field (L-STF), a legacy long training field (L-LTF), and a legacy signal (L-SIG) field. These legacy fields contain symbols based on an early design of an IEEE 802.11 specification. The L-STF, L-LTF, and L-SIG fields may be 8 μs, 8 μs, and 4 μs, respectively. Presence of these symbols would make any new design compatible with the legacy designs and products. The legacy header may be referred to as a legacy preamble. In one or more aspects, the term header may be referred to as a preamble.

In one or more implementations, the legacy STF, LTF, and SIG symbols are modulated/carried with FFT size of 64 on a 20 MHz sub-channel and are duplicated every 20 MHz if the frame has a channel bandwidth wider than 20 MHz. Therefore, the legacy field (i.e., the STF, LTF, and SIG fields) occupies the entire channel bandwidth of the frame. The L-STF field may be utilized for packet detection, automatic gain control (AGC), and coarse frequency-offset (FO) correction. In one aspect, the L-STF field does not utilize frequency domain processing (e.g., FFT processing) but rather utilizes time domain processing. Thus, in one aspect, the L-STF field is not affected by the channel dispersion. The L-LTF field may be utilized for channel estimation, fine frequency-offset correction, and symbol timing. The L-SIG field includes one orthogonal frequency division multiplexing (OFDM) symbol. Thus, in one aspect, the term L-SIG field may be used interchangeably with L-SIG symbol. In one or more aspects, the L-SIG field may contain information indicative of a data rate and a length (e.g., in bytes) associated with the HE frame **400**, which may be utilized by a receiver of the HE frame **400** to calculate a time duration of a transmission of the HE frame **400**.

The header may also include an HE header comprised of an HE-SIG-A field and an HE-SIG-B field. The HE-SIG-A field may sometimes be referred to simply as a SIG-A field. These fields contain symbols that carry control information that may be vital regarding each PLCP service data unit (PSDU) and regarding the radio frequency (RF), PHY, and MAC properties of a PPDU. Several sub-fields may be located either in the HE-SIG-A and/or HE-SIG-B fields. In one aspect, the HE-SIG-A field can be carried/modulated using an FFT size of 64. The HE-SIG-B field can be carried/modulated using an FFT size of e.g., 64 or 256 depending on implementation. The HE-SIG-A and HE-SIG-B fields may occupy the entire channel bandwidth of the frame. In some aspects, the size of the HE-SIG-A field and/or the HE-SIG-B field is variable. In other words, the number of symbols contained in the HE-SIG-A field and/or HE-SIG-B field can vary from frame to frame. An HE-SIG-B field is not always present in all frames. In some cases, single user (SU) packets and UL trigger-based packets do not contain the HE-SIG-B field. To facilitate decoding of the HE frame **400** by a receiver, the size of (e.g., number of symbols contained in) the HE-SIG-B field may be indicated in the HE-SIG-A field. In some aspects, the HE header also includes a repeated L-SIG (RL-SIG) field, whose content is the same as the L-SIG field.

For a 20 MHz channel, an FFT size of 64 is associated with a discrete Fourier transform (DFT) period of 3.2 μs and a subcarrier spacing of 312.5 kHz. For a 20 MHz channel, an FFT size of 256 is associated with a DFT period of 12.8 μs and a subcarrier spacing of 78.125 kHz. The DFT period may also be referred to as an inverse DFT period (IDFT) or an IDFT/DFT period. The DFT period may be denoted as T_{DFT}. The subcarrier spacing may be referred to as a subcarrier frequency spacing and may be denoted as Δ_F. The DFT period may be obtained by dividing the channel bandwidth by the FFT size. The subcarrier spacing is the reciprocal of the DFT period.

The HE header may further include HE-STF and HE-LTF fields, which contain symbols used to perform necessary RF and PHY processing for each PSDU and/or for the whole PPDU. The HE-LTF symbols may be modulated/carried with an FFT size of 256 for 20 MHz bandwidth and modulated over the entire bandwidth of the frame. Thus, the HE-LTF field may occupy the entire channel bandwidth of the frame. The HE-STF symbols may have a fixed pattern and a fixed duration. For example, the HE-STF symbols may have a predetermined repeating pattern. In one aspect, the HE-STF symbols do not require FFT processing. The HE frame **400** may include the data field, represented as HE-DATA, that contains data symbols. The data field may also be referred to as a payload field, data, payload or PSDU.

In one or more aspects, additional one or more of the HE-STF and/or HE-LTF fields may be included in the header. For example, an additional HE-STF field and/or an additional HE-LTF field may be included between the HE-SIG-A field and the HE-SIG-B field. The additional HE-STF and HE-LTF fields may be, for example, modulated/carried with FFT size of 64 on a 20 MHz channel and may be included as part of the first part of the HE frame **400**. In one or more implementations, a TX signal processing unit **380** (or an IFT **384**) illustrated FIG. **4A** may carry out the modulation described in this paragraph as well as the modulations described in other paragraphs above. In one or more implementations, an RX signal processing unit **390** (or an FT **392**) may perform demodulation for a receiver.

Each of the fields (e.g., L-LTF, HE-SIG-B, etc.) of the HE frame **400** includes one or more guard intervals and one or more OFDM symbols. The guard interval may be utilized to facilitate compensation of multi-path effects, which may cause inter-symbol interference (ISI). In one or more implementations, a guard interval is a cyclic prefix (CP), and a guard interval duration is a CP length. In one or more aspects, the term duration may be referred to as a length. In one aspect, no guard interval is used for symbols in the L-STF field and/or HE-STF field. Each guard interval may be associated with a symbol and may be present between symbols (or between consecutive symbols). In some aspects, each OFDM symbol is preceded (or followed) by a guard interval. In some aspects, the OFDM symbol may be referred to as including the guard interval that precedes (or follows) the OFDM symbol.

In one or more implementations of a transmitter, a GI inserter **385** illustrated in FIG. **4A** may prepend a guard interval to an OFDM symbol. For a receiver, a GI remover **391** of FIG. **4B** may remove the prepended guard interval.

Turning now to FIG. **5A**, a method **500** will be described for coordinating UL MU acknowledgement/response transmissions to a DL MU transmission according to one embodiment. As will explained in further detail below, the proposed method **500** facilitates UL MU acknowledgement/response transmissions for more advanced STAs (e.g., HE STAs), which support UL MU capabilities (e.g., UL OFDMA or UL MU-MIMO), while still being backwards compatible with legacy devices (e.g., High Throughput (HT) STAs, Very High Throughput (VHT) STAs, or other devices that do not support UL MU transmissions).

The method **500** may be performed by one or more devices in the network **200**. For example, one or more

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operations or sub-operations of the method **500** may be performed by the device **211**, which is operating as an AP in the network **200**, and/or the device **212-215**. In particular, in the method **500** the AP **211** may be in communication with two or more of the device **212-215**, which operate as separate STAs in the network **200**. In this configuration, the AP **211** and the STAs **212-215** may jointly performed the method **500** to efficiently acknowledge receipt of a DL MU PPDU/frame.

Each operation of the method **500** will be described by way of example below in relation to the transmission diagram shown in FIG. **5B**. Although one or more operations or sub-operations are described or shown in a particular sequential order, in other embodiments the operations/sub-operations may be rearranged in a different order, which may include performance of multiple operations/sub-operations in at least partially overlapping time periods.

The method **500** may commence at operation **501** with the generation of a DL MU PPDU/frame by an AP. The DL MU frame may be addressed to a set of target STAs operating in a network. For example, as shown in FIG. **5B**, the DL MU frame may be addressed to STA1, STA2, and STA3. In this example, STA1 and STA2 are non-legacy devices that support UL MU transmissions and STA3 is a legacy device that does not support UL MU transmissions. For example, STA1 and STA2 may be HE devices (i.e., devices that operate according to the IEEE 802.11ax standard, which is currently in development) and STA3 may be a VHT STA (i.e., a device that operates according to the IEEE 802.11ac standard), a HT STA (i.e., a device that operates according to the IEEE 802.11n standard), or another device that operates according to a wireless standard that does not support UL MU transmissions. The generated DL MU frame may be a MU-MIMO frame and/or an OFDMA frame. The generation of the frame at operation **501** may include the sub-operations described below.

At sub-operation **501A** the AP may generate one or more MAC Protocol Data Units (MPDUs) or aggregated-MPDUs (A-MPDUs) for each non-legacy STA. In the example, one or more MPDUs/A-MPDUs may be generated for STA1 and one or more MPDUs/A-MPDUs may be generated for STA2. Each MPDU may include data and/or control frames intended for each respective STA and may be placed in resource units within the DL MU frame assigned/allocated to each respective STA. The resource units may be particular spatial streams or sub-channels of a wireless channel upon which the DL MU frame will be transmitted.

In one embodiment, one or more MPDUs may include acknowledgement information that is used for indicating to respective STAs a scheme/technique used to transmit acknowledgement messages to the AP. For example, in one embodiment, generation of one or more MPDUs addressed to each STA may include setting an acknowledgement policy subfield (ACK policy subfield) in a header of the one or more MPDUs (i.e., a MAC header) such that STA1 and STA2 can identify which technique/scheme is to be used by each non-legacy STA for acknowledging successful receipt of the MPDUs by each respective STA. In one embodiment, the ACK policy subfield is two bits and is located in the Quality of Service (QoS) Control Field of the MAC header. However, in other embodiments, the ACK policy subfield may be located in different portions of the MAC header and may be of a different length (e.g., 1 bit, 3 bits, etc.).

In embodiments in which the ACK Policy subfield is two bits in length, the interpretation of these two bits may be given by Table 1 below.

TABLE 1

Bits in QoS Control field		
Bit 5	Bit 6	Meaning
0	0	Normal Ack or Implicit Block Ack Request In a frame that is a non-A-MPDU frame or VHT single MPDU: The addressed recipient returns an Ack or QoS +CF-Ack frame after a short interframe space (SIFS) period, according to the procedures defined in 9.3.2.9 (Ack procedure) and 9.22.3.5 (HCCA transfer rules) A non-DMG STA lets the Ack Policy subfield for individually addressed QoS Null (no data) frames to this value. Otherwise: The addressed recipient returns a BlockAck frame, either individually or as part of an A-MPDU starting a SIFS after the PPDU carrying the frame, according to the procedures defined in 9.3.2.10 (Block ack procedure), 9.24.7.5 (Generation and transmission of BlockAck frames by an HT STA or DMG STA), 9.24.8.3 (Operation of HT-delayed block ack), 9.28.3 (Rules for RD initiator), 9.28.4 (Rules for RD responder), and 9.32.3 (Explicit feedback beamforming).
1	0	No Ack The addressed recipient takes no action upon receipt of the frame. More details are provided in 9.25 (No Acknowledgment (No Ack)). The Ack Policy subfield is set to this value in all individually addressed frames in which the sender does not require acknowledgment. The Ack Policy subfield is also set to this value in all group addressed frames that use the QoS frame format except with a TID for which a block ack agreement exists. This value of the Ack Policy subfield is not used for QoS Data frames with a TID for which a block ack agreement exists. The Ack Policy subfield for group addressed QoS Null (no data) frames is set to this value.
0	1	No explicit acknowledgment or PSMP Ack. When bit 6 of the Frame Control field (see 8.2.4.1.3 (Type and Subtype field)) is set to 1: There may be a response frame to the frame that is received, but it is neither the Ack frame nor any Data frame of subtype +CF-Ack. The Ack Policy subfield for QoS CF-Poll and QoS CF-Ack +CF-Poll Data frames is set to this value.

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TABLE 1-continued

Bits in QoS Control field		
Bit 5	Bit 6	Meaning
		When bit 6 of the Frame Control field (see 8.2.4.1.3 (Type and Subtype fields)) is set to 0: The acknowledgment for a frame indicating PSMP Ack when it appears in a PSMP downlink transmission time (PSMP-DTT) is to be received in a later PSMP uplink transmission time (PSMP-UTT). The acknowledgment for a frame indicating PSMP Ack when it appears in a PSMP-UTT is to be received in a later PSMP-DTT. NOTE-Bit 6 of the Frame Control field (see 8.2.4.1.3 (Type and Subtype fields)) indicates the absence of a data payload. When equal to 1, the QoS Data frame contains no payload, and any response is generated in response to a QoS CF-Poll or QoS CF-Ack +CF-Poll frame, but does not signify an acknowledgment of data. When set to 0, the QoS Data frame contains a payload, which is acknowledged as described in 9.29.2.7 (PSMP acknowledgment rules).
1	1	Block Ack The addressed recipient takes no action upon the receipt of the frame except for recording the state. The recipient can expect a BlockAckReq frame in the future to which it responds using the procedure described in 9.24 (Block acknowledgment (block ack)).

In some embodiments, when the ACK Policy subfield is set to indicate an immediate acknowledgement, which in Table 1 above corresponds to "Normal Ack or Implicit Block Ack Request" and a bit sequence "00", another subfield (a second subfield or a MU ACK Policy subfield) indicates if the follow-up acknowledgement shall be a single user (SU) acknowledgement or an MU acknowledgement. Therefore, the MU acknowledgement that follows immediately after the DL MU PPDU transmission happens from those STAs for which the ACK Policy subfield is set to an immediate acknowledgement and the MU ACK Policy subfield is set to an MU acknowledgement. For example, both STA1 and STA2 in FIG. **5**B received MPDUs in which the ACK Policy subfield is set to an immediate acknowledgment (e.g., "00") and the MU ACK Policy subfield is set to "MU acknowledgement". Accordingly, both STA1 and STA2 may participate in an UL MU acknowledgement immediately following the DL MU transmission. Both the DL and UL MU transmissions may be an OFDMA transmission and/or may incorporate MU-MIMO techniques.

Conversely, those STAs that the ACK Policy subfield is set to immediate acknowledgement and the MU ACK Policy subfield is not set to "MU acknowledgement" and instead is set to "SU acknowledgement", or cannot interpret the MU ACK Policy subfield, will send acknowledgement frames in single user transmission manner as shown in the examples in FIG. **1**A and FIG. **1**B. For example, a STA may transmit an acknowledgment or a block acknowledgement in an SU manner immediately after the DL MU transmission or may wait for a BAR frame from the AP before transmitting an acknowledgment or a block acknowledgement in an SU manner.

In one embodiment, the QoS AP PS Buffer State subfield in the QoS Control field is used as the MU ACK Policy subfield. In particular, in one embodiment, the 8th bit (B8) of the QoS AP PS Buffer State subfield is used as the MU ACK Policy subfield. In one embodiment, if the MU ACK Policy subfield is set to a MU acknowledgement state, there is a second part in the DL MU PPDU that indicates (1) UL MU transmission method/scheme (e.g., MU-MIMO and/or OFDMA) and/or (2) resource allocation information for the MU acknowledgement frame transmission. In another embodiment, if the MU ACK Policy subfield is set to a MU acknowledgement state, resource allocation information regarding the UL MU transmission follows a pre-determined rule set and no explicit indication of the resource allocation information regarding UL MU transmission is included in the DL MU PPDU.

At sub-operation **501**B, the AP may generate MPDUs for legacy STAs (e.g., VHT STAs, HT STAs, or any STA implementing a protocol that does not support UL MU transmissions). Similar to operation **501**A for non-legacy STAs, operation **501**B may include setting an ACK Policy subfield in a QoS Control Field of a MAC header. In one embodiment, the ACK Policy subfield for legacy STAs may be set to a state that indicates non-immediate acknowledgement, which in Table 1 above corresponds to "Block Ack". In particular, as shown in FIG. **5**B, when "Block Ack" is selected, the AP may subsequently transmit a BAR frame to trigger STA3 to transmit an acknowledgment or a block acknowledgement in an SU manner. In another embodiment, the ACK Policy subfield for a legacy STA may be set to an immediate acknowledgement. In this embodiment, the ACK Policy subfield for all other scheduled STAs, including STAs that support UL MU transmissions, is to be a non-immediate acknowledgement. For example, STAs that are set to transmit a non-immediate MU acknowledgement will wait for a MU-BAR (i.e., a trigger frame) before transmitting.

Following generation of the DL MU frame/PPDU at operation **501**, the method **500** may move to operation **503**. At operation **503** the AP transmits the DL MU frame/PPDU to the addressed/targeted STAs. For example, as shown in FIG. **5**B, the DL MU PPDU may be transmitted to the non-legacy STA1 and STA2 and the legacy STA3. As noted above, the DL MU PPDU may utilize OFDMA and/or MIMO MU transmission techniques.

At operation **505** each STA addressed by the DL MU PPDU may receive and attempt to decode the DL MU PPDU. In particular, each targeted STA receives the DL MU PPDU and determines resource units or particular portions of the frame assigned to the STA by examining the preamble portion of the DL MU PPDU/frame. Further, the target STAs may examine decoded MPDUs to determine acknowledgement scheme information/properties/characteristics including (1) whether acknowledgement of the DL MU frame is immediate or non-immediate, (2) whether the acknowledgement is multi-user or single user, and/or (3) scheduling information (e.g., a resource unit within a UL transmission) when a multi-user acknowledgement is selected.

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At operation **507**, the STAs that successfully received and decoded the appropriate portions of the DL MU PPDU may acknowledge receipt through the generation and the transmission of acknowledgement frames by each respective STA according to the acknowledgement information extracted from the DL frame. Acknowledgment may be performed after a predetermined period has elapsed since receipt of the DL frame (e.g., a short interframe space (SIFS) period or another interframe space (IFS) period). As described above, non-legacy STAs may examine the ACK policy subfield and the MU ACK policy subfield in the corresponding MPDU to determine the acknowledgement scheme the STA should use. For example, as shown in FIG. **5**B and described above, ACK policy and the MU ACK policy subfields for STA1 and STA2 indicate that these devices are to participate in an immediate MU acknowledgement while STA3 is to perform a non-immediate (i.e., triggered by a BAR frame) SU acknowledgement. On this basis, STA1 and STA2 may participate in the transmission of a MU acknowledgement while STA3 may await a BAR frame before transmitting a SU acknowledgement. The UL MU transmission may be an OFDMA transmission and/or may incorporate MU-MIMO techniques.

As described above, the method **500** allows non-legacy devices to acknowledge receipt of a DL PPDU in an efficient manner through the use of UL MU techniques while remaining backwards compatible with legacy devices.

Turning now to FIG. **6**A, a method **600** will be described for coordinating UL MU acknowledgement/response transmissions to a DL MU transmission according to another embodiment. As will explained in further detail below, the proposed method **600** facilitates UL MU acknowledgement/response transmissions for more advanced STAs (e.g., HE STAs), which support UL MU capabilities (e.g., UL OFDMA or UL MU-MIMO).

Similar to the method **500**, the method **600** may be performed by one or more devices in the network **200**. For example, one or more operations or sub-operations of the method **600** may be performed by the device **211**, which is operating as an AP in the network **200**, and/or the devices **212-215**, which are operating as STAs in the network **200**.

Each operation of the method **600** will be described by way of example below in relation to the transmission diagram shown in FIG. **6**B. Although one or more operations or sub-operations are described or shown in a particular sequential order, in other embodiments the operations/sub-operations may be rearranged in a different order, which may include performance of multiple operations in at least partially overlapping time periods.

The method **600** may commence at operation **601** with the generation of a DL MU frame by an AP. The DL MU frame may be addressed to a set of STAs operating in a network. For example, as shown in FIG. **6**B, the DL MU frame may be addressed to STA1 and STA2. In this example, the AP schedules STA1 and STA2 for a DL OFDMA transmission, wherein STA1 is allocated a lower half of the transmission bandwidth and STA2 is allocated an upper half of the transmission bandwidth. In this example, STA1 and STA2 are HE STAs or other devices that support UL MU transmissions. Although shown as an OFDMA frame/PPDU, the generated DL MU frame may be a MU-MIMO frame/PPDU. The generation of the frame at operation **601** may include the sub-operations described below.

At sub-operation **601**A, the AP may generate a data MPDU for each STA participating in the DL MU transmission. For example, as shown in FIG. **6**B, the DL MU PPDU/frame may include a data MPDU for STA1 and a data MPDU for STA2. The data MPDU may include any type of data (e.g., voice, video, best effort, background, or control data) that is specifically intended for the particular STA and may be placed in resource units within the DL MU frame assigned/allocated to each respective STA. The resource units may be particular spatial streams or sub-channels of a wireless channel upon which the DL MU frame will be transmitted. In one embodiment, the generation of the data MPDU at sub-operation **601**A may include setting acknowledgment information in a header of the MPDU (e.g., the MAC header of the data MPDU). The acknowledgment information may describe/indicate properties of an acknowledgement technique/scheme used by the corresponding STA to acknowledge receipt of the MPDU. For example, the acknowledgment information may include an ACK Policy subfield and/or a MU ACK Policy subfield. As noted above in relation to the method **500**, the ACK Policy subfield may indicate whether the acknowledgement is immediate or non-immediate (e.g., corresponding to values represented in Table 1) and the MU ACK Policy subfield may indicate whether the acknowledgment is MU or SU. In some embodiments, the MU ACK Policy subfield is optional in the data MPDU.

At sub-operation **601**B, the AP may generate an ACK Info MPDU for each STA participating in the DL MU transmission that includes additional acknowledgement information. For example, the DL MU PPDU/frame may include an ACK Info MPDU for STA1 and an ACK Info MPDU for STA2 as both of these stations are participating in the UL MU acknowledgment transmission. The ACK Info MPDU further describes/indicates acknowledgement technique/scheme and other information/properties/characteristics (in addition to the acknowledgment information in the data MPDU) needed for each respective STA to acknowledge successful receipt of the DL MU transmission. For example, each ACK Info MPDU may indicate whether the acknowledgement is (1) immediate or non-immediate, (2) multi-user or single user, and/or (3) scheduling information (e.g., a resource unit within a UL transmission) when a multi-user acknowledgement is selected as shown in FIG. **6**B. For instance, in some embodiments the ACK Info MPDU may only be present when the MU ACK Info subfield of the corresponding data MPDU is set to indicate a MU UL acknowledgment. In another example embodiment, the data MPDU does not include acknowledgment information and all acknowledgment information is included in the ACK Info MPDU. In still another example embodiment, the data MPDU includes an ACK Policy subfield and this subfield is interpreted by STAs to indicate immediate/non-immediate and MU/SU acknowledgment. In this embodiment, the ACK Info MPDU includes scheduling/trigger information when an MU acknowledgment is scheduled. As legacy STAs cannot participate in UL MU transmissions, legacy STAs will be assigned SU acknowledgements, while non-legacy STAs (i.e., STAs that support UL MU transmissions) can be assigned MU acknowledgements.

In one embodiment, the scheduling information for the UL MU acknowledgement frame transmission includes common information and a per-STA information. The common information is information that is the same for every STA in the UL MU acknowledgement frame transmission and the per-STA information is specific resource allocation for each STA. Thus, different STAs scheduled in the same DL MU PPDU have different per-STA information while each STA has the same common information.

In some embodiments, the data MPDU and ACK Info MPDU for each STA may be aggregated into an A-MPDU

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at operation **601**C. Accordingly, the DL MU transmission includes a single A-MPDU for each STA that includes both data and acknowledgement scheduling information. In some embodiments, the ACK Info MPDU is the first MPDU in each A-MPDU while in other embodiments ACK Info MPDU is in another position in each A-MPDU, such as the last MPDU in each A-MPDU.

Although described and shown as including a single data MPDU, in other embodiments, each A-MPDU may include one or more data MPDUs. Further, in some embodiments, each STA may receive multiple A-MPDUs in a single DL MU frame/PPDU.

Following generation of the DL MU frame/PPDU at operation **601**, the method **600** may move to operation **603**. At operation **603**, the AP transmits the DL MU frame/PPDU to the addressed/target STAs. For example, as shown in FIG. **6**B, the DL MU PPDU may be sent to the non-legacy STA1 and STA2. As noted above, the DL MU PPDU may utilize OFDMA and/or MIMO MU transmission techniques.

At operation **605**, each STA addressed by the DL MU PPDU may receive and attempt to decode the DL MU PPDU. In particular, each targeted STA receives the DL MU PPDU and checks the preamble portion of the frame. In some embodiments, the preamble portion of the frame indicates the allocated resource for each target receiver in the MU transmission. Each target STA may thereafter decode the PPDU/resource unit that is allocated to that particular STA, including the data MPDU and the ACK Info MPDU. Based on the ACK Info MPDUs and/or the header of the data MPDUs, each STA can identify the type of acknowledgement transmission that is to be employed (e.g., MU or SU and immediate or non-immediate) and resource assignment when a MU transmission is indicated.

At operation **607**, the STAs that successfully received and decoded the appropriate portions of the DL MU PPDU may acknowledge receipt through the generation and the transmission of acknowledgement frames by each respective STA according to the acknowledgement information extracted from the DL frame. Acknowledgment may be performed after a predetermined period has elapsed since receipt of the DL frame (e.g., a short interframe space (SIFS) period or another interframe space (IFS) period). In one example shown in FIG. **6**B, STA1 and STA2 may participate in an UL MU acknowledgement based on scheduling information included in each respective ACK Info MPDU. As shown, STA1 is allocated the lower half of an UL OFDMA frame while STA2 is allocated the upper half of the UL OFDMA frame to carry an acknowledgement (e.g., a BA/ACK).

Turning now to FIG. **7**A, a method **700** will be described for coordinating UL MU acknowledgement/response transmissions to a DL MU transmission according to another embodiment. As will explained in further detail below, the proposed method **700** facilitates UL MU acknowledgement/response transmissions for more advanced STAs (e.g., HE STAs), which support UL MU capabilities (e.g., UL OFDMA or UL MU-MIMO).

Similar to the methods **500** and **600**, the method **700** may be performed by one or more devices in the network **200**. For example, one or more operations or sub-operations of the method **700** may be performed by the device **211**, which is operating as an AP in the network **200**, and/or the devices **212**-**215**, which are operating as STAs in the network **200**.

Each operation of the method **700** will be described by way of example below in relation to the transmission diagram shown in FIG. **7**B. Although one or more operations or sub-operations are described or shown in a particular sequential order, in other embodiments the operations/sub-operations may be rearranged in a different order, which may include performance of multiple operations in at least partially overlapping time periods.

The method **700** may commence at operation **701** with the generation of a DL MU frame by an AP. The DL MU frame may be addressed to a set of STAs operating in a network. For example, as shown in FIG. **7**B, the DL MU frame may be addressed to STA1 and STA2. In this example, the AP schedules a DL OFDMA transmission to STA1 and STA2, wherein STA1 is allocated a lower half of the transmission bandwidth and STA2 is allocated an upper half of the transmission bandwidth. In this example, STA1 and STA2 are HE STAs or other devices that support UL MU transmissions. Although shown as an OFDMA frame/PPDU, the generated DL MU frame may be a MU-MIMO frame/PPDU. The generation of the frame at operation **701** may include the sub-operations described below.

At sub-operation **701**A the AP may select/set an acknowledgement scheme for each target STA of the DL MU frame. For instance, in the example shown in FIG. **7**B, an acknowledgement scheme may be selected for both STA1 and STA2 at sub-operation **701**A. This information/properties/characteristics may indicate (1) whether the acknowledgement is immediate or non-immediate, (2) whether the acknowledgement is multi-user or single user, and/or (3) scheduling information (e.g., a resource unit within a UL transmission) when a multi-user acknowledgement is selected.

In one embodiment, the scheduling information for the UL MU acknowledgement frame transmission includes common information and a per-STA information. The common information is information that is the same for every STA in the UL MU acknowledgement frame transmission and the per-STA information is specific resource allocation for each STA. Thus, different STAs scheduled in the same DL MU PPDU have different per-STA information while each STA has the same common information.

However, in some embodiments, a distinction or division between common and per user information is not made. Since the acknowledgment/scheduling information is included in the header of the corresponding MPDU, it is understood that this information is intended for a specific STA.

Following selection of an acknowledgement scheme for each target STA, sub-operation **701**B may generate one or more MPDUs for each target STA and may place each MPDU in resource units within the DL MU frame assigned/allocated to each respective STA. The resource units may be particular spatial streams or sub-channels of a wireless channel upon which the DL MU frame will be transmitted. For example, as shown in FIG. **7**B, one or more MPDUs may be generated for STA1 and one or more MPDUs may be generated for STA2. At least one MPDU for each target STA may include corresponding (1) information indicating the acknowledgment scheme selected for each corresponding STA and (2) data (e.g., voice, video, best effort, background, or control data) that is specifically intended for the particular STA. In some embodiments, each MPDU for a particular STA may include the acknowledgment scheme information along with data.

In one embodiment, information indicating the acknowledgment scheme/information selected for each corresponding STA may be located in a header of each or at least one MPDU (e.g., a MAC header) and data may be located in a payload of the MPDU (e.g., MAC payload).

Using the above indications, since legacy STAs cannot participate in UL MU acknowledgement transmissions,

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legacy STAs may be assigned SU acknowledgements while non-legacy STAs may be assigned MU acknowledgements.

In some embodiments, the MPDUs for each STA may be separately aggregated into one or more A-MPDUs at operation **701**C. Accordingly, the DL MU transmission includes one or more A-MPDUs for each STA. In one embodiment, the HT Control field in the MAC header of one or more MPDUs within each AMPDU of the DL MU PPDU for each scheduled STA has a first indication that the scheduling information for a UL MU acknowledgement frame transmission is included in the MPDU. When the first indication is set, the size of the HE variant of the HT Control field is longer than the size of HT Control field when the first indication is not set. In another embodiment, the lengths of the HE variant of the HT Control field and the HT Control field are the same.

Following generation of the DL MU frame/PPDU at operation **701**, the method **700** may move to operation **703**. At operation **703** the AP transmits the DL MU frame/PPDU to the addressed/target STAs. For example, as shown in FIG. **7**B, the DL MU PPDU may be transmitted to STA1 and STA2 over a wireless channel. As noted above, the DL MU PPDU may utilize OFDMA and/or MIMO MU transmission techniques.

At operation **705** each STA addressed by the DL MU PPDU may receive and attempt to decode the DL MU PPDU. In particular, each targeted STA receives the DL MU PPDU and checks the header portion of one or more MPDUs in the one or more A-MPDUs. As noted above, the header portion of the frame may include acknowledgement scheme information/properties/characteristics, including (1) whether the acknowledgement is immediate or non-immediate, (2) whether the acknowledgement is multi-user or single user, and/or (3) scheduling information (e.g., a resource unit within a UL transmission) when a multi-user acknowledgement is selected.

At operation **707**, the STAs that successfully received and decoded the appropriate portions of the DL MU PPDU may acknowledge receipt through the generation and the transmission of acknowledgement frames by each respective STA according to the acknowledgement information extracted from the DL frame. Acknowledgment may be performed after a predetermined period has elapsed since receipt of the DL frame (e.g., a short interframe space (SIFS) period or another interframe space (IFS) period). In one example shown in FIG. **7**B, STA1 and STA2 may participate in an UL MU acknowledgement based on scheduling information included in headers of respective MPDUs. As shown, STA1 is allocated the lower half of an UL OFDMA frame while STA2 is allocated the upper half of the UL OFDMA frame to carry an acknowledgement (e.g., a BA/ACK).

Turning now to FIG. **8**A, a method **800** will be described for coordinating UL MU acknowledgement/response transmissions to a DL MU transmission according to another embodiment. Similar to the methods **500**, **600**, and **700**, the method **800** may be performed by one or more devices in the network **200**. For example, one or more operations or sub-operations of the method **800** may be performed by the device **211**, which is operating as an AP in the network **200**, and/or the devices **212**-**215**, which are operating as STAs in the network **200**.

Each operation of the method **800** will be described by way of example below in relation to the transmission diagram shown in FIG. **8**B. Although one or more operations or sub-operations are described or shown in a particular sequential order, in other embodiments the operations/sub-operations may be rearranged in a different order, which may include performance of multiple operations in at least partially overlapping time periods.

The method **800** may commence at operation **801** with the generation of a DL MU PPDU/frame by an AP. The DL MU frame may be addressed to a set of target STAs operating in a network. For example, as shown in FIG. **8**B, the DL MU frame may be addressed to STA1 and STA2. In this example, the AP schedules a DL OFDMA transmission to STA1 and STA2, wherein STA1 is allocated a lower third of the transmission bandwidth and STA2 is allocated a middle third of the transmission bandwidth. As will be described in greater detail below, the upper third of the transmission bandwidth may be used for a multicast or broadcast transmission to both STA1 and STA2. In the example shown in FIG. **8**B, STA1 and STA2 are HE STAs or other devices that support UL MU transmissions. Although shown as an OFDMA frame/PPDU, the generated DL MU frame may be a MU-MIMO frame/PPDU. The generation of the frame at operation **801** may include the sub-operations described below.

At operation **801**A, the AP may generate an MPDU that includes an acknowledgement scheme for each target STA of the DL MU frame. For instance, in the example shown in FIG. **8**B, an acknowledgement scheme may be selected for both STA1 and STA2 and included in the MPDU generated at sub-operation **801**A. This acknowledgement scheme information/properties/characteristics may indicate (1) whether the acknowledgement is immediate or non-immediate, (2) whether the acknowledgement is multi-user or single user, and/or (3) scheduling information (e.g., a resource unit within a UL transmission) when a multi-user acknowledgement is selected.

In one embodiment, the scheduling information for the UL MU acknowledgement frame transmission includes common information and a per-STA information. The common information is information that is the same for every STA in the UL MU acknowledgement frame transmission and the per-STA information is specific resource allocation information for each STA. Thus, different STAs scheduled in the same DL MU PPDU have different per-STA information while each STA has the same common information.

In one embodiment, the MPDU that includes an acknowledgement scheme for each target STA may be broadcast or multicast to target STAs. In one embodiment, the MPDU that includes an acknowledgement scheme for each target STA is multicast/broadcast to at least those STAs that are scheduled for an immediate MU acknowledgement transmission. For example, as shown in FIG. **8**B, acknowledgment information/scheduling MPDU may be transmitted to STA1 and STA 2 in a resource unit of an OFDMA frame (i.e., the upper third of the transmission bandwidth of the DL MU frame). However, in other embodiments, other multicast and broadcast techniques may be employed.

Although shown and described in relation to the STAs that participated in the DL MU transmission, in other embodiments, the DL MU transmission may request other STAs to participate in the UL MU acknowledgment transmission.

Following generation of an MPDU that includes an acknowledgement scheme for each target STA, sub-operation **801**B may generate one or more data MPDUs for each target STA. For example, as shown in FIG. **8**B, one or more MPDUs may be generated for STA1 and one or more MPDUs may be generated for STA2. The one or more MPDUs for each target STA may include data (e.g., voice, video, best effort, background, or control data) that is specifically intended for the particular STA. In some

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embodiments, the data MPDUs for each STA may be separately aggregated into one or more A-MPDUs.

Accordingly, the DL MU transmission includes (1) a single MPDU that includes an acknowledgement scheme for each target STA and (2) one or more MPDUs or A-MPDUs for each STA. The MPDU that includes an acknowledgement scheme for each target STA may be broadcast or multicast to target STAs while the data MPDUs/A-MPDUs are each addressed to a corresponding STA. For example, using the example in FIG. **8B**, the single MPDU that includes an acknowledgement scheme for each target STA is addressed to both STA1 and STA2 in an upper third of the DL MU PPDU, data MPDUs/A-MPDUs addressed to STA2 are located in a middle third of the DL MU PPDU, and data MPDUs/A-MPDUs addressed to STA1 are located in a lower third of the DL MU PPDU.

Using the above indications, since legacy STAs cannot participate in UL MU acknowledgement transmissions, legacy STAs may be assigned a SU acknowledgement while non-legacy STAs may be assigned a MU acknowledgement. In some embodiments, the data MPDUs may include an ACK Policy subfield that is set according to Table 1 and is consistent with the acknowledgment information in the broadcast/multicast frame in the DL MU PPDU.

Following generation of the DL MU frame/PPDU at operation **801**, the method **800** may move to operation **803**. At operation **803** the AP transmits the DL MU frame/PPDU to the addressed/target STAs. For example, as shown in FIG. **8B**, the DL MU PPDU may be transmitted to STA1 and STA2 over a wireless channel. As noted above, the DL MU PPDU may utilize OFDMA and/or MIMO MU transmission techniques.

At operation **805** each STA addressed by the DL MU PPDU may receive and attempt to decode the DL MU PPDU. In particular, each targeted STA receives the DL MU PPDU and determines resource units or particular portions of the frame assigned to the STA by examining the preamble portion of the DL MU PPDU/frame. In the example shown in FIG. **8B**, STA1 would determine that the lower third of the DL MU transmission bandwidth is a transmission intended for STA1 and the upper third of the DL MU transmission bandwidth is a multicast/broadcast transmission intended for STA1 and STA2. Specifically, as noted above, the upper third of the transmission bandwidth includes acknowledgement scheme information for STA1 and STA2, including (1) whether acknowledgement of the DL MU frame is immediate or non-immediate, (2) whether the acknowledgement is multi-user or single user, and/or (3) scheduling information (e.g., a resource unit within a UL transmission) when a multi-user acknowledgement is selected. In contrast, the unicast transmission directed to STA1 is data specifically intended for this device. In some embodiments, the broadcast/multicast frame may include scheduling/trigger information for coordinating the UL MU acknowledgment transmission while one or more data MPDUs addressed to each STA may include indications of whether the acknowledgment transmission is immediate/non-immediate and/or MU/SU.

At operation **807**, the STAs that successfully received and decoded the appropriate portions of the DL MU PPDU may acknowledge receipt through the generation and the transmission of acknowledgement frames by each respective STA according to the acknowledgement information extracted from the DL frame. Acknowledgment may be performed after a predetermined period has elapsed since receipt of the DL frame (e.g., a short interframe space (SIFS) period or another interframe space (IFS) period). In one example shown in FIG. **8B**, STA1 and STA2 may participate in an UL MU acknowledgement based on scheduling information included in a multicast/broadcast MPDU. As shown, STA1 is allocated the lower half of an UL OFDMA frame while STA2 is allocated the upper half of the UL OFDMA frame to carry an acknowledgement (e.g., a BA/ACK).

As described in methods **500**, **600**, **700**, and **800**, each target STA of a DL MU transmission may transmit an acknowledgement according to one or more schemes/techniques. In some embodiments, the acknowledgement schemes/techniques may involve a delayed acknowledgement. In these situations, the AP may transmit a trigger frame to trigger the STAs participating in the delayed acknowledgement to transmit a respective portion of the acknowledgement frame. For example, FIG. **9** show one example of this procedure.

As shown in FIG. **9**, an access point transmits a DL MU frame to a set of target STAs (e.g., STA1, STA2, STA3, and STA4). The DL MU frame may indicate that a non-immediate acknowledgement is to be transmitted by one or more of the target STAs. As shown in FIG. **9**, the ACK policy subfield for each target STA is set to "11", which indicates that each STA is to participate in a non-immediate (i.e., block) acknowledgement.

The participating STAs may wait for a BAR or a MU BAR frame (hereinafter to be described in relation to MU BAR for simplicity). The MU BAR frame may be a trigger frame that includes trigger information and per-STA BAR control and bitmap information. Upon receipt of the MU BAR, each STA retrieves corresponding scheduling information from the MU BAR frame. The BAR frame may be implemented using various schemes and techniques. For example, a single MU BAR frame may be constructed and transmitted by the AP, wherein the MU BAR frame comprises BAR information for each scheduled STA and UL BA transmission scheduling information for each scheduled STA. In another example embodiment, an AP sends an A-MPDU to each scheduled STA in the DL MU transmission and the A-MPDU comprises BAR information and UL BA transmission scheduling information. In another embodiment, an AP sends the following frames in a DL MU transmission: 1) one BAR frame to each STA and 2) one broadcast/multicast frame for UL MU BA transmission. Based on the scheduling information, each STA participates in the MU acknowledgement a predetermined period following receipt of the MU BAR (e.g., a SIFS period).

In some embodiments, either a SU or MU immediate acknowledgement may be scheduled by the DL MU frame and may be transmitted prior to the MU BAR and consequential MU delayed acknowledgement. In some embodiments, multiple delayed SU or MU acknowledgements may be triggered for one DL MU frame and different sets of STAs. For example, a DL MU frame may be addressed to a first set of STAs and a second set of STAs. The AP may transmit a first BAR to trigger an acknowledgment transmission from the first set of STAs and a second BAR to trigger an acknowledgement transmission from the second set of STAs.

Although the methods and techniques above are described and shown separately, in one or more embodiments, these methods and techniques may be combined. For example, in some embodiments, acknowledgment information for a first STA may be located in the header of a data MPDU while acknowledgment information for a second STA may be located in a separate MPDU. In this example, the acknowledgment information may facilitate/trigger both the first and

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second STA to participate in the same UL MU transmission or in separate UL SU/MU transmissions.

Although the methods and techniques above have been described in relation to pure acknowledgment transmissions, in some embodiments the UL MU acknowledgment transmission may allow data transmission from some STAs. For example, a first set of STAs may transmit a set of acknowledgements while a second set of STAs may transmit data (e.g., video, voice, etc.) in designated resource units of the same UL MU transmission. In another example, a STA (either participating in a SU or MU transmission) may transmit both an acknowledgement and data in the same PPDU.

As noted above, acknowledgements may be transmitted using several MU multiplexing techniques, including OFDMA and MU-MIMO. However, multiplexing acknowledgement frames together in an OFDMA manner may have several technical issues that need to be resolved. One of the issues is that multiplexed acknowledgement frames cannot use a non-HT frame format because non-HT frame formats do not support MU transmissions, such as MU-MIMO and OFDMA. Therefore, in some embodiments, multiplexed acknowledgement frames shall use the HE frame format as defined in 802.11ax and shown in FIG. **4**C.

FIG. **10** shows another example of an HE frame format. In FIGS. **4**C and **10**, the legacy preamble may include fields that are needed to support backward compatibility with previous frame formats. These legacy fields may include a legacy-short training field (L-STF), a legacy-long training field (L-LTF), and a legacy-signaling field (L-SIG). A High Efficiency signaling field (HE-SIG) includes information required to interpret a HE PPDU. HE-SIG fields may include at least an HE-SIG-A field and optionally a HE-SIG-B field. The size of the HE-SIG-A field is fixed and the HE-SIG-A field indicates common control information for the frame. The HE-SIG-B field comprises per-STA specific information. After the HE-SIG fields, the HE-STF/LTF fields follow, wherein the HE-STF/LTF fields are needed for automatic gain control (AGC) settings, frequency offset compensation, channel estimation, etc. Further, the HE-LTF section may start at the same time and end at the same time across all users/STAs in case of MU transmission.

In case of a UL MU transmission, an UL MU PPDU (e.g., MU-MIMO and/or OFDMA frame) is sent as an immediate response to a trigger frame sent by an AP (as shown in FIG. **9**). In this case, the legacy preamble part of the UL MU PPDU is combined together in the air based on transmissions from all the participating STAs. Accordingly, all participating STAs need to have the same information/data in the legacy preamble to ensure proper combination in the air. In some embodiments, the trigger frame may indicate to each STA what information is needed in the legacy preamble portion of the frame such that each STA transmits identical information for the legacy preamble portion of the UL MU PPDU.

Similarly, the HE-SIG fields must use identical information to ensure proper in air combination. Accordingly, per-STA information in the HE-SIG fields can be removed as the target receiver of the UL MU PPDU already knows this information. Further, the HE-SIG-B field of the HE UL MU PPDU can be entirely omitted. Since no HE-SIG-B field exists in the UL MU PPDU, there will not be an explicit indication of per-STA information such as bandwidth, modulation and coding scheme (MCS), and number of space-time streams (NSTS) in the legacy preamble and HE-SIG fields of the UL MU PPDU.

In some UL MU transmissions that are sent as immediate responses to a DL trigger frame, because the trigger frame includes per-STA information such as MCS/NSTS/duration information for every STA, it is possible for each participating STA to identify how many LTFs to be used for the UL MU PPDU. In these cases, the number of HE-LTF symbols of a UL MU PPDU is equal to or greater than the required HE-LTF symbols for all participating STAs' transmissions. FIG. **11** illustrates one example on the number of required HE-LTF symbols. In this example, STA1 and STA2 are allocated for a MU transmission, wherein STA1 occupies the upper half of the channel bandwidth and STA2 occupies the lower half of the channel bandwidth. Further, the NSTS (e.g., the number of spatial streams) for STA1 is one and the NSTS for STA2 is four. In this case, to align the start and end point of the HE-LTF fields for both STAs, the number of HE-LTF symbols is set to four, which is the maximum required NSTS for STA1 and STA2.

However, in the case an acknowledgement frame is sent in a UL MU manner in response to DL MU transmission and there is no trigger information and/or no trigger frame (i.e., a frame separate and distinct from the DL MU transmission and that is sent to multiple STAs in the DL MU transmission in a broadcast/multicast manner to cause these STAs to participate in a UL MU acknowledgement), it is hard for each STA to figure out the other STA's transmission information. Therefore, it is hard for each STA to identify the NSTS of the acknowledgement frame as each STA's transmission information is not shared. As described above, this information is necessary such that each STA may transmit an appropriate number of HE-LTF sequences to accommodate the largest NSTS of other STAs.

To overcome this problem with acknowledgement frame transmissions that are in response to a DL MU frame transmission, mechanisms are proposed that select an MCS and a number of spatial streams (or space-time streams) for transmitting response frames.

In one embodiment, if a control response frame is to be transmitted in an UL MU PPDU, the number of spatial streams (or space-time streams) per STA shall be limited to one. Therefore, every STA participating a UL MU transmission in response to a DL MU transmission will send an ACK/BA frame having the same number of HE-LTF symbols regardless of other participating STAs' channel conditions. Since each STA transmits the same number of HE-LTF symbols (e.g., one), the HE-LTF section of the ACK/BA frame can start and end at the same time for all transmission without knowing the transmission conditions for other STAs.

In some embodiments, a UL MU transmission may include both acknowledgment frames from a first set of STAs and data frames from a second set of STAs. In this case, the first set of STAs would transmit using a single spatial stream.

This above concept may be achieved in multiple ways. Some of the possible implementations are described herein; however, embodiments mentioned herein do not limit the applicability of the above concept.

In one embodiment, if a control response frame is to be transmitted in a UL MU manner, all participating STAs transmit the control response frame at a predetermined time after receiving an eliciting frame (e.g., a SIFS period or another IFS period). Further, the transmission sets the number of HE-LTF symbols to a value corresponding to a single space-time stream. The HE-LTF symbols provide a means for the receiver to estimate the MIMO channel between the set of constellation mapper outputs and the receive chain.

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FIG. 12 shows an example of this embodiment. In this example, an AP transmits data frames to STA1 and STA2 in a DL OFDMA manner, wherein STA1's data is assigned to the upper half of the channel bandwidth and STA2's data is assigned to the lower half of the channel bandwidth. Due to different channel conditions, the AP uses a single stream transmission to STA1 and two stream transmissions (spatial multiplexing) to STA2. To align the transmission time, the AP uses HE-LTF symbols corresponding to a two stream transmission (i.e., the number of HE-LTF symbols is two) for both STA1 and STA2.

After successfully decoding the DL OFDMA frame, STA1 and STA2 send back acknowledgement (ACK or BA) frames in an OFDMA manner a predetermined time (e.g., SIFS) after receiving the DL OFDMA frame. When STA1 and STA2 construct the acknowledgement frame in an OFDMA manner, the number of HE-LTF symbols is set to a value corresponding to a single space-time stream (i.e., the number of HE-LTF symbols is equal to one). Although a single space-time stream is used herein, in other embodiments, other numbers of space-time streams may be used (e.g., two space-time streams may be used, which would correspond to two HE-LTF symbols in the UL MU frame).

In some embodiments, Space-Time-Block-Coding (STBC) shall be disabled for the acknowledgement frame transmission. For example, STBC may be disabled when the number of space-time streams is equal to one.

In one embodiment in which the number of HE-LTF symbols in a UL MU transmission is set to a value, a first value is indicated by the transmitter of the eliciting frame as the length of the control response frame and the MCS of the control response frame is set such that the length of the control response frame is not greater than the first value.

For example, the first value may be included in the eliciting frame. In another example the first value is indicated before sending the eliciting frame (e.g., the first value is included in a first management frame (e.g., a beacon frame, a Probe Response frame, or an Association response frame) sent by the transmitter of the eliciting frame).

In one embodiment, if a control response frame is to be transmitted in a UL MU manner, an MCS shall be selected from a first set, wherein the MCS defines modulation/coding schemes and the number of space-time streams, wherein the number of space-time streams of the first set is limited to one. In one embodiment, all <VHT-MCS, NSS> tuples defined in the IEEE 802.11ac standard are further eliminated from the first set. In one embodiment, all MCSs that have a data rate greater than the data rate of the eliciting PPDU are further eliminated from the first set. In one embodiment, a transmitter of an eliciting frame for the control response frame further informs information related to the length of the control response frame. All MCSs that result in the encoded control response frame having a length that exceeds the informed length are further eliminated from the first set. In one embodiment, all MCSs that do not meet certain criteria are further eliminated from the first set and if the first set is empty, the MCS shall be selected from a second set.

In another embodiment, if a control response frame is to be transmitted in a UL MU manner, all participating STAs transmit the control response frame in a predetermined time (e.g., SIFS) after receiving an eliciting frame. In this embodiment, the eliciting frame may indicate that the number of HE-LTF symbols for the control response frame is a second value. In some embodiments, the second value is indicated by the transmitter of the eliciting frame and the HE-LTF symbols provide a means for the receiver to estimate the MIMO channel between the set of constellation mapper outputs and the receive chain. In one embodiment, a first value is indicated by the transmitter of the eliciting frame as the length of the control response frame. The MCS of the control response frame is set such that the length of the control response frame is not greater than the first value. In one embodiment, the first value and/or the second value are included in the eliciting frame. In another embodiment, the first value and/or the second value are indicated before sending the eliciting frame. For example, the first value is included in a first management frame (e.g., a Beacon Frame, a Probe Response frame, or Association Response frame) sent by the transmitter of the eliciting frame.

In another embodiment, if a control response frame is to be transmitted in a UL MU manner, an MCS shall be selected from a first set, wherein the MCS defines modulation/coding schemes and the number of space-time streams. In this embodiment, the number of space-time streams of the first set is limited to a second value. In one embodiment, information on the second value is included in the eliciting frame. In another embodiment, the second value is indicated before sending the eliciting frame. For example, the second value is included in a first management frame (e.g., a Beacon Frame, a Probe Response frame, or an Association Response frame) sent by the transmitter of the eliciting frame. In one embodiment, all <VHT-MCS, NSS> tuples defined in the IEEE 802.11ac standard are further eliminated from the first set. In one embodiment, all MCSs that have a data rate greater than the data rate of the eliciting PPDU are further eliminated from the first set. In one embodiment, a transmitter of an eliciting frame for the control response frame further informs information related to the length of the control response frame, and all MCSs that the length of the encoded control response frame exceeds the informed length of the control response frame are further eliminated from the first set. In one embodiment, upon determining that the highest number of spatial streams (or space-time streams) value of the MCS in the first set is less than or equal to a third number of spatial streams (or space-time streams) value of the received frame, eliminating all MCSs from the first set that have the number of spatial streams (or space-time streams) value that is not equal to the third number of streams. In one embodiment, all MCSs that do not meet certain criteria are further eliminated from the first set and if the first set is empty, the MCS shall be selected from a second set.

As described above, an apparatus or a station comprising means (e.g., **310**) may be adapted for performing one or more methods or operations described herein. Further, these apparatuses or stations may include a computer-readable storage medium (e.g., **340**, one or more internal, external or remote memories, or one or more registers) comprising instructions stored therein, the instructions comprising code for performing one or more methods or operations described herein.

In one aspect, a method may be an operation, an instruction, or a function and vice versa. In one aspect, a clause may be amended to include some or all of the words (e.g., instructions, operations, functions, or components) recited in other one or more clauses, one or more sentences, one or more phrases, one or more paragraphs, and/or one or more claims.

To illustrate the interchangeability of hardware and software, items such as the various illustrative blocks, modules, components, methods, operations, instructions, and algorithms have been described generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular applica-

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tion and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application.

A reference to an element in the singular is not intended to mean one and only one unless specifically so stated, but rather one or more. For example, "a" module may refer to one or more modules. An element proceeded by "a," "an," "the," or "said" does not, without further constraints, preclude the existence of additional same elements.

Headings and subheadings, if any, are used for convenience only and do not limit the invention. The word exemplary is used to mean serving as an example or illustration. To the extent that the term include, have, or the like is used, such term is intended to be inclusive in a manner similar to the term comprise as comprise is interpreted when employed as a transitional word in a claim. Relational terms such as first and second and the like may be used to distinguish one entity or action from another without necessarily requiring or implying any actual such relationship or order between such entities or actions.

Phrases such as an aspect, the aspect, another aspect, some aspects, one or more aspects, an implementation, the implementation, another implementation, some implementations, one or more implementations, an embodiment, the embodiment, another embodiment, some embodiments, one or more embodiments, a configuration, the configuration, another configuration, some configurations, one or more configurations, the subject technology, the disclosure, the present disclosure, other variations thereof and alike are for convenience and do not imply that a disclosure relating to such phrase(s) is essential to the subject technology or that such disclosure applies to all configurations of the subject technology. A disclosure relating to such phrase(s) may apply to all configurations, or one or more configurations. A disclosure relating to such phrase(s) may provide one or more examples. A phrase such as an aspect or some aspects may refer to one or more aspects and vice versa, and this applies similarly to other foregoing phrases.

A phrase "at least one of" preceding a series of items, with the terms "and" or "or" to separate any of the items, modifies the list as a whole, rather than each member of the list. The phrase "at least one of" does not require selection of at least one item; rather, the phrase allows a meaning that includes at least one of any one of the items, and/or at least one of any combination of the items, and/or at least one of each of the items. By way of example, each of the phrases "at least one of A, B, and C" or "at least one of A, B, or C" refers to only A, only B, or only C; any combination of A, B, and C; and/or at least one of each of A, B, and C.

It is understood that the specific order or hierarchy of steps, operations, or processes disclosed is an illustration of exemplary approaches. Unless explicitly stated otherwise, it is understood that the specific order or hierarchy of steps, operations, or processes may be performed in different order. Some of the steps, operations, or processes may be performed simultaneously. The accompanying method claims, if any, present elements of the various steps, operations or processes in a sample order, and are not meant to be limited to the specific order or hierarchy presented. These may be performed in serial, linearly, in parallel or in different order. It should be understood that the described instructions, operations, and systems can generally be integrated together in a single software/hardware product or packaged into multiple software/hardware products.

The disclosure is provided to enable any person skilled in the art to practice the various aspects described herein. In some instances, well-known structures and components are shown in block diagram form in order to avoid obscuring the concepts of the subject technology. The disclosure provides various examples of the subject technology, and the subject technology is not limited to these examples. Various modifications to these aspects will be readily apparent to those skilled in the art, and the principles described herein may be applied to other aspects.

All structural and functional equivalents to the elements of the various aspects described throughout the disclosure that are known or later come to be known to those of ordinary skill in the art are expressly incorporated herein by reference and are intended to be encompassed by the claims. Moreover, nothing disclosed herein is intended to be dedicated to the public regardless of whether such disclosure is explicitly recited in the claims. No claim element is to be construed under the provisions of 35 U.S.C. §112, sixth paragraph, unless the element is expressly recited using a phrase means for or, in the case of a method claim, the element is recited using the phrase step for.

The title, background, brief description of the drawings, abstract, and drawings are hereby incorporated into the disclosure and are provided as illustrative examples of the disclosure, not as restrictive descriptions. It is submitted with the understanding that they will not be used to limit the scope or meaning of the claims. In addition, in the detailed description, it can be seen that the description provides illustrative examples and the various features are grouped together in various implementations for the purpose of streamlining the disclosure. The method of disclosure is not to be interpreted as reflecting an intention that the claimed subject matter requires more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive subject matter lies in less than all features of a single disclosed configuration or operation. The following claims are hereby incorporated into the detailed description, with each claim standing on its own as a separately claimed subject matter.

The claims are not intended to be limited to the aspects described herein, but are to be accorded the full scope consistent with the language claims and to encompass all legal equivalents. Notwithstanding, none of the claims are intended to embrace subject matter that fails to satisfy the requirements of the applicable patent law, nor should they be interpreted in such a way.

What is claimed is:

1. A method, implemented by a network device in a wireless network, for coordinating an uplink multi-user response transmission to a downlink multi-user transmission, the method comprising:

generating, by the network device, a downlink multi-user frame addressed to a plurality of stations operating in the wireless network, the downlink multi-user frame including a plurality of resource units (RUs), wherein generating the downlink multi-user frame comprises:

assigning each RU of the plurality of RUs to a respective station in the plurality of stations, and

including a respective set of MAC Protocol Data Units (MPDUs) in each RU of the plurality of RUs,

wherein an MPDU in one or more of the RUs in the plurality of RUs includes acknowledgement information indicating properties of a multi-user acknowledgement transmission that the station in the plurality of stations to which the RU is assigned is requested to transmit to acknowledge the downlink multi-user frame;

transmitting the downlink multi-user frame to the plurality of stations over a wireless channel; and

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receiving the uplink multi-user response transmission, the uplink multi-user response transmission including multi-user acknowledgement transmissions respectively and simultaneously transmitted by two or more stations in the plurality of stations,

wherein the plurality of RUs respectively correspond to a plurality of simultaneous uplink transmissions, and each of the plurality of simultaneous uplink transmissions uses a sub-channel, spatial stream, or sub-channel and spatial stream combination that is not used by any other of the plurality of simultaneous uplink transmissions.

2. The method of claim 1, wherein generating the downlink multi-user frame further comprises:

including the acknowledgement information, for indicating properties of the multi-user acknowledgement transmission transmitted by each respective station in the plurality of stations to acknowledge the downlink multi-user frame, in a header of the one or more MPDUs.

3. The method of claim 2, wherein the header is a MAC header of the one or more MPDUs.

4. The method of claim 1, wherein one of the one or more MPDUs in each of the RUs of the plurality of RUs is a unicast trigger frame that contains the acknowledgement information for the respective station in the plurality of stations.

5. The method of claim 4, wherein the trigger frame instigates each respective station in the plurality of stations to transmit the multi-user acknowledgement transmission after an interframe spacing period following receipt of the downlink multi-user frame.

6. The method of claim 1, further comprising:

generating, by the network device, a multi-user block acknowledgement request frame to solicit acknowledgements from two or more stations of the plurality of stations; and

transmitting the multi-user block acknowledgment request frame following transmission of the downlink multi-user frame.

7. The method of claim 1, wherein the acknowledgement information includes one or more of: (1) an indication of whether the acknowledgement transmission is multi-user or single user, and (2) an indication of whether the acknowledgment transmission is immediate or non-immediate, and further includes resource scheduling information when the multi-user acknowledgement transmission is indicated.

8. A method, implemented by a first station in a wireless network, for transmitting an uplink acknowledgment, the method comprising:

receiving a downlink multi-user frame addressed to a plurality of stations, including the first station, and received from an access point in the wireless network;

processing a first MAC Protocol Data Units (MPDU) in the downlink multi-user frame to determine acknowledgement information indicating properties of a first multi-user acknowledgement frame;

generating the first multi-user acknowledgment frame based on the acknowledgement information; and

transmitting the first multi-user acknowledgement frame to the access point to acknowledge the downlink multi-user frame,

wherein the first multi-user acknowledgement frame is transmitted simultaneously to a second multi-user acknowledgement frame transmitted by a second station.

9. The method of claim 8, wherein the first MPDU is located in a first resource unit of the downlink multi-user frame allocated to the first station, wherein the downlink multi-user frame includes a second resource unit that contains a second MPDU that includes acknowledgement information for the second multi-user acknowledgement frame.

10. The method of claim 9, wherein the first multi-user acknowledgement frame and the second multi-user acknowledgement frame together form a multi-user acknowledgement frame for acknowledging the downlink multi-user frame.

11. The method of claim 8, wherein processing the first MPDU comprises:

extracting the acknowledgement information indicating the properties of the first multi-user acknowledgement frame from a header of the first MPDU.

12. The method of claim 11, wherein the header is a MAC header of the first MPDU.

13. The method of claim 8, wherein processing the MPDU comprises:

extracting the acknowledgement information indicating the properties of the first multi-user acknowledgement frame transmission from a payload of the first MPDU, wherein the first MPDU is a unicast trigger frame.

14. The method of claim 13, further comprising:

processing a second MPDU in a same resource unit as the first MPDU, wherein the second MPDU includes data intended for the first station.

15. The method of claim 13, wherein the trigger frame instigates the first station to transmit the first multi-user acknowledgement after an interframe spacing period following receipt of the downlink multi-user frame.

16. The method of claim 8, further comprising:

receiving a multi-user block acknowledgement request frame that solicits acknowledgements from the first and second station, wherein the first multi-user acknowledgement frame is transmitted after receipt of and in response to the multi-user block acknowledgement request frame.

17. The method of claim 8, wherein the acknowledgement information includes one or more of: (1) an indication of whether the first multi-user acknowledgement frame is part of a multi-user or a single user transmission, and (2) an indication of whether the first multi-user acknowledgement frame is transmitted immediately following receipt of the downlink multi-user frame or upon receipt of a multi-user block acknowledgement request frame, and further includes resource scheduling information when the first multi-user acknowledgement frame is indicated as being part of the multi-user transmission.

18. A method, implemented by a first station in a wireless network, for transmitting an uplink acknowledgment, the method comprising:

receiving a downlink multi-user frame addressed to a plurality of stations, including the first station, wherein the downlink multi-user frame is received from an access point in the wireless network;

receiving a multi-user block acknowledgement request frame that solicits acknowledgements from the first station and a second station, wherein the multi-user block acknowledgement request frame includes acknowledgement information indicating properties of a first multi-user acknowledgement frame;

generating the first multi-user acknowledgment frame based on the acknowledgement information; and

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acknowledging the receipt of the downlink multi-user frame by transmitting the first multi-user acknowledgement frame to the access point,

wherein the first multi-user acknowledgement frame is transmitted simultaneously with a second multi-user acknowledgement frame generated and transmitted by the second station.

19. The method of claim **18**, wherein the acknowledgement information includes one or more of: (1) an indication of whether the first multi-user acknowledgement frame is part of a multi-user or single user transmission and (2) resource scheduling information for the first multi-user acknowledgement transmission.

20. The method of claim **18**, wherein the acknowledgment scheduling information includes properties of the second multi-user acknowledgement frame generated and transmitted by the second station, wherein the first multi-user acknowledgement frame and the second multi-user acknowledgement together form a multi-user transmission.

* * * * *

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EXHIBIT 1A

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:	Confirmation No.: 2806
Young Hoon KWON et al.	Examiner: PHAN, TRI H
Application No.: 15/078,920	Technology Center/Art Unit: 2471
Filed: March 23, 2016	AMENDMENT
For: APPARATUS AND METHOD FOR DOWNLINK AND UPLINK MULTI-USER TRANSMISSIONS	
Customer No.: 83220	

Mail Stop Amendment
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

In response to the Office Action mailed June 09, 2016, and the Interview held with the Examiner on July 20, 2016, please enter the following amendments and remarks:

Amendments to the Claims are reflected in the listing of claims beginning on page **2** of this paper.

Remarks/Arguments begin on page 7 of this paper.

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Amendments to the Claims:

This listing of claims will replace all prior versions and listings of claims in the application:

Listing of Claims:

1. (Currently amended) A method, implemented by a network device in a wireless network, for coordinating an uplink multi-user response transmission to a downlink multi-user transmission, the method comprising:

generating, by the network device, a downlink multi-user frame addressed to a plurality of stations operating in the wireless network, the downlink multi-user frame including a plurality of resource units ~~that are each assigned to a station in the plurality of stations~~ (RUs), wherein generating the downlink multi-user frame comprises:

assigning each RU of the plurality of RUs to a respective station in the plurality of stations, and

including a respective set of MAC Protocol Data Units (MPDUs) in each ~~resource unit~~ RU of the plurality of ~~resource units~~ RUs,

wherein ~~one or more MPDUs~~ an MPDU in ~~each~~ one or more of the ~~resource units~~RUs in the plurality of RUs ~~downlink multi-user frame~~ includes acknowledgement information [[for]] indicating properties of a multi-user acknowledgement transmission ~~transmitted by each respective~~ that the station in the plurality of stations to which the RU is assigned is requested to transmit to acknowledge the downlink multi-user frame; [[and]]

transmitting the downlink multi-user frame to the plurality of stations over a wireless channel; and

receiving the uplink multi-user response transmission, the uplink multi-user response transmission including multi-user acknowledgement transmissions respectively and simultaneously transmitted by two or more stations in the plurality of stations,

wherein the plurality of RUs respectively correspond to a plurality of simultaneous uplink transmissions, and each of the plurality of simultaneous uplink transmissions uses a sub-channel, spatial stream, or sub-channel and spatial stream combination that is not used by any other of the plurality of simultaneous uplink transmissions.

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2. (Original) The method of claim 1, wherein generating the downlink multi-user frame further comprises:

including the acknowledgement information, for indicating properties of the multi-user acknowledgement transmission transmitted by each respective station in the plurality of stations to acknowledge the downlink multi-user frame, in a header of the one or more MPDUs.

3. (Original) The method of claim 2, wherein the header is a MAC header of the one or more MPDUs.

4. (Currently amended) The method of claim 1, wherein one of the one or more MPDUs in each of the ~~resource units in the downlink multi-user frame~~ RUs of the plurality of RUs is a unicast trigger frame that contains the acknowledgement information for the respective station in the plurality of stations.

5. (Original) The method of claim 4, wherein the trigger frame instigates each respective station in the plurality of stations to transmit the multi-user acknowledgement transmission after an interframe spacing period following receipt of the downlink multi-user frame.

6. (Original) The method of claim 1, further comprising:

generating, by the network device, a multi-user block acknowledgement request frame to solicit acknowledgements from two or more stations of the plurality of stations; and

transmitting the multi-user block acknowledgment request frame following transmission of the downlink multi-user frame.

7. (Currently amended) The method of claim 1, wherein the acknowledgement information includes one or more of: (1) an indication of whether the acknowledgement transmission is multi-user or single user, and (2) an indication of whether the acknowledgment transmission is immediate or non-immediate, and ~~(3)~~ further includes resource scheduling information ~~for~~ when the multi-user acknowledgement transmission is indicated.

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8. (Currently amended) A method, implemented by a first station in a wireless network, for transmitting an uplink acknowledgment, the method comprising:

receiving a downlink multi-user frame addressed to a plurality of stations, including the first station, and received from an access point in the wireless network;

processing a first MAC Protocol Data Units (MPDU) in the downlink multi-user frame to determine acknowledgement information [[for]] indicating properties of a first multi-user acknowledgement frame ~~to acknowledge the downlink multi-user frame by two or more stations~~;

generating the first multi-user acknowledgment frame based on the acknowledgement information; and

transmitting the first multi-user acknowledgement frame to the access point ~~based on the acknowledgement information~~ to acknowledge the downlink multi-user frame,

wherein the first multi-user acknowledgement frame is transmitted simultaneously to a second multi-user acknowledgement frame transmitted by a second station.

9. (Currently amended) The method of claim 8, wherein the first MPDU is located in a first resource unit of the downlink multi-user frame allocated to the first station, wherein the downlink multi-user frame includes a second resource unit that contains a second MPDU ~~with~~ that includes acknowledgement information for ~~a second station to transmit a~~the second multi-user acknowledgement frame.

10. (Original) The method of claim 9, wherein the first multi-user acknowledgement frame and the second multi-user acknowledgement frame together form a multi-user acknowledgement frame for acknowledging the downlink multi-user frame.

11. (Currently amended) The method of claim 8, wherein processing the first MPDU comprises:

extracting the acknowledgement information~~, for~~ indicating the properties of the first multi-user acknowledgement frame~~, in~~ from a header of the first MPDU.

12. (Original) The method of claim 11, wherein the header is a MAC header of the first MPDU.

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13. (Currently amended) The method of claim 8, wherein processing the MPDU comprises:

extracting the acknowledgement information~~, for~~ indicating the properties of the first multi-user acknowledgement frame transmission[[,]] from a payload of the first MPDU, wherein the first MPDU is a unicast trigger frame.

14. (Original) The method of claim 13, further comprising:

processing a second MPDU in a same resource unit as the first MPDU, wherein the second MPDU includes data intended for the first station.

15. (Original) The method of claim 13, wherein the trigger frame instigates the first station to transmit the first multi-user acknowledgement after an interframe spacing period following receipt of the downlink multi-user frame.

16. (Currently amended) The method of claim 8, further comprising:

receiving a multi-user block acknowledgement request frame that solicits acknowledgements from ~~two or more stations~~the first and second station, wherein the first multi-user acknowledgement frame is transmitted after receipt of and in response to the multi-user block acknowledgement request frame.

17. (Currently amended) The method of claim 8, wherein the acknowledgement information includes one or more of: (1) an indication of whether the first multi-user acknowledgement frame is part of a multi-user or a single user transmission, and (2) an indication of whether the first multi-user acknowledgement frame is transmitted immediately following receipt of the downlink multi-user frame or upon receipt of a multi-user block acknowledgement request frame, and [[(3)]]further includes resource scheduling information ~~for an uplink~~ when the first multi-user acknowledgement ~~transmission~~frame is indicated as being part of the multi-user transmission

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18. (Currently amended) A method, implemented by a first station in a wireless network, for transmitting an uplink acknowledgment, the method comprising:

receiving a downlink multi-user frame addressed to a plurality of stations, including the first station, wherein the downlink multi-user frame is received from an access point in the wireless network;

receiving a multi-user block acknowledgement request frame that solicits acknowledgements from ~~two or more stations~~ the first station and a second station, wherein the multi-user block acknowledgement request frame includes acknowledgement information [[for]] indicating properties of a first multi-user acknowledgement frame ~~that acknowledges receipt of the downlink multi-user frame by the first station~~;

generating the first multi-user acknowledgment frame based on the acknowledgement information; and

acknowledging the receipt of the downlink multi-user frame by transmitting the first multi-user acknowledgement frame to the access point ~~based on the acknowledgement information~~,

wherein the first multi-user acknowledgement frame is transmitted simultaneously with a second multi-user acknowledgement frame generated and transmitted by the second station.

19. (Currently amended) The method of claim 18, wherein the acknowledgement information includes one or more of: (1) an indication of whether the first multi-user acknowledgement frame is part of a multi-user or single user transmission and (2) resource scheduling information for the first multi-user acknowledgement transmission.

20. (Currently amended) The method of claim 18, wherein the acknowledgment scheduling information includes properties of [[a]]the second multi-user acknowledgement frame generated and transmitted by [[a]]the second station, wherein the first multi-user acknowledgement frame and the second multi-user acknowledgement together form a multi-user transmission.

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INTERVIEW SUMMARY

In the Interview with the Examiner held on July 20, 2016, the amendments to the claims presented herein were discussed. Applicants appreciate the Examiner's acknowledgement during the Interview that these amendments are sufficient to overcome the current rejections of the claims, and that additional search of the art would be required to determine the allowability of the claims.

Applicants also appreciate the Examiner's willingness to contact Applicant's undersigned representative with suggestions that may expedite the prosecution of the present application.

REMARKS/ARGUMENTS

The claims have been amended as indicated above. No new matter has been added.

Claims 1-20 stand rejected under 35 U.S.C. §103(a) as allegedly unpatentable over US Pub. No. 2013/0301569 to Wang et al. (Wang). Applicants respectfully traverse the rejections.

As discussed with the Examiner at the July 20, 2016 interview, the claims are directed to Up-Link (UL) Multi-User (MU) transmissions, and in particular to UL MU acknowledgement transmissions transmitted in response to a Down-Link (DL) frame. The UL MU transmissions may be simultaneous transmitted from respective stations to an Access Point (AP).

Wang does not disclose UL MU transmissions, much less UL MU acknowledgement transmissions. Wang only discloses DL MU transmissions, such as the DL MU Block Ack (BA) frame 950 shown being transmitted by a single device (an AP) in FIG. 9 of Wang.

Because Wang does not disclose UL MU transmissions, then per the discussion held during the Interview of July 20, continued maintenance of the current rejection of the claims as unpatentable over Wang would be improper and the rejections should be withdrawn.

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CONCLUSION

In view of the foregoing, Applicants believe all claims now pending in this Application are in condition for allowance. The issuance of a formal Notice of Allowance at an early date is respectfully requested.

The Commissioner is authorized to charge any deficiency in any fees required under 37 C.F.R. 1.16 and/or 1.17, including extension of time fees, and credit any overpayment to Deposit Account No. 50-4713.

If the Examiner believes a telephone conference would expedite prosecution of this Application, please telephone the undersigned at 602-885-8150.

Respectfully submitted,

/Dennis M. O'Connor/

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Electronic Acknowledgement Receipt

EFS ID:	26436070
Application Number:	15078920
International Application Number:	
Confirmation Number:	2806
Title of Invention:	APPARATUS AND METHOD FOR DOWNLINK AND UPLINK MULTI-USER TRANSMISSIONS
First Named Inventor/Applicant Name:	Young Hoon KWON
Customer Number:	83220
Filer:	Dennis Michael O'Connor
Filer Authorized By:	
Attorney Docket Number:	A303AA-012300US
Receipt Date:	22-JUL-2016
Filing Date:	23-MAR-2016
Time Stamp:	19:19:47
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Amendment/Req. Reconsideration-After Non-Final Reject	2016_07_22_AMD_A303AA-012300US.pdf	110852 [illegible]	no	8

Warnings:

Information:	
Total Files Size (in bytes):	110852

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

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EXHIBIT 2

U 8176575

THE UNITED STATES OF AMERICA

TO ALL TO WHOM THESE PRESENTS SHALL COME:

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office

August 27, 2021

THIS IS TO CERTIFY THAT ANNEXED HERETO IS A TRUE COPY FROM THE RECORDS OF THIS OFFICE OF:

U.S. PATENT: *9,763,259*
ISSUE DATE: *September 12, 2017*

By Authority of the
Under Secretary of Commerce for Intellectual Property
and Director of the United States Patent and Trademark Office

SYLVIA HOLLEY
Certifying Officer

ATLAS-00004620

US009763259B2

(12) **United States Patent**
Kwon et al.

(10) **Patent No.: US 9,763,259 B2**
(45) **Date of Patent: Sep. 12, 2017**

(54) **SOUNDING METHOD**

(71) Applicant: **NEWRACOM, INC.**, Irvine, CA (US)

(72) Inventors: **Yongjin Kwon**, Daejeon (KR); **Hyungu Park**, Daejeon (KR); **Jongee Oh**, Irvine, CA (US); **Inkyeong Choi**, Daejeon (KR)

(73) Assignee: **NEWRACOM, INC.**, Irvine, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 65 days.

(21) Appl. No.: **14/862,078**

(22) Filed: **Sep. 22, 2015**

(65) **Prior Publication Data**

US 2016/0088641 A1 Mar. 24, 2016

Related U.S. Application Data

(60) Provisional application No. 62/054,270, filed on Sep. 23, 2014.

(30) **Foreign Application Priority Data**

Aug. 19, 2015 (KR) 10-2015-0116576

(51) **Int. Cl.**
H04B 7/02 (2017.01)
H04W 72/08 (2009.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H04W 72/085*** (2013.01); ***H04L 1/00*** (2013.01); ***H04L 5/006*** (2013.01); ***H04L 5/0044*** (2013.01);
(Continued)

(58) **Field of Classification Search**
None
See application file for complete search history.

(56) **References Cited**

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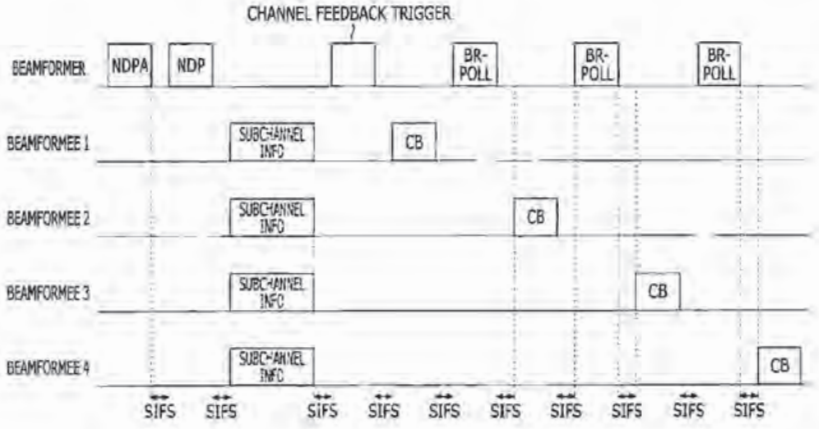
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Primary Examiner — Chi H Pham
Assistant Examiner — Shick Hom
(74) *Attorney, Agent, or Firm* — McDermott, Will & Emery LLP

(57) **ABSTRACT**

A sounding method by a receiving device is provided. The receiving device receives an NDPA frame from a transmitting device, and then receives an NDP frame from the transmitting device. After receiving the NDP frame, the receiving device transmits to the transmitting device a feedback frame including subchannel information measured on a subchannel that is allocated to the first receiving device among a plurality of subchannels into which a predetermined band is divided.

18 Claims, 24 Drawing Sheets



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(51) **Int. Cl.**

H04W 16/28	(2009.01)
H04L 1/00	(2006.01)
H04W 24/00	(2009.01)
H04L 5/00	(2006.01)
H04W 72/04	(2009.01)
H04W 84/12	(2009.01)

(52) **U.S. Cl.**
CPC ***H04W 16/28*** (2013.01); ***H04W 24/00*** (2013.01); *H04W 72/046* (2013.01); *H04W 84/12* (2013.01)

(56) **References Cited**

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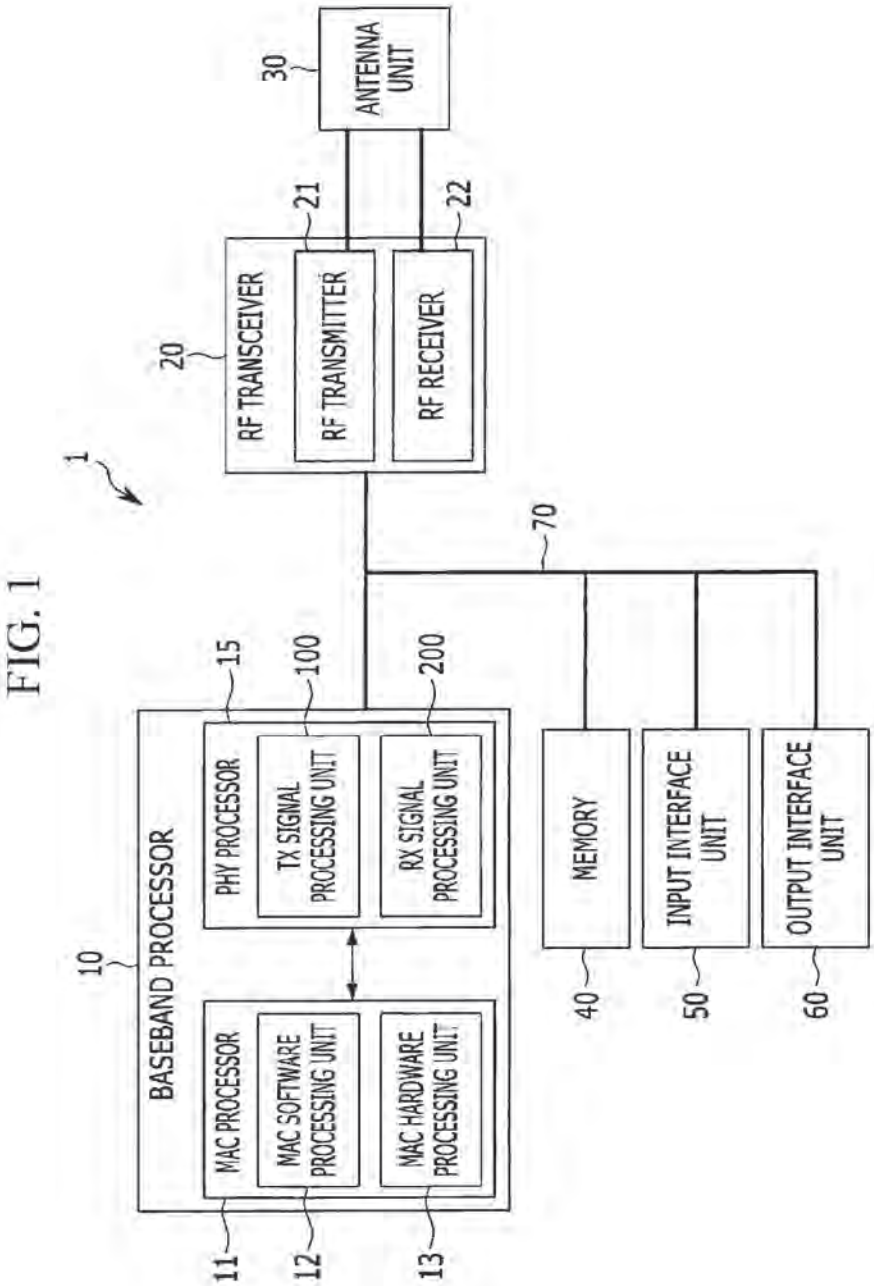


FIG. 1

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FIG. 2

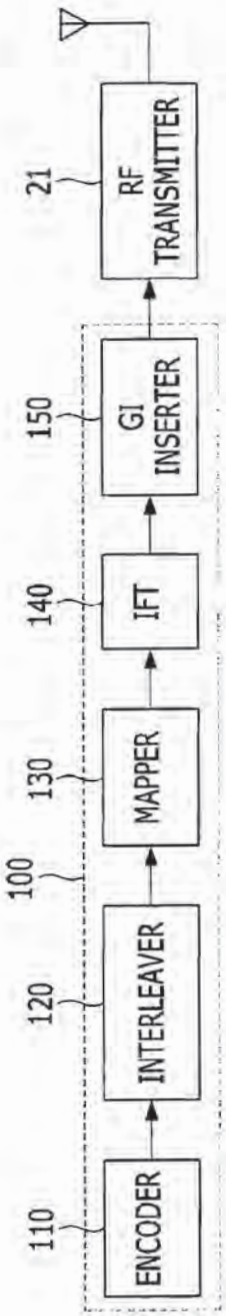
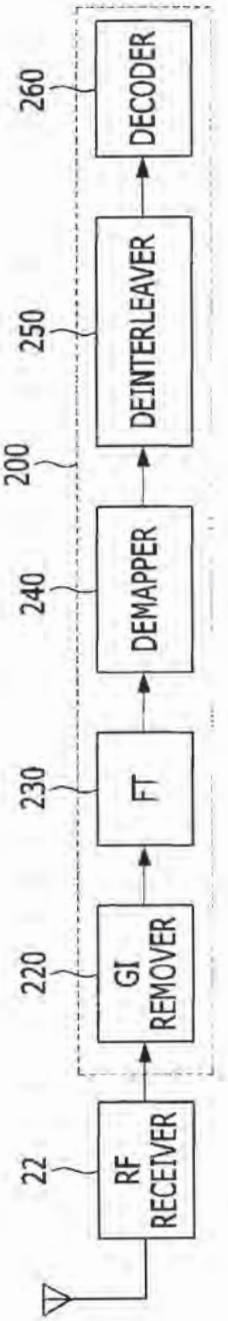
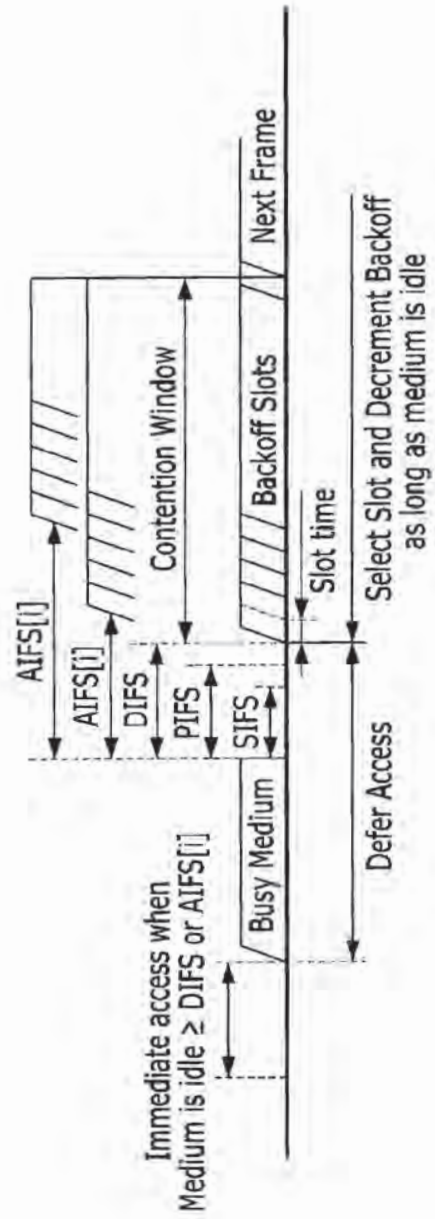


FIG. 3



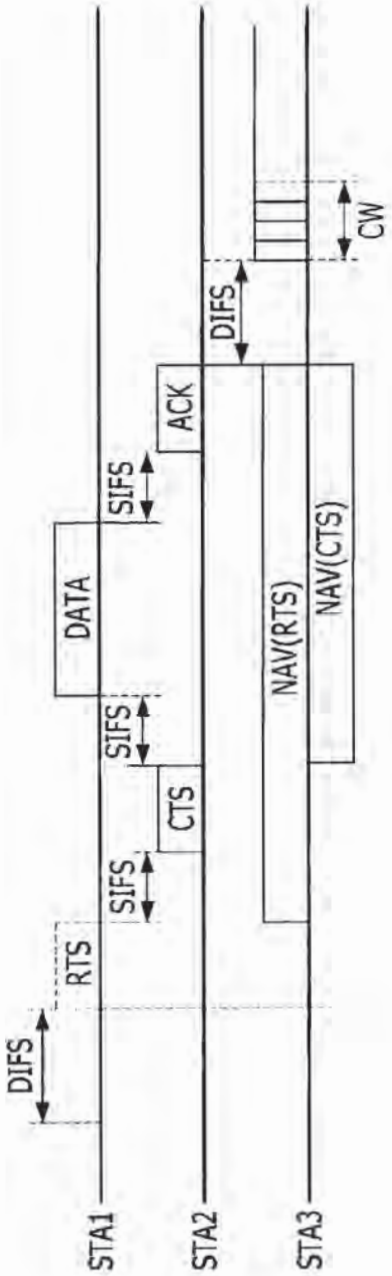
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FIG. 4



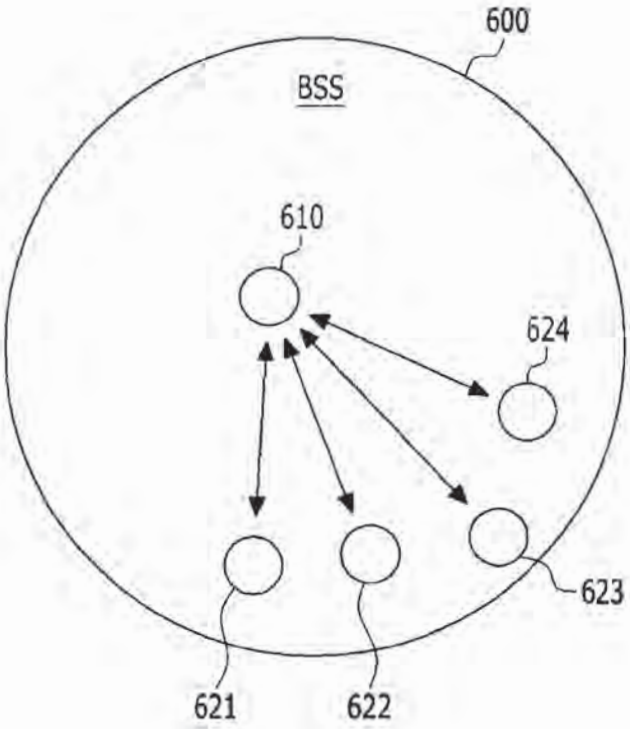
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FIG. 5



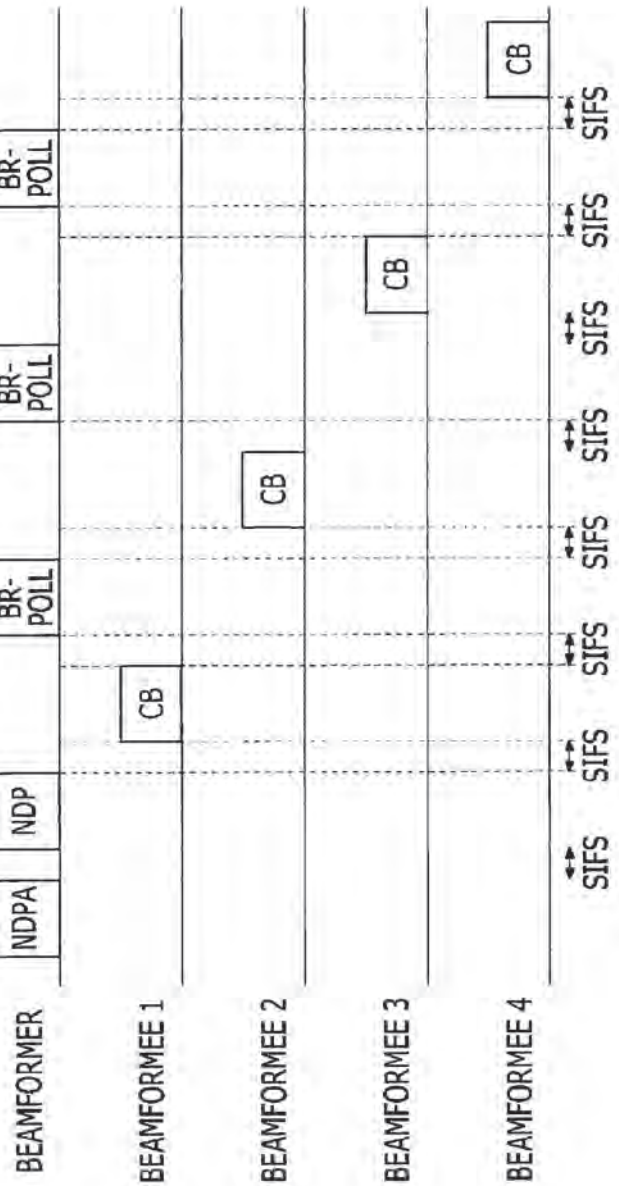
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FIG. 6



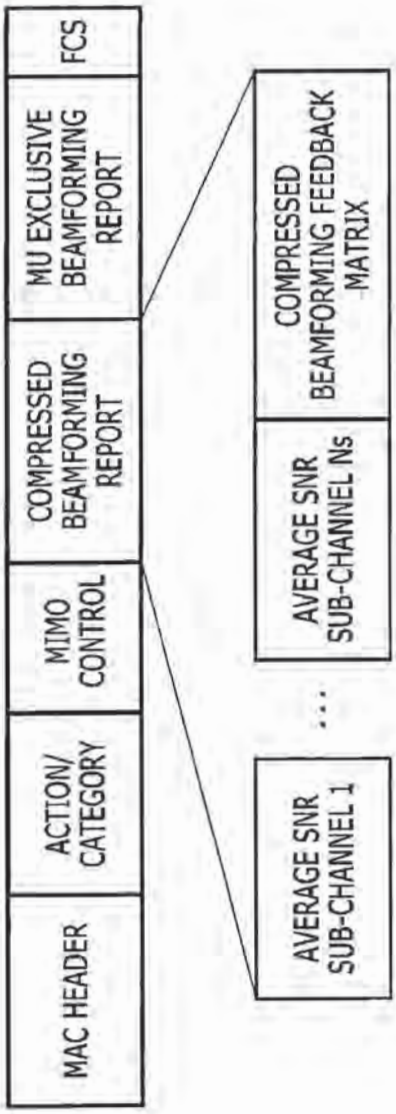
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FIG. 7



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FIG. 8



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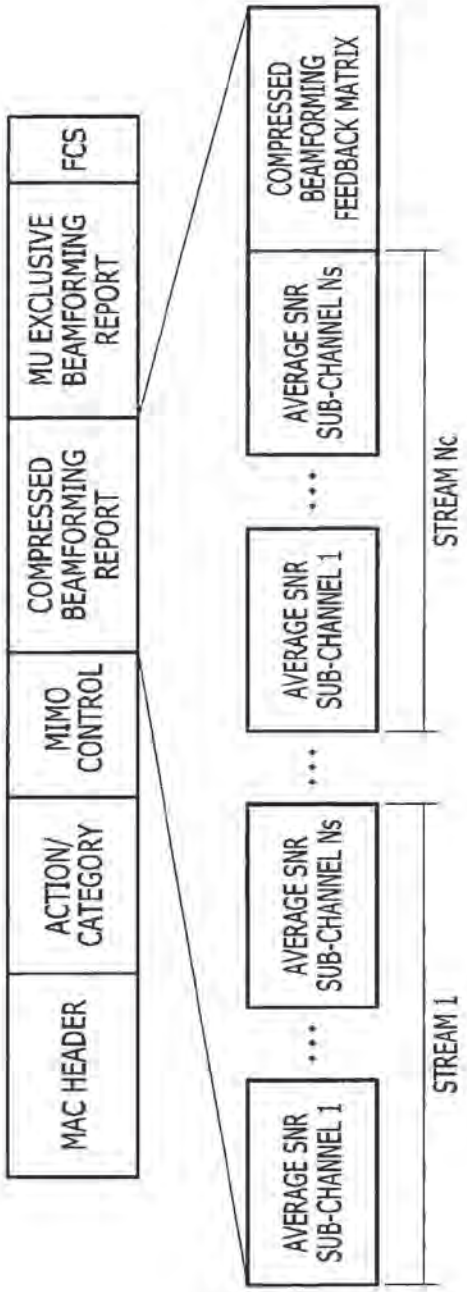


FIG. 9

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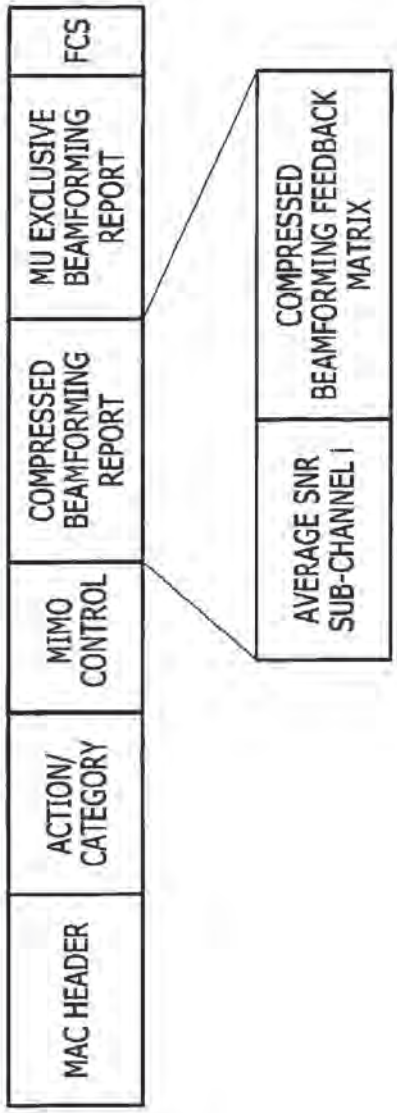
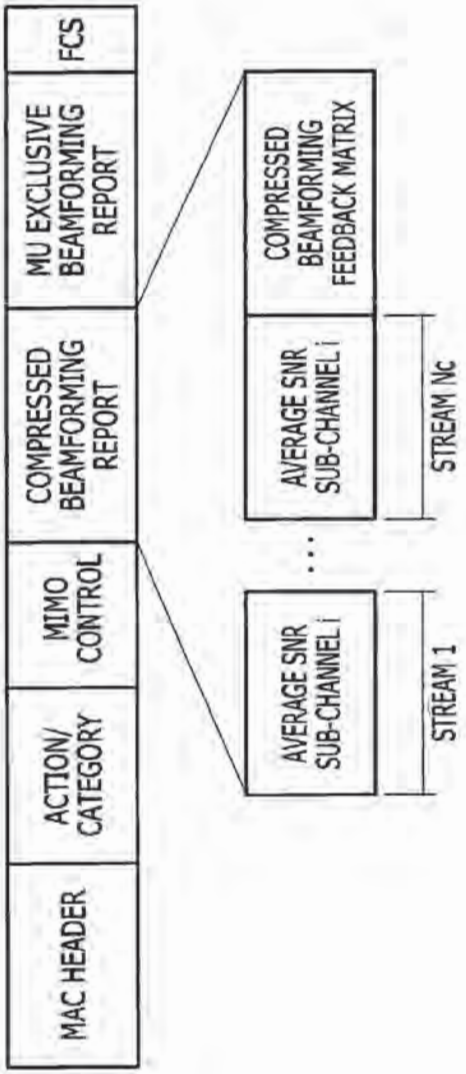


FIG. 10

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FIG. 11



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FIG. 12

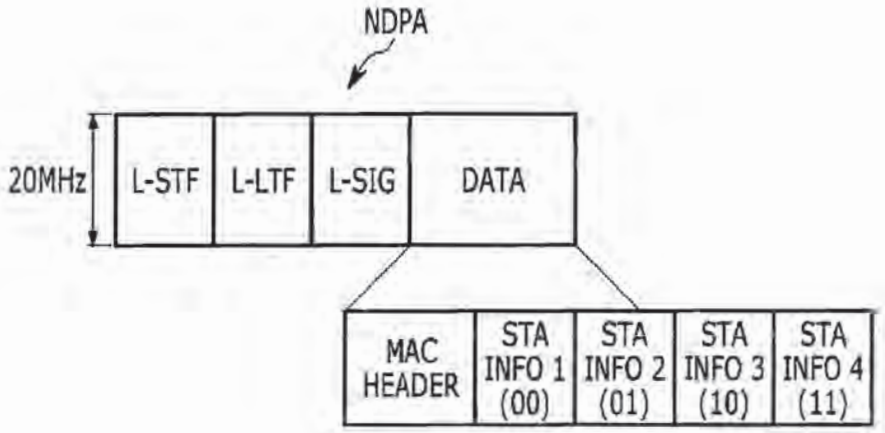
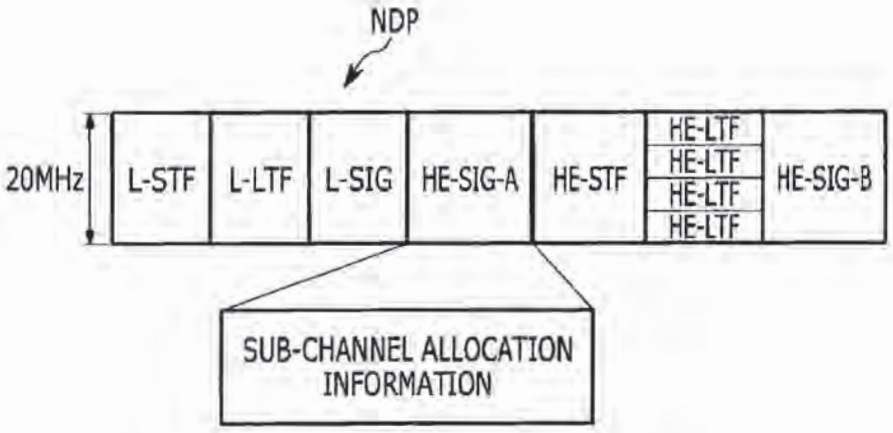
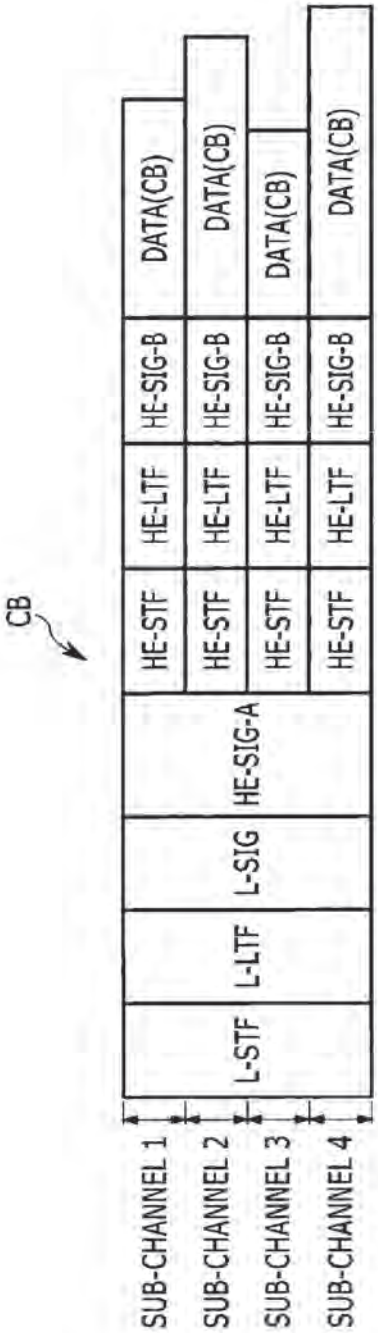


FIG. 13



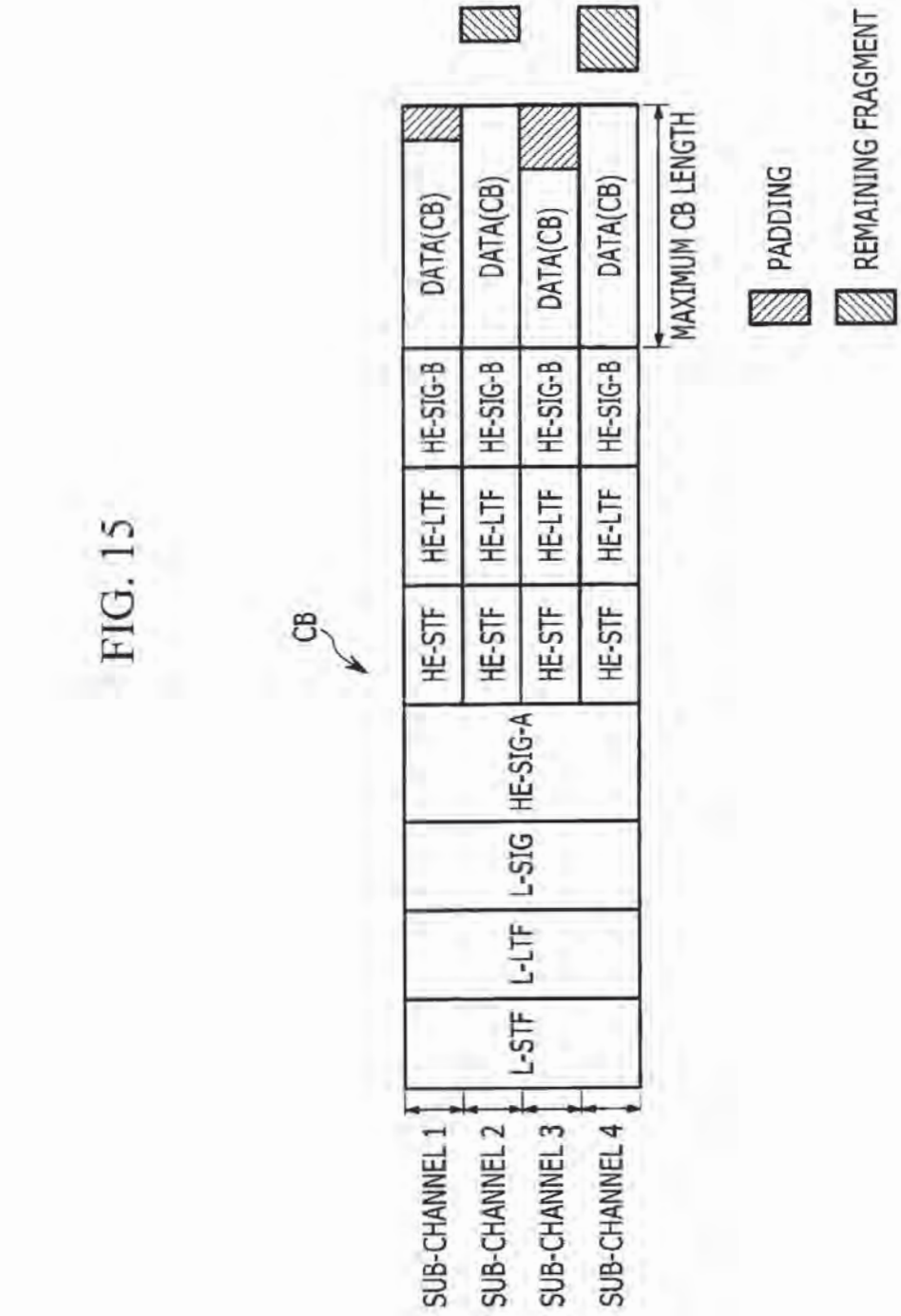
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FIG. 14



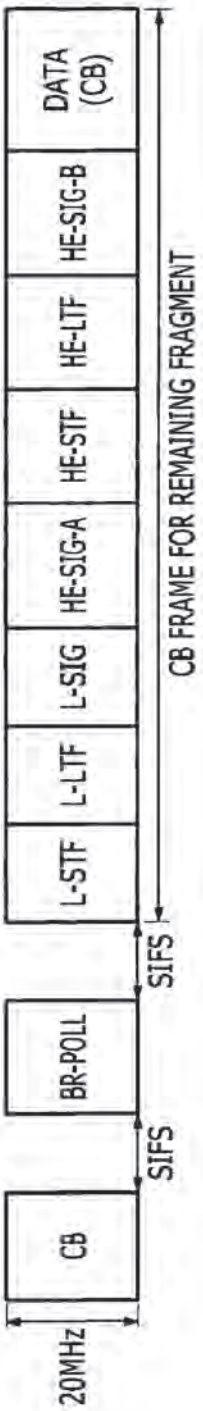
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FIG. 15



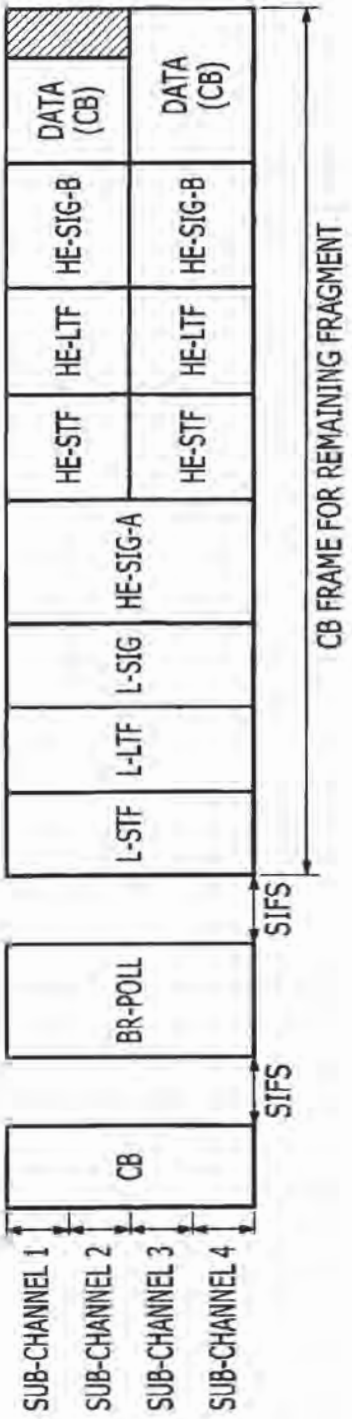
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FIG. 16



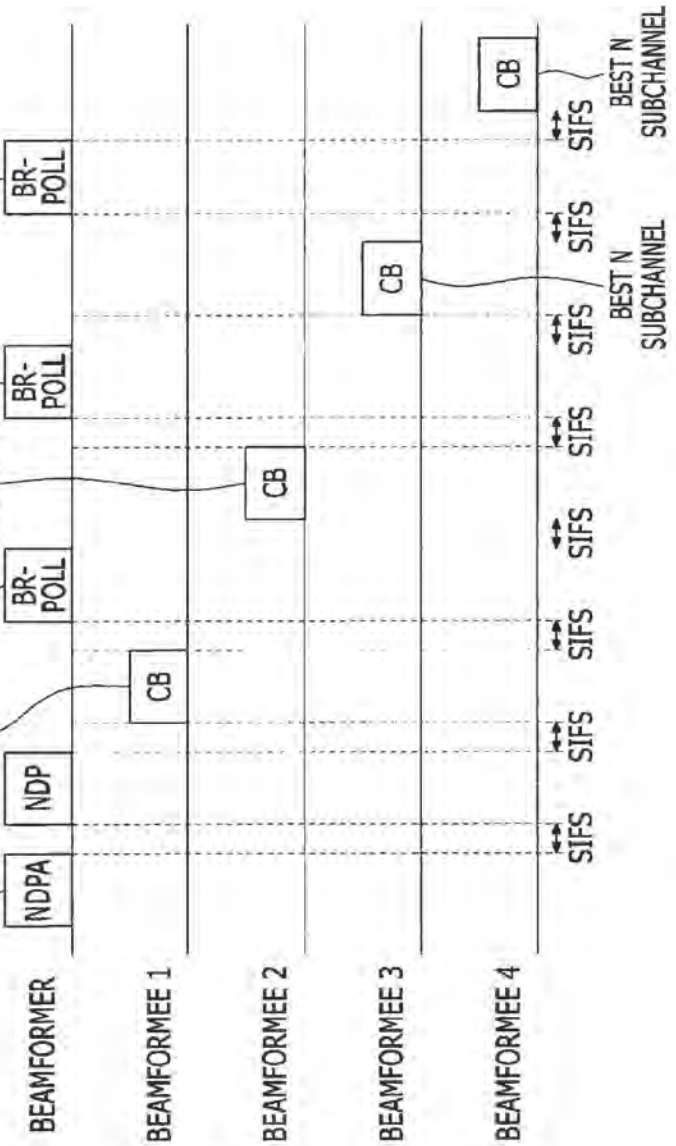
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FIG. 17



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FIG. 18

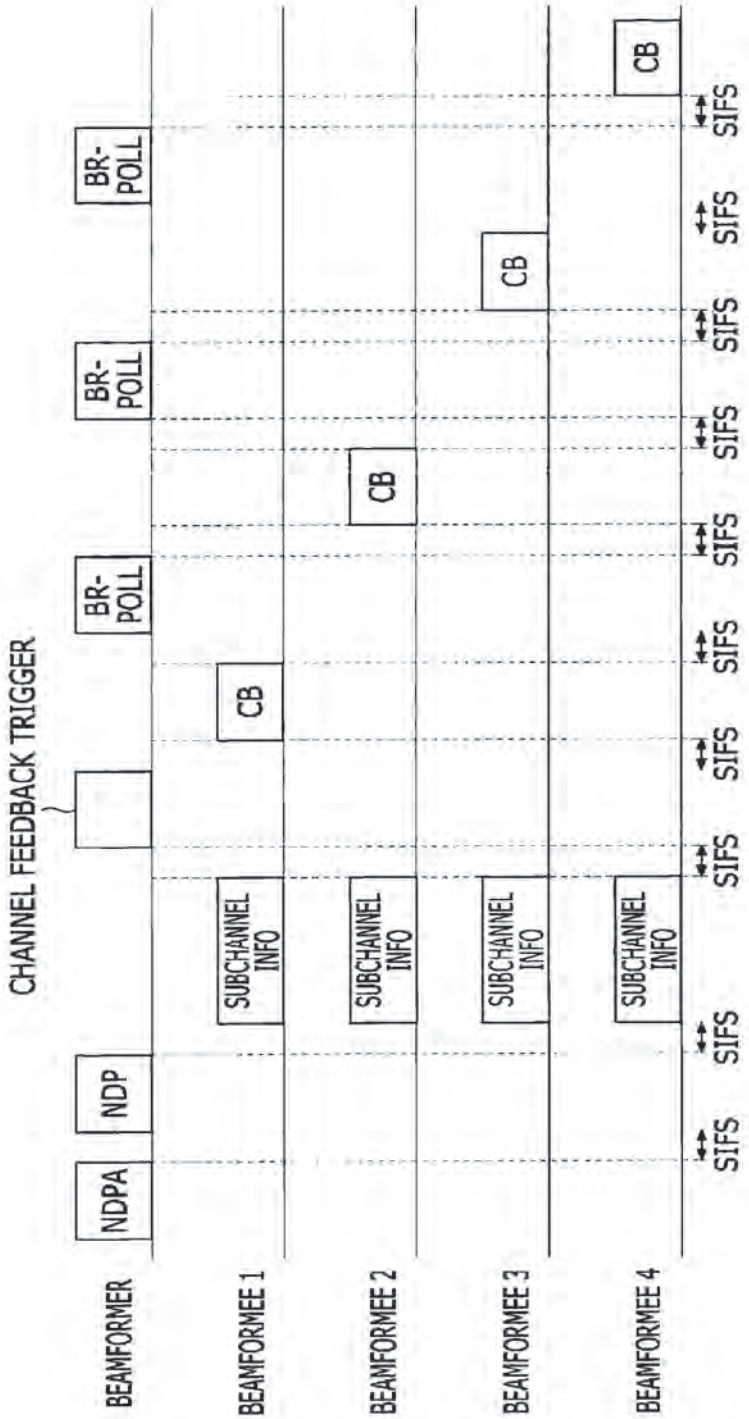


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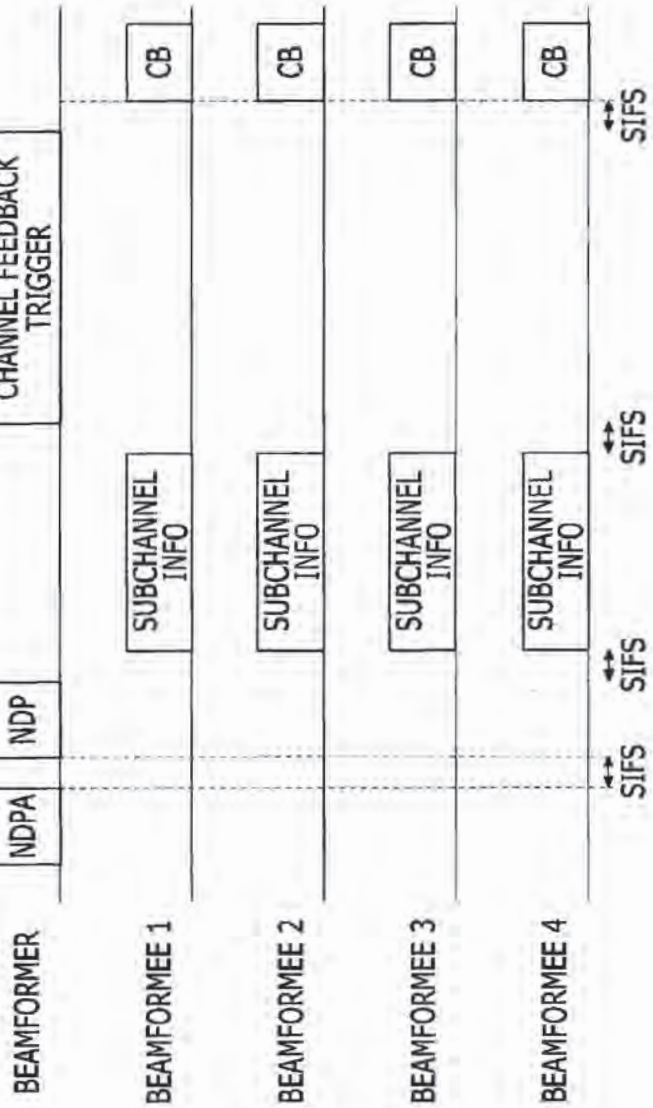
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FIG. 19



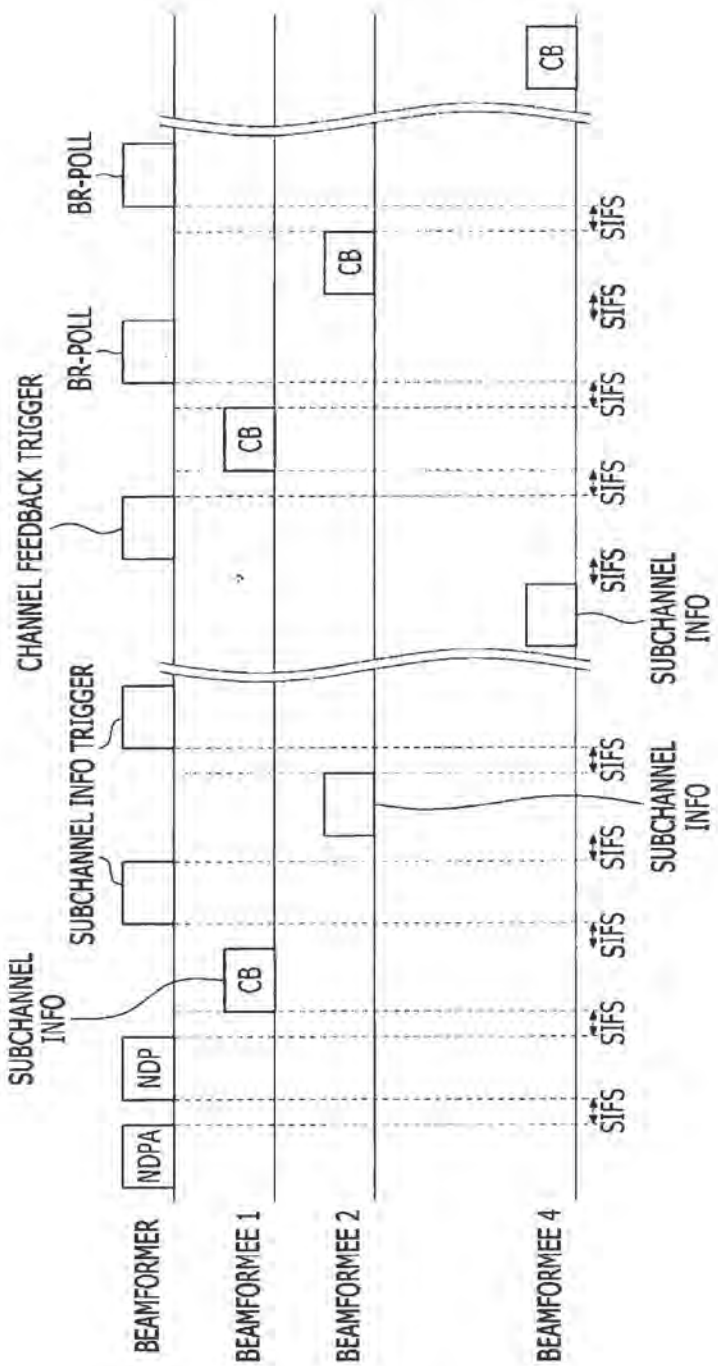
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FIG. 20



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FIG. 21

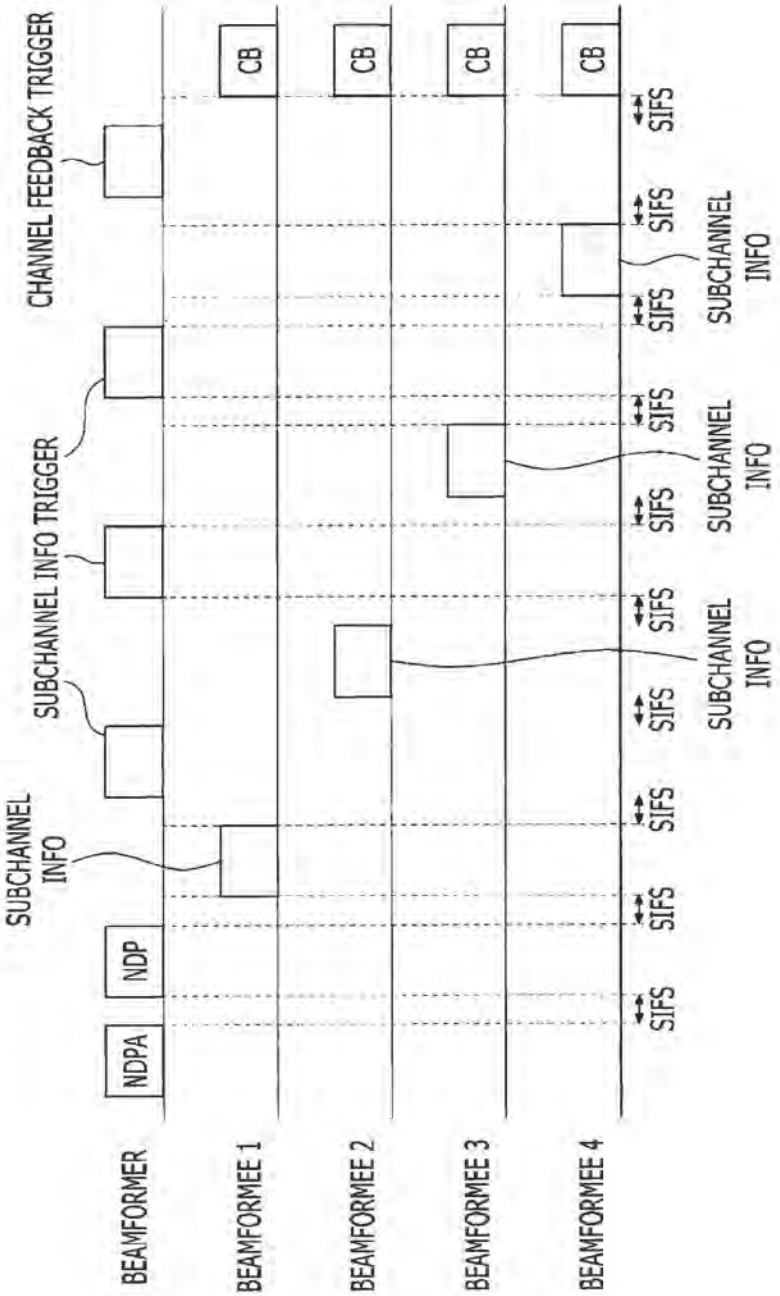


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FIG. 22

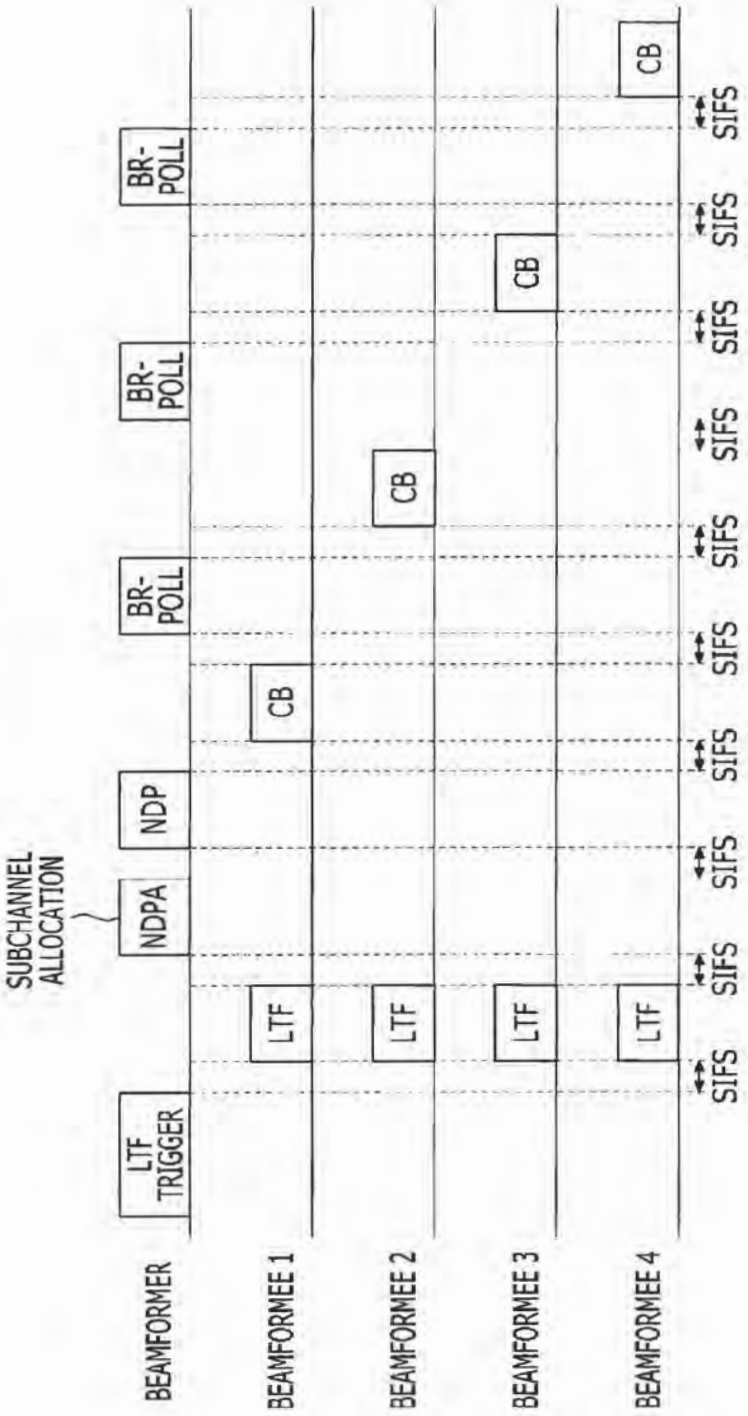


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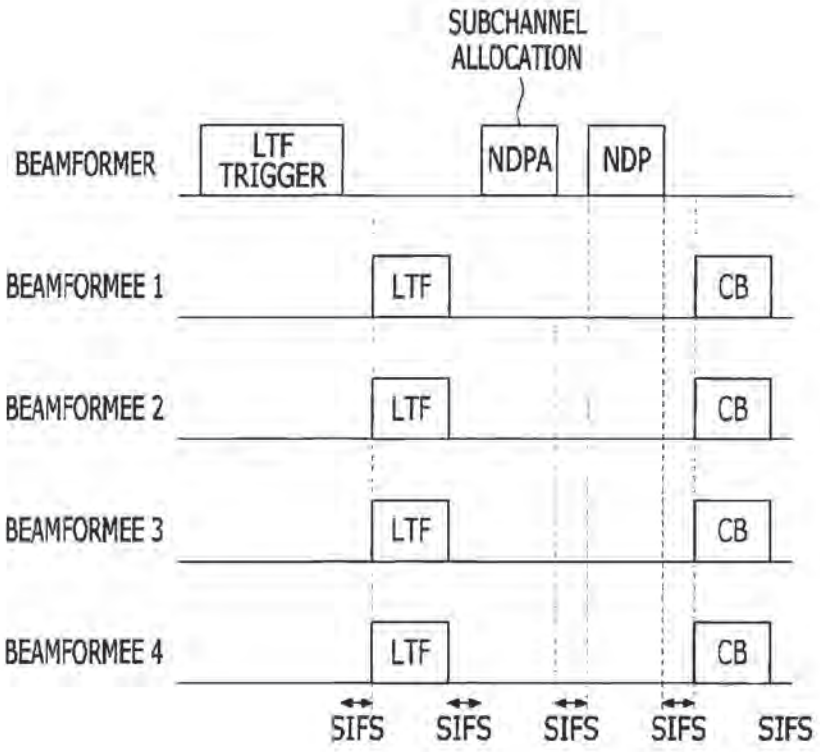
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FIG. 23



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FIG. 24



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FIG. 25

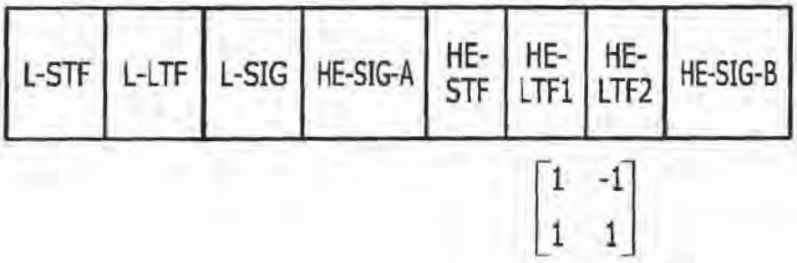
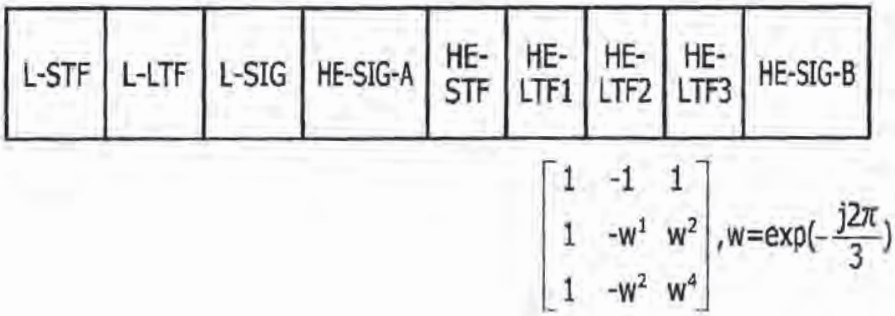
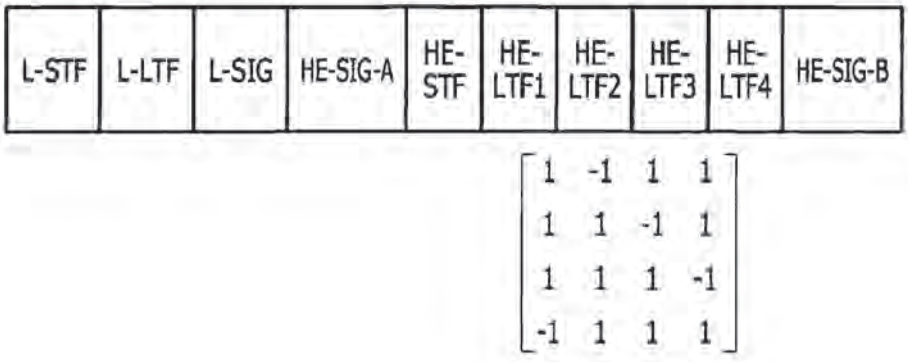


FIG. 26



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FIG. 27



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SOUNDING METHOD

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority to and the benefit of U.S. Provisional Application No. 62/054,270, filed on Sep. 23, 2014, in the U.S. Patent and Trademark Office and priority to and the benefit of Korean Patent Application No. 10-2015-0116576, filed on Aug. 19, 2015, in the Korean Intellectual Property Office, the entire contents of which are incorporated herein by reference.

BACKGROUND

(a) Field

The described technology relates generally to a sounding method. More particularly, the described technology relates generally to a sounding method in a wireless local area network (WLAN).

(b) Description of the Related Art

A WLAN transmits or receives data using an unlicensed band of 2.4 GHz or 5 GHz and is being standardized by the IEEE (Institute of Electrical and Electronics Engineers) Part 11 under the name of "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications."

After an original standard was published in 1999, new version standards are continuously published by amendments. The IEEE standard 802.11a (IEEE Std 802.11a-1999) supporting 2.4 GHz band was published in 1999, the IEEE standard 802.11b (IEEE Std 802.11b-1999) supporting 5 GHz band was published in 1999, and the IEEE standard 802.11g (IEEE Std 802.11g-2003) supporting 5 GHz band was published in 2003. These standards are called legacy. Subsequently, the IEEE standard 802.11n (IEEE Std 802.11n-2009) for enhancements for higher throughput (HT) was published in 2009, and the IEEE standard 802.11 ac (IEEE 802.11 ac-2013) for enhancements for very high throughput (VHT) was published in 2013. Recently, a high efficiency (HE) WLAN for enhancing the system throughput in high density scenarios is being developed by the IEEE 802.11ax task group.

The HE WLAN or a subsequent WLAN may use a multi-user transmission. For example, a device may simultaneously transmit data to a plurality of devices or the plurality of devices may simultaneously transmit data by using a scheme such as orthogonal frequency division multiple access (OFDMA).

For the multi-user transmission, a given bandwidth may be divided into a plurality of subchannels and the plurality of subchannels may be allocated to multi users. In this case, a scheme such as beamforming may be applied to the plurality of subchannels to improve the transmission gain. For this, a sounding procedure is required for the plurality of subchannels.

SUMMARY

An embodiment of the present disclosure provides a sounding method for multi users.

According to an embodiment, a sounding method by a first receiving device is provided. The method includes receiving a null data packet announcement (NDPA) frame from a transmitting device, receiving a null data packet (NDP) frame from the transmitting device after receiving the NPDA frame, and transmitting to the transmitting device a feedback frame including subchannel information measured on a first subchannel after receiving the NDP frame. The first subchannel is a subchannel that is allocated to the first receiving device among a plurality of subchannels into which a predetermined band is divided.

The subchannel information may include an average signal-to-noise ratio (SNR) of the first subchannel.

The subchannel information may include average SNRs of the first subchannel for a plurality of space-time streams.

The feedback frame may further include subchannel information measured on other subchannels excluding the first subchannel.

Transmitting the feedback frame may include transmitting the feedback frame to the transmitting device before a second feedback frame including subchannel information measured on a second subchannel is transmitted to the transmitting device by a second receiving device or after the second feedback frame is transmitted to the transmitting device by the second receiving device, the second subchannel being a subchannel that is allocated to the second receiving device among the plurality of subchannels.

Transmitting the feedback frame may include transmitting the feedback frame to the transmitting device while a second feedback frame including subchannel information measured on the second subchannel is transmitted to the transmitting device by a second receiving device, the second subchannel being a subchannel that is allocated to the second receiving device among the plurality of subchannels.

Transmitting the feedback frame may include adding pad bits to a data field of the feedback frame when a length of data to be transmitted by the feedback frame is shorter than a predetermined length, or partitioning the data into a plurality of fragments and inserting any one of the fragments to the data field of the feedback frame when the length of the data is longer than the predetermined length.

The NDPA frame or the NDP frame may indicate information corresponding to the predetermined length.

The NDPA frame or the NDP frame may include allocation information of the first subchannel.

The subchannel information may be measured on each of a predetermined number of subchannels including the first subchannel, and the first subchannel may be allocated based on the subchannel information.

The NDPA frame may include information on the predetermined number.

The method may further include receiving a frame including selected subchannel information from the transmitting device, the selected subchannel information indicating a subchannel that is selected by other receiving device among the plurality of subchannels. The predetermined number of subchannels may not include the subchannel that that is selected by the other receiving device.

The selected subchannel information may be represented by a bitmap having a plurality of bits that correspond to the plurality of subchannels respectively, and a predetermined value in each of the plurality of bits may indicate that a corresponding subchannel is selected by the other device.

Transmitting the feedback frame may include transmitting a subchannel information frame to the transmitting device after receiving the NDP frame, the subchannel information frame including measurement information that is measured on each of the plurality of subchannels by the first receiving device. Transmitting the feedback frame may further include receiving from the transmitting device a channel feedback trigger frame including allocation information of the plurality of subchannels and transmitting the feedback frame to the transmitting device after receiving the channel feedback trigger frame.

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Transmitting the subchannel information frame may include transmitting the subchannel information frame to the transmitting device before a second subchannel information frame is transmitted to the transmitting device by a second receiving device or after the second subchannel information frame is transmitted to the transmitting device by the second receiving device, the second subchannel information frame including measurement information that is measured on each of plurality of subchannels by the second receiving device.

Transmitting the subchannel information frame may include transmitting the subchannel information frame to the transmitting device while a second subchannel information frame is transmitted to the transmitting device by a second receiving device, the second subchannel information frame including measurement information that is measured on each of plurality of subchannels by the second receiving device.

The method may further include receiving a trigger frame from a transmitting device and transmitting a frame including a plurality of long training fields to the transmitting device after receiving the trigger frame. The plurality of long training fields may be multiplied by a predetermined identification code allocated to the first receiving device among a plurality of receiving devices.

A number of the plurality of long training fields may be equal to a number of the plurality of receiving devices.

The trigger frame may include information on a predetermined identification code allocated to each of the plurality of receiving devices.

According to another embodiment, a sounding method by a transmitting device is provided. The method includes transmitting an NDPA frame to a plurality of receiving devices, transmitting an NDP frame to the plurality of receiving devices after transmitting the NPDA frame, and receiving from each receiving device a feedback frame including subchannel information measured on a subchannel that is allocated to each receiving device among a plurality of subchannels into which a band is divided, after transmitting the NDP frame.

According to yet another embodiment, a sounding apparatus of a receiving device is provided. The sounding apparatus includes a processor and a transceiver. The transceiver receives an NDPA frame from a transmitting device and receives an NDP frame from the transmitting device after receiving the NPDA frame. The processor generates a feedback frame including subchannel information measured on a first subchannel after receiving the NDP frame. The first subchannel is a subchannel that is allocated to the first receiving device among a plurality of subchannels into which a predetermined band is divided. The transceiver transmits the feedback frame to the transmitting device.

According to still another embodiment, a sounding apparatus of a transmitting device is provided. The sounding apparatus includes a processor and a transceiver. The processor generates an NDPA frame and an NDP frame. The transceiver transmits the NDPA frame to a plurality of receiving devices, transmits the NDP frame to the plurality of receiving devices after transmitting the NPDA frame, and receives from each receiving device a feedback frame including subchannel information measured on a subchannel that is allocated to each receiving device among a plurality of subchannels into which a band is divided, after transmitting the NDP frame.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic block diagram of a WLAN device according to an embodiment.

FIG. **2** is a schematic block diagram of a transmitting signal processor in an embodiment suitable for use in a WLAN.

FIG. **3** is a schematic block diagram of a receiving signal processing unit in an embodiment suitable for use in the WLAN.

FIG. **4** exemplifies illustrates Inter-Frame Space (IFS) relationships.

FIG. **5** is a schematic diagram illustrating a CSMA/CA based frame transmission procedure for avoiding collision between frames in a channel.

FIG. **6** shows an example of a wireless communication network according to an embodiment.

FIG. **7** shows a sounding procedure in a wireless communication network according to an embodiment.

FIG. **8**, FIG. **9**, FIG. **10** and FIG. **11** show CB frames according to various embodiments.

FIG. **12** and FIG. **13** each shows a subchannel allocation notification method in a wireless communication network according to various embodiments.

FIG. **14**, FIG. **15**, FIG. **16**, and FIG. **17** each shows a parallel transmission method of a CB frame in a wireless communication network according to various embodiments.

FIG. **18**, FIG. **19**, FIG. **20**, FIG. **21**, FIG. **22**, FIG. **23**, and FIG. **24** each shows a subchannel allocation method in a wireless communication network according to various embodiments.

FIG. **25**, FIG. **26**, and FIG. **27** each shows an LTF frame in a wireless communication network according to various embodiments.

DETAILED DESCRIPTION OF EMBODIMENTS

In the following detailed description, only certain embodiments have been shown and described, simply by way of illustration. As those skilled in the art would realize, the described embodiments may be modified in various different ways, all without departing from the spirit or scope of the present disclosure. Accordingly, the drawings and description are to be regarded as illustrative in nature and not restrictive. Like reference numerals designate like elements throughout the specification.

In a wireless local area network (WLAN), a basic service set (BSS) includes a plurality of WLAN devices. The WLAN device may include a medium access control (MAC) layer and a physical (PHY) layer according to the IEEE (Institute of Electrical and Electronics Engineers) standard 802.11. The plurality of WLAN devices may include a WLAN device that is an access point and the other WLAN devices that are non-AP stations (non-AP STAs). Alternatively, all of the plurality of WLAN devices may be non-AP STAs in ad-hoc networking. In general, the AP STA and the non-AP STA may be collectively called the STAs. However, for ease of description, herein, only the non-AP STA are referred to as the STAs.

FIG. **1** is a schematic block diagram exemplifying a WLAN device according to an embodiment.

Referring to FIG. **1**, the WLAN device **1** includes a baseband processor **10**, a radio frequency (RF) transceiver **20**, an antenna unit **30**, a memory **40** including non-transitory computer-readable media, an input interface unit **50**, an output interface unit **60**, and a bus **70**.

The baseband processor **10** performs baseband signal processing, and includes a MAC processor **11** and a PHY processor **15**.

In one embodiment, the MAC processor **11** may include a MAC software processing unit **12** and a MAC hardware

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processing unit **13**. The memory **40** may store software (hereinafter referred to as "MAC software") including at least some functions of the MAC layer. The MAC software processing unit **12** executes the MAC software to implement the some functions of the MAC layer, and the MAC hardware processing unit **13** may implement remaining functions of the MAC layer as hardware (hereinafter referred to "MAC hardware"). However, the MAC processor **11** is not limited to this.

The PHY processor **15** includes a transmitting (Tx) signal processing unit **100** and a receiving (Rx) signal processing unit **200**.

The baseband processor **10**, the memory **40**, the input interface unit **50**, and the output interface unit **60** may communicate with each other via the bus **70**.

The RF transceiver **20** includes an RF transmitter **21** and an RF receiver **22**.

The memory **40** may further store an operating system and applications. The input interface unit **50** receives information from a user, and the output interface unit **60** outputs information to the user.

The antenna unit **30** includes one or more antennas. When multiple-input multiple-output (MIMO) or multi-user MIMO (MU-MIMO) is used, the antenna unit **30** may include a plurality of antennas.

FIG. **2** is a schematic block diagram of a transmitting signal processor **100** in an embodiment suitable for use in a WLAN.

Referring to FIG. **2**, a transmitting signal processing unit **100** includes an encoder **110**, an interleaver **120**, a mapper **130**, an inverse Fourier transformer (IFT) **140**, and a guard interval (GI) inserter **150**.

The encoder **110** encodes input data. For example, the encoder **100** may be a forward error correction (FEC) encoder. The FEC encoder may include a binary convolutional code (BCC) encoder followed by a puncturing device, or may include a low-density parity-check (LDPC) encoder.

The transmitting signal processing unit **100** may further include a scrambler for scrambling the input data before the encoding to reduce the probability of long sequences of 0s or 1s. If BCC encoding is used in the encoder, the transmitting signal processing unit **100** may further include an encoder parser for demultiplexing the scrambled bits among a plurality of BCC encoders. If LDPC encoding is used in the encoder, the transmitting signal processing unit **100** may not use the encoder parser.

The interleaver **120** interleaves the bits of each stream output from the encoder to change an order of bits. Interleaving may be applied only when BCC encoding is used. The mapper **130** maps the sequence of bits output from the interleaver to constellation points. If the LDPC encoding is used in the encoder, the mapper **130** may further perform LDPC tone mapping besides the constellation mapping.

When the MIMO or the MU-MIMO is used, the transmitting signal processing unit **100** may use a plurality of interleavers **120** and a plurality of mappers **130** corresponding to a number of spatial streams N_{SS}. In this case, the transmitting signal processing unit **100** may further include a stream parser for dividing outputs of the BCC encoders or the LDPC encoder into blocks that are sent to different interleavers **120** or mappers **130**. The transmitting signal processing unit **100** may further include a space-time block code (STBC) encoder for spreading the constellation points from the N_{SS} spatial streams into N_{STS} space-time streams and a spatial mapper for mapping the space-time streams to transmit chains. The spatial mapper may use direct mapping, spatial expansion, or beamforming.

The IFT **140** converts a block of the constellation points output from the mapper **130** or the spatial mapper to a time domain block (i.e., a symbol) by using an inverse discrete Fourier transform (IDFT) or an inverse fast Fourier transform (IFFT). If the STBC encoder and the spatial mapper are used, the inverse Fourier transformer **140** may be provided for each transmit chain.

When the MIMO or the MU-MIMO is used, the transmitting signal processing unit **100** may insert cyclic shift diversities (CSDs) to prevent unintentional beamforming. The CSD insertion may occur before or after the inverse Fourier transform. The CSD may be specified per transmit chain or may be specified per space-time stream. Alternatively, the CSD may be applied as a part of the spatial mapper.

When the MU-MIMO is used, some blocks before the spatial mapper may be provided for each user.

The GI inserter **150** prepends a guard interval (GI) to the symbol. The transmitting signal processing unit **100** may optionally perform windowing to smooth edges of each symbol after inserting the GI. The RF transmitter **21** converts the symbols into an RF signal and transmits the RF signal via the antenna unit **30**. When the MIMO or the MU-MIMO is used, the GI inserter **150** and the RF transmitter **21** may be provided for each transmit chain.

FIG. **3** is a schematic block diagram of a receiving signal processing unit according to an embodiment suitable for use in the WLAN.

Referring to FIG. **3**, a receiving signal processing unit **200** includes a GI remover **220**, a Fourier transformer (FT) **230**, a demapper **240**, a deinterleaver **250**, and a decoder **260**.

An RF receiver **22** receives an RF signal via the antenna unit **30** and converts the RF signal into a symbol. The GI remover **220** removes the GI from the symbol. When the MIMO or the MU-MIMO is used, the RF receiver **22** and the GI remover **220** may be provided for each receive chain.

The FT **230** converts the symbol (i.e., the time domain block) into a block of the constellation points by using a discrete Fourier transform (DFT) or a fast Fourier transform (FFT). The Fourier transformer **230** may be provided for each receive chain.

When the MIMO or the MU-MIMO is used, the receiving signal processing unit **200** may include a spatial demapper for converting the Fourier transformed received symbols to constellation points of the space-time streams, and an STBC decoder for despreading the constellation points from the space-time streams into the spatial streams.

The demapper **240** demaps the constellation points output from the Fourier transformer **230** or the STBC decoder to the bit streams. If the LDPC encoding is used, the demapper **240** may further perform LDPC tone demapping before the constellation demapping. The deinterleaver **250** deinterleaves the bits of each stream output from the demapper **240**. Deinterleaving may be applied only when BCC encoding is used.

When the MIMO or the MU-MIMO is used, the receiving signal processing unit **200** may use a plurality of demappers **240** and a plurality of deinterleavers **250** corresponding to the number of spatial streams. In this case, the receiving signal processing unit **200** may further include a stream deparser for combining the streams output from the deinterleavers **250**.

The decoder **260** decodes the streams output from the deinterleaver **250** or the stream deparser. For example, the decoder **100** may be an FEC decoder. The FEC decoder may include a BCC decoder or an LDPC decoder. The receiving signal processing unit **200** may further include a descram-

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bler for descrambling the decoded data. If BCC decoding is used in the decoder, the receiving signal processing unit **200** may further include an encoder deparser for multiplexing the data decoded by a plurality of BCC decoders. If LDPC decoding is used in the decoder, the receiving signal processing unit **100** may not use the encoder deparser.

FIG. **4** illustrates interframe space (IFS) relationships.

A data frame, a control frame, or a management frame may be exchanged between WLAN devices.

The data frame is used for transmission of data forwarded to a higher layer. The WLAN device transmits the data frame after performing backoff if a distributed coordination function IFS (DIFS) has elapsed from a time when the medium has been idle. The management frame is used for exchanging management information which is not forwarded to the higher layer. Subtype frames of the management frame include a beacon frame, an association request/response frame, a probe request/response frame, and an authentication request/response frame. The control frame is used for controlling access to the medium. Subtype frames of the control frame include a request to send (RTS) frame, a clear to send (CTS) frame, and an acknowledgement (ACK) frame. When the control frame is not a response frame of a previous frame, the WLAN device transmits the control frame after performing backoff when the DIFS has elapsed. When the control frame is the response frame of a previous frame, the WLAN device transmits the control frame without performing backoff when a short IFS (SIFS) has elapsed. The type and subtype of a frame may be identified by a type field and a subtype field in a frame control field.

On the other hand, a Quality of Service (QoS) STA may transmit the frame after performing backoff when an arbitration IFS (AIFS) for access category (AC), i.e., AIFS[AC], has elapsed. In this case, the data frame, the management frame, or the control frame which is not the response frame may use the AIFS[AC].

FIG. **5** is a schematic diagram illustrating a CSMA (carrier sense multiple access)/CA (collision avoidance) based frame transmission procedure for avoiding collision between frames in a channel.

Referring to FIG. **5**, STA**1** is a transmit WLAN device for transmitting data, STA**2** is a receive WLAN device for receiving the data, and STA**3** is a third WLAN device which may be located at an area where a frame transmitted from the STA**1** and/or a frame transmitted from the STA**2** can be received by the third WLAN device.

The STA**1** may determine whether the channel is busy by carrier sensing. The STA**1** may determine the channel occupation based on an energy level on the channel or correlation of signals in the channel, or may determine the channel occupation by using a network allocation vector (NAV) timer.

When it is determined that the channel is not in use by other devices during DIFS (that is, that the channel is idle), the STA**1** may transmit an RTS frame to the STA**2** after performing backoff. Upon receiving the RTS frame, the STA**2** may transmit a CTS frame as a response of the CTS frame after a SIFS.

When the STA**3** receives the RTS frame, it may set the NAV timer for a transmission duration of subsequently transmitted frames (for example, a duration of SIFS+CTS frame duration+SIFS+data frame duration+SIFS+ACK frame duration) by using duration information included in the RTS frame. For example, the NAV timer may be set for a duration of SIFS+CTS frame duration+SIFS+data frame duration+SIFS+ACK frame duration. When the STA**3** receives the CTS frame, it may set the NAV timer for a transmission duration of subsequently transmitted frames (for example, a duration of SIFS+data frame duration+SIFS+ACK frame duration) by using duration information included in the RTS CTS frame. For example, the NAV timer may be set for a duration of SIFS+data frame duration+SIFS+ACK frame duration. Upon receiving a new frame before the NAV timer expires, the STA**3** may update the NAV timer by using duration information included in the new frame. The STA**3** does not attempt to access the channel until the NAV timer expires.

When the STA**1** receives the CTS frame from the STA**2**, it may transmit a data frame to the STA**2** after SIFS elapses from a time when the CTS frame has been completely received. Upon successfully receiving the data frame, the STA**2** may transmit an ACK frame as a response of the data frame after a SIFS elapses.

When the NAV timer expires, the STA**3** may determine whether the channel is busy by the carrier sensing. Upon determining that the channel is not in use by the other devices during DIFS after the NAV timer has expired, the STA**3** may attempt the channel access after a contention window according to random backoff elapses.

Now, a sounding method in a wireless communication network according to an embodiment is described with reference to the drawings.

FIG. **6** shows an example of a wireless communication network according to an embodiment.

Referring to FIG. **6**, a basic service set (BSS) **600** includes a plurality of WLAN devices. The plurality of WLAN devices include a beamformer device **610** and beamformee devices **621**, **622**, **623**, and **624**. The beamformer device **610** may be a device for transmitting a PHY protocol data unit (PPDU) by using a beamforming steering matrix. The beamformee devices **621**, **622**, **623**, and **624** may be devices for receiving the PPDU that is transmitted by using the beamforming steering matrix. The four beamformee devices **621**, **622**, **623**, and **624** are exemplified in FIG. **6** for convenience, but the number of beamformee devices is not limited thereto.

In some embodiments, the beamformer device may be an AP and the beamformee devices may be stations.

The beamformer device **610** and the beamformee devices **621**, **622**, **623**, and **624** support a wireless communication network according to an embodiment. For example, the wireless communication network according to an embodiment may be a high efficiency (HE) WLAN developed by the IEEE 802.11 ax task group. Hereinafter, it is assumed for convenience that the wireless communication network according to an embodiment is the HE WLAN.

In the wireless communication network according to an embodiment, a predetermined band is divided into a plurality of subbands (i.e., subchannels) and the plurality of subchannels are allocated to the plurality of beamformer devices. In one embodiment, one subchannel may be allocated to one beamformer device. In another embodiment, two or more subchannels may be allocated to one beamformer device, or one subchannel may be allocated to two or more beamformer devices. In some embodiments, an OFDMA scheme may be used for transmissions on the plurality of subchannels.

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The BSS **600** may further include a previous version device. The previous version device may be, for example, a device (hereinafter referred to as a "legacy device") supporting the IEEE standard 802.11a, 802.11b or 802.11g (IEEE Std 802.11a-1999, IEEE Std 802.11b-1999 or IEEE Std 802.11g-2003), a device (hereinafter referred to as an "HT device") supporting the IEEE standard 802.11n (IEEE Std 802.11n-2009) for enhancements for higher throughput (HT), or a device (hereinafter referred to as a "VHT device") supporting the IEEE standard 802.11ac (IEEE Std 802.11 ac-2013) for enhancements for very high throughput (VHT).

FIG. **7** shows a sounding procedure in a wireless communication network according to an embodiment.

Referring to FIG. **7**, a beamformer device transmits a null data packet announcement (NDPA) frame to beamformee devices, and then transmits a null data packet (NDP) frame to the beamformee devices after a SIFS interval. The first beamformee device (e.g., beamformee device **1**) among the plurality of beamformee devices receiving the NDP frame feeds a feedback frame back to the beamformer device as a response of the NDP frame after a SIFS interval. For example, the feedback frame may be a compressed beamforming (CB) frame. The beamformer device receiving the CB frame from the beamformee device **1** transmits a beamforming report poll (BR-poll) frame to the second beamformee device (e.g., beamformee device **2**) after the SIFS interval. The beamformee device **2** receiving the BR-poll frame feeds a CB frame back to the beamformer device as a response of the BR-poll frame after the SIFS interval. The beamformer device receiving the CB frame from the beamformee device **2** transmits a BR-poll frame to the third beamformee device (e.g., beamformee device **3**) after the SIFS interval. The beamformee device **3** receiving the BR-poll frame feeds a CB frame back to the beamformer device as a response of the BR-poll frame after the SIFS interval. The beamformer device receiving the CB frame from the beamformee device **3** transmits a BR-poll frame to the fourth beamformee device (e.g., beamformee device **4**) after the SIFS interval. The beamformee device **4** receiving the BR-poll frame feeds a CB frame back to the beamformer device as a response of the BR-poll frame after the SIFS interval.

In some embodiments, the CB frame transmitted by each beamformer device includes beamforming report information as feedback information. In one embodiment, the beamforming report information may be compressed beamforming report information.

FIG. **8**, FIG. **9**, FIG. **10** and FIG. **11** show CB frames according to various embodiments.

Referring to FIG. **8**, in an embodiment, compressed beamforming report information of each CB frame includes subchannel information that is measured on each of a plurality of subchannels. The beamformee device may measure the subchannel information based on an NDP frame. In one embodiment, the subchannel information for a subchannel may include an average signal-to-noise ratio (SNR). When the number of subchannels is Ns, the compressed beamforming report information includes an average SNR of subchannel **1**, an average SNR of subchannel **2**, . . . , an average SNR of subchannel Ns.

The average SNR of subchannel i may be obtained by calculating SNRs per subcarrier for a plurality of subcarriers of subchannel i and calculating an arithmetic mean of the SNRs per subcarrier. In some embodiments, when a plurality of space-time streams are used, the average SNR of subchannel i may be calculated by averaging arithmetic means of the SNRs per subcarrier for the plurality of space-time streams.

Referring to FIG. **9**, in another embodiment, compressed beamforming report information of each CB frame includes subchannel information that is measured on each of a plurality of space-time streams. The beamformee device may measure the subchannel information based on an NDP frame. In some embodiments, the subchannel information of a space-time stream may include average SNR information of the space-time stream.

In some embodiments, when an STBC encoder spreads input data into Nc space-time streams, the compressed beamforming report information includes average SNR information of space-time stream **1**, average SNR information of space-time stream **2**, . . . , average SNR information of space-time stream Nc. The average SNR information of each space-time stream includes average SNRs for the plurality of subchannels. That is, the average SNR information of space-time stream j includes the average SNR of subchannel **1**, the average SNR of subchannel **2**, . . . , the average SNR of subchannel Ns.

The average SNR of subchannel i in space-time stream j may be obtained by calculating SNRs per subcarrier for a plurality of subcarriers of subchannel i in space-time stream j and calculating an arithmetic mean of the SNRs per subcarrier.

Since each of the plurality of beamformee devices is allocated a corresponding subchannel in an embodiment, each beamformee device may not provide the feedback information for the entire subchannels. As shown in FIG. **10** and FIG. **11**, in some embodiments, each beamformer device may provide the feedback information for the allocated subchannel.

Referring to FIG. **10**, in yet another embodiment, compressed beamforming report information of a CB frame that is fed back by each beamformee device includes subchannel information of a subchannel allocated to the beamformee device. In some embodiments, the subchannel information may include an average SNR of the subchannel. The compressed beamforming report information of the CB frame that is fed back by beamformee device **1** includes the average SNR of subchannel **1**, the compressed beamforming report information of the CB frame that is fed back by beamformee device **2** includes the average SNR of subchannel **2**, the compressed beamforming report information of the CB frame that is fed back by beamformee device **3** includes the average SNR of subchannel **3**, and the compressed beamforming report information of the CB frame that is fed back by beamformee device **4** includes the average SNR of subchannel **4**.

Referring to FIG. **11**, in still another embodiment, compressed beamforming report information of a CB frame that is fed back by each beamformee device includes subchannel information of a subchannel allocated to the beamformee device for a plurality of space-time streams. In some embodiments, the subchannel information may include an average SNR of the subchannel in the plurality of space-time streams. The compressed beamforming report information of the CB frame that is fed back by beamformee device **1** includes the average SNRs of subchannel **1** in the plurality of space-time streams, the compressed beamforming report information of the CB frame that is fed back by beamformee device **2** includes the average SNRs of subchannel **2** in the

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plurality of space-time streams, the compressed beamforming report information of the CB frame that is fed back by beamformee device 3 includes the average SNRs of subchannel 3 in the plurality of space-time streams, and the compressed beamforming report information of the CB frame that is fed back by beamformee device 4 includes the average SNRs of subchannel 4 in the plurality of space-time streams.

According to embodiments shown in FIG. 10 and FIG. 11, because each beamformee device provides the feedback information for the allocated subchannel, the overhead of the CB frame can be reduced.

As described with reference to FIG. 8 to FIG. 11, when the beamformer device receives the average SNR information of each subchannel through the CB frames from the plurality of beamformee devices, the beamformer device may determine a coding and modulation scheme (MCS) of a frame to be transmitted by beamforming based on the average SNR information.

Referring to FIG. 8 to FIG. 11 again, in some embodiments, the compressed beamforming report information may further include beamforming feedback matrix information. The beamforming feedback matrix information may be compressed beamforming feedback matrix information. The compressed beamforming feedback matrix information may be provided in the form of angles representing compressed beamforming feedback matrices for use by the beamformer device to determine steering matrices.

In some embodiments, the CB frame may be a management frame including a MAC header, a frame body field, and a frame check sequence (FCS) field. The frame body field may further include an action/category field, a MIMO control field and an MU (multi-user) exclusive beamforming report field in addition to the compressed beamforming report information.

The action/category field provides a mechanism for specifying extended management actions, and may include a category field and an action details field. The category field is set as any one of predefined values. For example, the category field may be set as a value corresponding to a category of the CB frame described in FIG. 8 to FIG. 11. The action details field includes the details of the actions.

The MIMO control field carries control values necessary for a MIMO transmission when the MIMO transmission is used. For example, the MIMO control field may carry a control value of the compressed beamforming feedback matrix. The MU exclusive beamforming report field may be used to determine the steering matrices.

Hereinafter, a method of notifying beamformee devices of allocated subchannels by a beamformer device is described with reference to FIG. 12 and FIG. 13.

FIG. 12 and FIG. 13 each shows a subchannel allocation notification method in a wireless communication network according to various embodiments.

Referring to FIG. 12, an NDPA frame includes subchannel information of a subchannel allocated to each beamformee device.

In some embodiments, the NDPA frame may have a legacy frame format. The NDPA frame includes a legacy short training field (L-STF), a legacy long training field (L-LTF), a legacy signal field (L-SIG), and a data field. A MAC frame is inserted to the data field, and the MAC frame includes a MAC header and a frame body field. The frame body field includes a station information field (STA Info). When a plurality of beamformee devices (e.g., station), the frame body field includes a plurality of station information field (STA Info 1, . . . , STA Info n) corresponding to the plurality of beamformee devices respectively.

Each station information field (STA Info i) includes information of a corresponding beamformee device and allocation information of a subchannel allocated to the corresponding beamformee device. The information of the beamformee device may include some LSBs (least significant bits) of a association identifier (AID) of the beamformee device. The subchannel allocation information may include information indicating a position of the allocated subchannel. For example, when a band with a 20 MHz bandwidth is divided into four 5 MHz subchannels, the four 5 MHz subchannels (subchannel 1, subchannel 2, subchannel 3, and subchannel 4) may correspond to four values defined two bits, i.e., '00', '01', '10', and '11' respectively. Accordingly, the subchannel allocation information may have any one of the four values '00', '01', '10', and '11' according to the allocated subchannel.

Each of the plurality of beamformee devices receiving the NDPA frame can identify its allocated subchannel.

Referring to FIG. 13, an NDP frame includes allocation information of a subchannel allocated to each beamformee device.

In some embodiments, the NDP frame may have a frame format defined by a wireless communication network (i.e., HE WLAN) according to an embodiment. Such the frame format is referred to as an "HE frame format."

The NDP frame includes a legacy compatible part and an HE compatible part.

The legacy compatible part can be decoded based on a legacy preamble, and the HE compatible part can be decoded based on an HE preamble. The legacy compatible part includes a legacy short training field (L-STF), a legacy long training field (L-LTF), a legacy signal field (L-SIG), and an HE signal field (HE-SIG-A). The L-STF, the L-LTF, and the L-SIG correspond to the legacy preamble. The HE-SIG-A carries signaling information for a device supporting the HE WLAN and may include the subchannel allocation information as the signaling information. The subchannel allocation information includes information on a subchannel allocated to each beamformee device.

The HE compatible part includes the HE preamble and may further include an additional HE signal field (HE-SIG-B). HE preamble may include a HE short training field (HE-STF) and a HE long training field (HE-LTF). The HE-STF may be used for automatic gain control of the HE compatible part, and the HE-LTF may be used for channel estimation of the HE compatible part. In the NDP frame, the HE compatible part does not include a data field.

Each of the beamformee devices receiving the NDP frame can identify its allocated subchannel through the subchannel allocation information carried by the HE signal field.

In some embodiments, the HE-LTF may be transmitted for each subband as shown in FIG. 13 such that the channel estimation can be performed for each subchannel.

In some embodiments, a bandwidth unit of the subchannel may be 2.5 MHz, 5 MHz, 10 MHz, 20 MHz, 40 MHz, or 80 MHz when hardware supporting previous WLANs, for example a VHT WLAN and a WLAN according to the IEEE standard 802.11ah is reused. Accordingly, each subchannel may be allocated a bandwidth as shown in Table 1, in accordance with the number of divided subchannels.

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TABLE 1

	Number of subchannels	Bit index	Sub-channel allocation for OFDMA 20 MHz	40 MHz	80 MHz	160 MHz
OFDM	1	N/A	20	40	80	160
OFDMA	2	0	(10, 10)	(20, 20)	(40, 40)	(80, 80)
	3	1	(10, 5, 5)	(20, 10, 10)	(40, 20, 20)	(80, 40, 40)
		2	(5, 10, 5)	(10, 20, 10)	(20, 40, 20)	(40, 80, 40)
		3	(5, 5, 10)	(10, 10, 20)	(20, 20, 40)	(40, 40, 80)
	4	4	(10, 5, 2.5, 2.5)	(20, 10, 5, 5)	(40, 20, 10, 10)	(80, 40, 20, 20)
		5	(10, 2.5, 5, 2.5)	(20, 5, 10, 5)	(40, 10, 20, 10)	(80, 20, 40, 20)
		6	(10, 2.5, 2.5, 5)	(20, 5, 5, 10)	(40, 10, 10, 20)	(80, 20, 20, 40)
		7	(5, 10, 2.5, 2.5)	(10, 20, 5, 5)	(20, 40, 10, 10)	(40, 80, 20, 20)
		8	(2.5, 10, 5, 2.5)	(5, 20, 10, 5)	(10, 40, 20, 10)	(20, 80, 40, 20)
		9	(2.5, 10, 2.5, 5)	(5, 20, 5, 10)	(10, 40, 10, 20)	(20, 80, 20, 40)
		10	(5, 2.5, 10, 2.5)	(10, 5, 20, 5)	(20, 10, 40, 10)	(40, 20, 80, 20)
		11	(2.5, 5, 10, 2.5)	(5, 10, 20, 5)	(10, 20, 40, 10)	(20, 40, 80, 20)
		12	(2.5, 2.5, 10, 5)	(5, 5, 20, 10)	(10, 10, 40, 20)	(20, 20, 80, 40)
		13	(5, 2.5, 2.5, 10)	(10, 5, 5, 20)	(20, 10, 10, 40)	(40, 20, 20, 80)
		14	(2.5, 5, 2.5, 10)	(5, 10, 5, 20)	(10, 20, 10, 40)	(20, 40, 20, 80)
		15	(2.5, 2.5, 5, 10)	(5, 5, 10, 20)	(10, 10, 20, 40)	(20, 20, 40, 80)
		16	(5, 5, 5, 5)	(10, 10, 10, 10)	(20, 20, 20, 20)	(40, 40, 40, 40)

In Table 1, (a,b) represents a case that bandwidths with a and b are allocated to two subchannel respectively, (a,b,c) represents a case that bandwidths with a, b, and c are allocated to three subchannel respectively, and (a,b,c,d) represents a case that bandwidths with a, b, c, and are allocated to four subchannel respectively.

Referring to Table 1, when a 20 MHz bandwidth is allocated to two users, the 20 MHz bandwidth may be divided into two 10 MHz subchannels. When the 20 MHz bandwidth is allocated to three users, the 20 MHz bandwidth may be divided into 10 MHz, 5 MHz, and 5 MHz subchannels; 5 MHz, 10 MHz, and 5 MHz subchannels; or 5 MHz, 5 MHz, and 10 MHz subchannels. When the 20 MHz bandwidth is allocated to four users, the 20 MHz bandwidth may be divided into 10 MHz, 5 MHz, 2.5 MHz, and 2.5 MHz subchannels; 10 MHz, 2.5 MHz, 5 MHz, and 2.5 MHz subchannels; 10 MHz, 2.5 MHz, 2.5 MHz, and 5 MHz subchannels; 5 MHz, 10 MHz, 2.5 MHz, and 2.5 MHz subchannels; 2.5 MHz, 10 MHz, 5 MHz, and 2.5 MHz subchannels; 2.5 MHz, 10 MHz, 2.5 MHz, and 5 MHz subchannels; 5 MHz, 2.5 MHz, 10 MHz, and 2.5 MHz subchannels; 2.5 MHz, 5 MHz, 10 MHz, and 2.5 MHz subchannels; 2.5 MHz, 2.5 MHz, 10 MHz, and 5 MHz subchannels; 5 MHz, 2.5 MHz, 2.5 MHz, and 10 MHz subchannels; 2.5 MHz, 5 MHz, 2.5 MHz, and 10 MHz subchannel; 2.5 MHz, 2.5 MHz, 5 MHz, and 10 MHz subchannels; or 5 MHz, 5 MHz, 5 MHz, and 5 MHz.

As shown in Table 1, a 40 MHz bandwidth, an 80 MHz bandwidth, and a 160 MHz bandwidth may be divided in the same way.

In one embodiment, since seventeen subchannel division schemes are provided for each bandwidth in an example shown in Table 1, the subchannel allocation information may have five bits in order to differentiate the subchannel division schemes. The seventeen subchannel division schemes may correspond to values of 0 to 16 among values of 0 to 31 represented by 5 bits.

In another embodiment, when only one user exists, an orthogonal frequency division multiplexing (OFDM) transmission may be used. Accordingly, the subchannel allocation information may further have one bit for differentiating the OFDM transmission and the OFDMA transmission. That is, the subchannel allocation information may have sixth bits

In yet another embodiment, the OFDM transmission may be indicated by any one of values (for example, values of 17 to 31) that do not correspond to the seventeen subchannel division schemes among the values of 0 to 31 represented by the subchannel allocation information with five bits.

It is shown in FIG. **7** that the beamformee devices sequentially transmit the CB frames. However, the beamformee devices may transmit the CB frames in parallel. Such embodiments are described with reference to FIG. **14** to FIG. **17**.

FIG. **14**, FIG. **15**, FIG. **16**, and FIG. **17** each shows a parallel transmission method of a CB frame in a wireless communication network according to various embodiments. FIG. **14** shows an example of transmitting a CB frame in parallel in a wireless communication network according to an embodiment. FIG. **15** shows another example of transmitting a CB frame in parallel in a wireless communication network according to an embodiment, and FIG. **16** and FIG. **17** show examples of transmitting remaining fragments of a CB frame in a wireless communication network according to an embodiment.

Referring to FIG. **14**, in an embodiment, a plurality of beamformee devices transmit CB frames in parallel. In some embodiments, the beamformee device may transmit the CB frames in an uplink OFDMA scheme.

The CB frame transmitted by each beamformee device includes beamforming report information of its allocated subchannel at a data field. In some embodiments, each beamformee device may transmit the CB frame on its allocated subchannel. For example, beamformee device **1** may transmit the CB frame on subchannel 1, beamformee device **2** may transmit the CB frame on subchannel **2**, beamformee device **3** may transmit the CB frame on subchannel **3**, and beamformee device **4** may transmit the CB frame on subchannel **4**.

In some embodiments, the CB frame may have a HE frame format. In one embodiment, each beamformee device may transmit a legacy compatible part of the CB frame on entire subchannels and may transmit a HE compatible part on its allocated subchannel.

The legacy compatible part includes a legacy short training field (L-STF), a legacy long training field (L-LTF), a legacy signal field (L-SIG), and an HE signal field (HE-SIG-A). The HE compatible part includes a HE preamble and a data field, and may further include an additional HE signal field (HE-SIG-B). The HE preamble may include a HE short training field (HE-STF) and a HE long training field (HE-LTF).

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As such, the beamformee devices transmit the CB frames in parallel, thereby reducing a time necessary for transmitting the CB frames compared with a case that the CB frames are sequentially transmitted. Further, since each beamformee device can transmit the beamforming report information of its allocated subchannel, the overhead of the CB frame can be reduced.

As shown in FIG. **14**, lengths of the CB frames (i.e., lengths of data fields in the CB frames) transmitted by the beamformee devices may be different from each other. When receiving the CB frames having different lengths in parallel, the beamformer device may not decode the received CB frames. Because the length of the data field in the CB frame is determined by each beamformee device, each beamformee device cannot know the length of the data field to be transmitted by the other beamformee device such that padding for adjusting the length of the data field cannot be performed.

Referring to FIG. **15**, in another embodiment, each beamformee device may transmit a CB frame by adjusting a length of the CB frame to a maximum CB length. Therefore, when the length of data to be transmitted through the data field of the CB frame is shorter than the maximum CB length, the beamformee device may perform the padding for adding pad bits to remaining portion of the data field. When the length of data to be transmitted through the data field of the CB frame is longer than the maximum CB length, the beamformee device may partition the beamforming report information into two or more fragments and transmit two or more CB frames.

In some embodiments, the beamformer device may partition a MAC service data unit (MSDU) or a MAC management protocol data unit (MMPDU) including the beamforming report information into two or more smaller MAC protocol data units (MPDUs). The beamformer device may transmit the two or more CB frames that include the two or more MPDUs respectively.

In some embodiments, the beamformer device may indicate the maximum CB length to the beamformee devices. The maximum CB length may be a maximum length of the data field in the CB frame or a maximum length of the CB frame.

In one embodiment, the beamformer device may indicate the maximum CB length using the NDPA frame. For example, a data field of the NDPA frame, i.e., a frame body field of a MAC frame inserted to the NDPA frame may include information on the maximum CB length.

In another embodiment, the beamformer device may indicate the maximum CB length using the NDP frame. For example, a HE signal field (HE-SIG-A or HE-SIG-B) of the NDP frame may include the maximum CB length as the signaling information.

As such, when the beamformer device indicates the maximum CB length using the NDPA frame or the NDP frame, the beamformer device and the beamformee devices may change the maximum CB length each time performing a sounding procedure.

On the other hand, the MAC efficiency may be deteriorated because the beamformee device may perform unnecessary padding or fragmentation due to the maximum CB length. Accordingly, in yet another embodiment, the beamformer device may select the maximum CB length based on other information. For example, the beamformer device may determine the maximum CB length based on a previous CB frame length or the number of antennas.

Referring to FIG. **16**, in some embodiments, when beamforming report information is partitioned, a beamformer device may receive the first CB frames from a plurality of beamformee devices and then transmit a BR-poll frame to a beamformee device having a remaining fragment to allow the beamformee device to transmit the remaining fragment. The beamformer device receiving the BR-poll frame transmits a next CB frame including the remaining fragment to the beamformer device.

In some embodiments, a MAC header of the CB frame may indicate whether the remaining fragment exists. In one embodiment, a more fragments field of the MAC header may indicate whether the remaining fragment exists. Therefore, the beamformer device can determine which beamformee device has the remaining fragment based on the MAC header of the received CB frame.

In some embodiments, when a plurality of beamformee devices have the remaining fragment, the beamformee devices may transmit CB frames including the remaining fragment in parallel. In one embodiment, when the beamformee devices transmit the next CB frames in parallel, each beamformee device may transmit the next CB frame on its allocated subchannel.

In another embodiment, the feedback of the CB frame may terminate in a part of a plurality of beamformee devices joining in beamforming. In this case, when the next CB frames are transmitted, remaining beamformee devices may use subchannels different from subchannels used for transmitting the first CB frames. For example, as shown in FIG. **17**, the feedback of the CB frame may terminate in beamformee device **1** and beamformee device **2**, and beamformee device **3** and beamformee device **4** may have remaining fragments. Then, beamformee device **3** may transmit the CB frame through subchannels **1** and **2**, and beamformee device **4** may transmit the CB frame through subchannels **3** and **4**. The beamformer device may include changed subchannel allocation information to the BR-poll frame. Since the maximum CB length may be changed when the subchannel allocation is changed, the BR-poll frame may further include information on the maximum CB length.

In some embodiments, the BR-poll frame may include information on the fragment that has not been successfully received. Accordingly, the beamformee device may retransmit a CB frame including the fragment which the beamformer device has not successfully received.

Hereinafter, embodiments for allocating subchannels in a sounding procedure are described with reference to FIG. **18** to FIG. **24**.

FIG. **18**, FIG. **19**, FIG. **20**, FIG. **21**, FIG. **22**, FIG. **23**, and FIG. **24** each shows a subchannel allocation method in a wireless communication network according to various embodiments.

Referring to FIG. **18**, in an embodiment, a beamformer device transmits an NDPA frame to beamformee devices. The NDPA frame includes information on the number of best subchannels to be fed back by the beamformee device through a CB frame. In some embodiments, the NDPA frame may include information requesting to transmit feedback information on the best N subchannels, i.e., information indicating N. Herein, N is an integer greater than or equal to 1, and may be determined by the beamformer device. The beamformer device transmits the NDPA frame and then transmits an NDP frame to the beamformee device after a SIFS interval.

The beamformee devices receiving the NDP frame sequentially transmit CB frames. The CB frame may include the feedback information on the best N subchannels.

In some embodiments, beamformee device **1** among the beamformee devices receiving the NDP frame feeds the CB

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frame back to the beamformer device as a response of the NDPA frame after the SIFS interval. The CB frame transmitted by beamformee device 1 includes the feedback information on the best N subchannels for beamformee device 1 among a plurality of subchannels.

The beamformer device receiving the CB frame from beamformee device 1 transmits a BR-poll frame to beamformee device 2 after the SIFS interval. In one embodiment, the beamformer device may select a subchannel for beamformee device 1 based on the feedback information on the best N subchannels that is provided by beamformee device 1. The BR-poll frame may include selected subchannel information indicating the selected subchannel for a previous beamformee device, i.e., beamformee device 1. In one embodiment, the selected subchannel information may be transferred by a selected subchannel bitmap field that is represented in the form of bitmap. The selected subchannel bitmap has a plurality of bits that correspond to the plurality of subchannels respectively. When a bit has a predetermined value (for example, '1'), it is indicated that a subchannel corresponding to the bit is selected for the previous beamformee device.

Beamformee device 2 receiving the BR-poll frame selects its best N subchannels from among the plurality of subchannels based on the selected subchannel information and transmits the CB frame including the feedback information on the selected best N subchannels. In one embodiment, beamformee device 2 may select the N subchannels from among subchannels excluding the subchannel selected for the previous beamformee device (i.e., beamformee device 1) based on the selected subchannel information.

The beamformer device receiving the CB frame from beamformee device 2 transmits a BR-poll frame to beamformee device 3 after the SIFS interval. In one embodiment, the beamformer device may select a subchannel for beamformee device 2 based on the feedback information on the best N subchannels that is provided by beamformee device 2. The BR-poll frame may include selected subchannel information indicating the selected subchannel for the previous beamformee devices, i.e., beamformee devices 1 and 2. In one embodiment, the selected subchannel information may be the selected subchannel bitmap where bits corresponding to the subchannels selected for the previous beamformee devices (i.e., beamformee devices 1 and 2) have the predetermined value.

As described above, beamformee device 3 receiving the BR-poll frame selects its best N subchannels from among the plurality of subchannels based on the selected subchannel information and transmits the CB frame including the feedback information on the selected best N subchannels. The beamformer device receiving the CB frame from beamformee device 3 may select a subchannel for beamformee device 3 based on the feedback information on the best N subchannels, and transmits to beamformee device 4 a BR-poll frame including selected subchannel information for the previous beamformee devices. Beamformee device 4 receiving the BR-poll frame selects its best N subchannels based on the selected subchannel information and transmits the CB frame including the feedback information on the selected best N subchannels. The beamformer device receiving the CB frame from beamformee device 4 may select a subchannel for beamformee device 4 based on the feedback information on the best N subchannels.

Accordingly, the beamformer device can allocate the subchannels to the beamformee devices. Further, the beamformer device may provide the beamformee device with subchannel allocation information on the subchannel selected for the beamformee device. In some embodiments, the beamformer device may provide the subchannel allocation information using a HE signal field.

According to the above embodiment, the subchannels can be allocated to the beamformee devices by using the sounding procedure described with reference to FIG. 7.

Referring to FIG. 19, in another embodiment, a beamformer device transmits an NDPA frame to beamformee devices and then transmits an NDP frame to the beamformee devices after a SIFS interval.

Each beamformee device measures a plurality of subchannels based on the NDP frame and transmits a subchannel information frame including measured information for each of the plurality of subchannels. In some embodiment, the measured information may include an average SNR of each subchannel. In some embodiments, the beamformee devices may transmit the subchannel information frames in parallel.

The beamformer device receiving the subchannel information frames from the beamformee devices allocates a subchannel to each beamformee device based on the measured information. The beamformer device transmits to the beamformee devices a channel feedback trigger frame including allocation information of the subchannels. In some embodiments, the channel feedback trigger frame may have a frame format that is similar to a frame format of the NDPA frame or the NDP frame. When the channel feedback trigger frame has the similar frame format to the NDPA frame, a frame body field of a MAC frame inserted to a data field of the channel feedback trigger frame may include the subchannel allocation information. When the channel feedback trigger frame has the similar frame format to the NDP frame, a HE signal field (HE-SIG-A or HE-SIG-B) of the channel feedback trigger frame may include the subchannel allocation information.

Beamformee device 1 among the beamformee devices receiving the channel feedback trigger frame transmits a CB frame to the beamformer device as a response of the channel feedback trigger frame after a SIFS interval. The beamformer device receiving the CB frame from beamformee device 1 transmits a BR-poll frame to beamformee device 2. Beamformee device 2 receiving the BR-poll frame feeds a CB frame back to the beamformer device, and the beamformer device receiving the CB frame from beamformee device 2 transmits a BR-poll frame to beamformee device 3. Beamformee device 4 receiving the BR-poll frame feeds a CB frame back to the beamformer device, and the beamformer device receiving the CB frame from beamformee device 3 transmits a BR-poll frame to beamformee device 4. Beamformee device 4 receiving the BR-poll frame feeds a CB frame back to the beamformer device.

In some embodiments, the CB frame transmitted by each beamformee device includes subchannel information of its allocated subchannel as described with reference to FIG. 8 to FIG. 11.

Referring to FIG. 20, in another embodiment, a plurality of beamformee devices transmits CB frames in parallel after receiving a channel feedback trigger frame. In some embodiments, the beamformee devices may transmit the CB frames using an uplink OFDMA scheme.

Since each beamformee device can identify its allocated subchannel using the channel feedback trigger frame, it can transmit the CB frame through the allocated subchannel. For example, beamformee device 1 may transmit the CB frame on subchannel 1, beamformee device 2 may transmit the CB frame on subchannel 2, beamformee device 3 may transmit the CB frame on subchannel 3, and beamformee device 4 may transmit the CB frame on subchannel 4.

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Referring to FIG. **21** and FIG. **22**, in yet another embodiment, a plurality of beamformee devices sequentially transmits subchannel information frames.

Each beamformee device measure subchannel information of a plurality of subchannels based on an NDP frame, and beamformee device **1** first transmits the subchannel information frame including the measured information to a beamformer device. The beamformer device receiving the subchannel information frame from beamformee device **1** transmits a subchannel information trigger frame to beamformee device **2**. The beamformee device **2** receiving the subchannel information trigger frame feeds the subchannel information frame including the measured information back to the beamformer device, and the beamformer device receiving the subchannel information frame from beamformee device **2** transmits a subchannel information trigger frame to beamformee device **3**. The beamformee device **3** receiving the subchannel information trigger frame feeds the subchannel information frame including the measured information back to the beamformer device, and the beamformer device receiving the subchannel information frame from beamformee device **3** transmits a subchannel information trigger frame to beamformee device **4**. The beamformee device **4** receiving the subchannel information trigger frame feeds the subchannel information frame including the measured information back to the beamformer device.

Accordingly, the beamformer device can receive the measured information of the subchannels from the beamformee devices, allocate the subchannels to the beamformee devices based on the measured information, and provide the beamformee devices with a channel feedback trigger frame including the subchannel allocation information.

In one embodiment, the beamformee devices receiving the channel feedback trigger frame may sequentially transmit CB frames as shown in FIG. **21**.

In another embodiment, the beamformee devices receiving the channel feedback trigger frame may transmit CB frames in parallel as shown in FIG. **22**.

According to the above embodiments, after a subchannel allocation procedure is performed, the feedback on the allocated subchannel can be provided. Therefore, the sounding procedure can be divided into the subchannel allocation procedure and the channel feedback procedure.

Referring to FIG. **23**, in some embodiments, a beamformer device may directly measure subchannels and allocate the subchannels.

The beamformer device transmits a trigger frame to a plurality of beamformee devices, and the beamformee devices transmit channel measurement frames to the beamformer device in parallel.

The beamformer device measures subchannels for each beamformee device based on the channel measurement frame and allocates the subchannels to the beamformee devices based on the measured information of the subchannels. In some embodiments, the beamformer device may measure an average SNR of each of the subchannels for each beamformee device and allocated the subchannels based on the average SNRs.

Subsequently, the beamformer device performs a sounding procedure in a similar way to the above embodiments. For example, as described with reference to FIG. **7**, the beamformer device transmits an NDPA frame and an NDP frame to the beamformee devices, and the beamformee devices sequentially feed CB frames back to the beamformer device. In one embodiment, as shown in FIG. **23**, the NDPA frame may include the subchannel allocation information. In another embodiment, a HE signal field (HE-SIG-A or HE-SIG-B) of the NDP frame may include the subchannel allocation information.

Referring to FIG. **24**, in another embodiment, a plurality of beamformee devices may transmit CB frames in parallel.

In some embodiments, since a long training field (LTF) can be used for channel estimation, the channel measurement frame transmitted by the beamformee device may be an LTF frame including the LTF. In this case, the beamformee devices may transmit the LTF frames in a code division multiple access (CDMA) scheme in order to differentiate the LTF frames transmitted by the beamformee devices. That is, the beamformee devices may be differentiated by applying predetermined identification codes (for example, Hadamard orthogonal codes) to the LTFs. The trigger frame transmitted by the beamformer device may include information on the LTFs to be used by the beamformee devices. In one embodiment, the information of the LTFs may include information indicating the number of beamformee devices (i.e., users) for transmitting the LTF frames and a code (i.e., the identification code) to be used by each beamformee device.

FIG. **25**, FIG. **26**, and FIG. **27** each shows an LTF frame in a wireless communication network according to various embodiments.

Referring to FIG. **25**, FIG. **26**, and FIG. **27**, an LTF frame includes a legacy compatible part and a HE compatible part. The legacy compatible part includes a legacy short training field (L-STF), a legacy long training field (L-LTF), a legacy signal field (L-SIG), and an HE signal field (HE-SIG-A). The beamformee devices transmit common information through the legacy compatible part.

The HE compatible part includes a plurality of HE LTFs to be used for subchannel measurement. The HE compatible part may further include a HE short training field (HE-STF) to used for automatic gain control of the HE compatible part. The HE compatible part may further include an additional HE signal field (HE-SIG-B).

As shown in FIG. **25**, when two beamformee devices transmit LTF frames, the beamformer device may provide information on two identification codes. The LTF frame may include two HE-LTFs (HE-LTF**1** and HE-LTF**2**). For example, a code matrix defined in Equation 1 may be used. An identification code [1 −1] corresponding to the first row of the code matrix may be allocated to beamformee device **1**, and an identification code [1 1] corresponding to the second row of the code matrix may be allocated to beamformee device **2**. Then, beamformee device **1** may transmit the LTF frame by multiplying the HE-LTF by 1 and multiplying HE-LTF**2** by −1, and beamformee device **2** may transmit the LTF frame by multiplying the HE-LTF**1** by 1 and multiplying the HE-LTF**2** by 1. The trigger frame may include information on the code matrix and information on a row to be used by each beamformee device. Alternatively, when the code matrix is predefined between the beamformer device and the beamformee devices, the trigger frame may include the number of beamformee devices and information on a row to be used by each beamformee device.

$$\begin{bmatrix} 1 & -1 \\ 1 & 1 \end{bmatrix} \quad \text{Equation 1}$$

As shown in FIG. **26**, when three beamformee devices transmit LTF frames, the beamformer device may provide information on three identification codes. The LTF frame

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may include three HE-LTFs (HE-LTF1, HE-LTF2, and HE-LTF3). For example, a code matrix defined in Equation 2 may be used. An identification code [1 −1 1] corresponding to the first row of the code matrix may be allocated to beamformee device **1**, an identification code [1 $-w^1$ w^2] corresponding to the second row of the code matrix may be allocated to beamformee device **2**, and an identification code [1 $-w^2$ w^4] corresponding to the second row of the code matrix may be allocated to beamformee device **3**. Then, beamformee device **1** may transmit the LTF frame by multiplying the HE-LTF by 1, multiplying HE-LTF2 by −1, and multiplying HE-LTF3 by 1. Beamformee device **2** may transmit the LTF frame by multiplying the HE-LTF1 by 1, multiplying the HE-LTF2 by $-w^1$, and multiplying the HE-LTF3 by w^2. Beamformee device **3** may transmit the LTF frame by multiplying the HE-LTF1 by 1, multiplying the HE-LTF2 by $-w^2$, and multiplying the HE-LTF3 by w^4.

$$\begin{bmatrix} 1 & -1 & 1 \\ 1 & -w^1 & w^2 \\ 1 & -w^2 & w^4 \end{bmatrix}, \quad w = \exp\left(-\frac{j2\pi}{3}\right) \qquad \text{Equation 2}$$

As shown in FIG. **26**, when four beamformee devices transmit LTF frames, the beamformer device may provide information on four identification codes. The LTF frame may include four HE-LTFs (HE-LTF1, HE-LTF2, HE-LTF3, and HE-LTF4). For example, a code matrix defined in Equation 3 may be used. An identification code [1 −1 1 1] corresponding to the first row of the code matrix may be allocated to beamformee device **1**, an identification code [1 1 −1 1] corresponding to the second row of the code matrix may be allocated to beamformee device **2**, an identification code [1 1 1 −1] corresponding to the second row of the code matrix may be allocated to beamformee device **4**, and an identification code [−1 1 1 1] corresponding to the second row of the code matrix may be allocated to beamformee device **4**. Then, beamformee device **1** may transmit the LTF frame by multiplying the HE-LTF1 by 1, multiplying the HE-LTF2 by −1, multiplying the HE-LTF3 by 1, and multiplying the HE-LTF4 by 1. Beamformee device **2** may transmit the LTF frame by multiplying the HE-LTF1 by 1, multiplying the HE-LTF2 by 1, multiplying the HE-LTF3 by −1, and multiplying the HE-LTF4 by 1. Beamformee device **3** may transmit the LTF frame by multiplying the HE-LTF1 by 1, multiplying the HE-LTF2 by 1, multiplying the HE-LTF3 by 1, multiplying the HE-LTF4 by −1. Beamformee device **4** may transmit the LTF frame by multiplying the HE-LTF1 by −1, multiplying the HE-LTF2 by 1, multiplying the HE-LTF3 by 1, and multiplying the HE-LTF4 by 1.

$$\begin{bmatrix} 1 & -1 & 1 & 1 \\ 1 & 1 & -1 & 1 \\ 1 & 1 & 1 & -1 \\ -1 & 1 & 1 & 1 \end{bmatrix} \qquad \text{Equation 3}$$

In one embodiment, when the LTF frame includes the additional HE signal field (HE-SIG-B), the beamformee devices may transmit common information by multiplying the HE-SIG-Bs by the same sequence. In another embodiment, the beamformee devices may transmit different information by multiplying the HE-SIG-Bs by different sequences. The sequence for HE-SIG-B may be the same as the identification code for the HE-LTFs.

While a 20 MHz bandwidth has been used for description in FIG. **25**, FIG. **26**, and FIG. **27**, the same code matrix may be used in the different bandwidth such that each beamformee device may use a corresponding identification code of the code matrix.

As such, when the beamformee devices transmit the LTF frames using the different identification codes, the beamformer device may despread the received HE-LTFs and then measure an average SNR per subchannel for each beamformee device.

A sounding method according to above embodiments may be executed by a baseband processor **10** shown in FIG. **1** to FIG. **3**. In one embodiment, instructions for executing the frame transmitting method and the frame receiving method according to above embodiments may be stored in a non-transitory computer-readable recording medium such as a memory **40**. In another embodiment, at least some of the instructions may be MAC software. In yet another embodiment, at least some of the instructions may be transmitted from a non-transitory computer-readable recording medium of a certain server and may be stored in the memory **40**.

While this invention has been described in connection with what is presently considered to be practical embodiments, it is to be understood that the invention is not limited to the disclosed embodiments, but, on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims. Further, two or more embodiments may be combined.

What is claimed is:

1. A sounding method by a first receiving device, the method comprising:

receiving a null data packet announcement (NDPA) frame from a transmitting device;

receiving a null data packet (NDP) frame from the transmitting device after receiving the NPDA frame; and

transmitting to the transmitting device a feedback frame including subchannel information measured on a first subchannel after receiving the NDP frame, the first subchannel being a subchannel that is allocated to the first receiving device among a plurality of subchannels into which a predetermined band is divided,

wherein transmitting the feedback frame includes:

transmitting the feedback frame to the transmitting device while a second feedback frame including subchannel information measured on the second subchannel is transmitted to the transmitting device by a second receiving device, the second subchannel being a subchannel that is allocated to the second receiving device among the plurality of subchannels.

2. The method of claim **1**, wherein the subchannel information includes an average signal-to-noise ratio (SNR) of the first subchannel.

3. The method of claim **1**, wherein the subchannel information includes average signal-to-noise ratios (SNRs) of the first subchannel for a plurality of space-time streams.

4. The method of claim **1**, wherein the feedback frame further includes subchannel information measured on other subchannels excluding the first subchannel.

5. The method of claim **1**, wherein transmitting the feedback frame includes

adding pad bits to a data field of the feedback frame when a length of data to be transmitted by the feedback frame is shorter than a predetermined length, or partitioning

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the data into a plurality of fragments and inserting any one of the fragments to the data field of the feedback frame when the length of the data is longer than the predetermined length.

6. The method of claim **5**, wherein the NDPA frame indicates information corresponding to the predetermined length.

7. The method of claim **1**, wherein the NDPA frame includes allocation information of the first subchannel.

8. The method of claim **1**, wherein the subchannel information is measured on each of a predetermined number of subchannels including the first subchannel, and

wherein the first subchannel is allocated based on the subchannel information.

9. The method of claim **8**, wherein the NDPA frame includes information on the predetermined number.

10. The method of claim **8**, further comprising receiving a frame including selected subchannel information from the transmitting device, the selected subchannel information indicating a subchannel that is selected by other receiving device among the plurality of subchannels,

wherein the predetermined number of subchannels do not include the subchannel that that is selected by the other receiving device.

11. The method of claim **10**, wherein the selected subchannel information is represented by a bitmap having a plurality of bits that correspond to the plurality of subchannels respectively, and

wherein a predetermined value in each of the plurality of bits indicates that a corresponding subchannel is selected by the other receiving device.

12. The method of claim **1**, wherein transmitting the feedback frame includes:

transmitting a subchannel information frame to the transmitting device after receiving the NDP frame, the subchannel information frame including measurement information that is measured on each of the plurality of subchannels by the first receiving device;

receiving from the transmitting device a channel feedback trigger frame including allocation information of the plurality of subchannels; and

transmitting the feedback frame to the transmitting device after receiving the channel feedback trigger frame.

13. The method of claim **12**, wherein transmitting the subchannel information frame includes

transmitting the subchannel information frame to the transmitting device before a second subchannel information frame is transmitted to the transmitting device by the second receiving device or after the second subchannel information frame is transmitted to the transmitting device by the second receiving device, the second subchannel information frame including measurement information that is measured on each of the plurality of subchannels by the second receiving device.

14. The method of claim **12**, wherein transmitting the subchannel information frame includes

transmitting the subchannel information frame to the transmitting device while a second subchannel information frame is transmitted to the transmitting device by the second receiving device, the second subchannel information frame including measurement information that is measured on each of the plurality of subchannels by the second receiving device.

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

receiving a trigger frame from a transmitting device; and

transmitting a frame including a plurality of long training fields to the transmitting device after receiving the trigger frame,

wherein the plurality of long training fields are multiplied by a predetermined identification code allocated to the first receiving device among a plurality of receiving devices.

16. The method of claim **15**, wherein a number of the plurality of long training fields is equal to a number of the plurality of receiving devices.

17. The method of claim **15**, wherein the trigger frame includes information on a predetermined identification code allocated to each of the plurality of receiving devices.

18. A sounding method by a transmitting device, the method comprising:

transmitting a null data packet announcement (NDPA) frame to a plurality of receiving devices;

transmitting a null data packet (NDP) frame to the plurality of receiving devices after transmitting the NPDA frame; and

receiving from each receiving device a feedback frame including subchannel information measured on a subchannel that is allocated to each receiving device among a plurality of subchannels into which a band is divided, after transmitting the NDP frame,

wherein the plurality of feedback frames from the plurality of receiving devices are received at a same time, and the NDPA frame includes allocation information of the plurality of subchannels.

* * * * *

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EXHIBIT 3

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August 23, 2021

THIS IS TO CERTIFY THAT ANNEXED HERETO IS A TRUE COPY FROM THE RECORDS OF THIS OFFICE OF:

U.S. PATENT: *9,825,738*
ISSUE DATE: *November 21, 2017*

By Authority of the
Under Secretary of Commerce for Intellectual Property
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SYLVIA HOLLEY
Certifying Officer

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(12) **United States Patent**
Kwon et al.

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(54) **ACKNOWLEDGEMENT METHOD AND MULTI USER TRANSMISSION METHOD**

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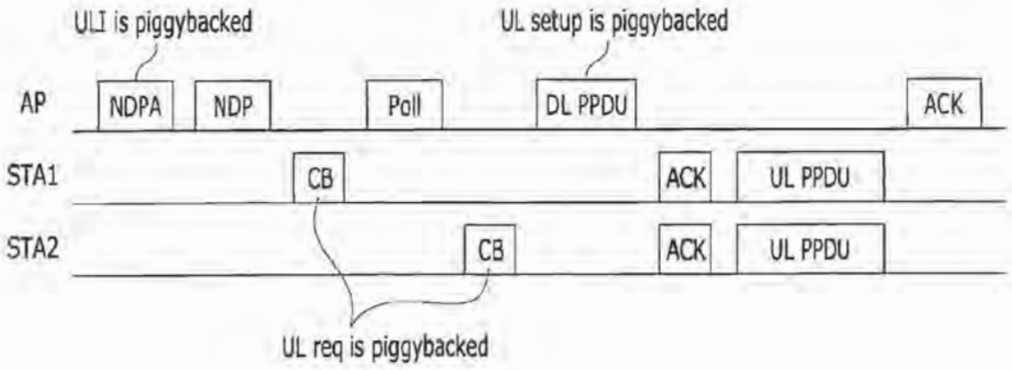
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(57) **ABSTRACT**

An Acknowledgment (ACK) method is provided by a receiving device in a Wireless Local Area Network (WLAN). The receiving device receives a plurality of data units having a plurality of Traffic Identifiers (TIDs) and transmits an ACK frame including a plurality of ACK information fields for at least part of the plurality of data units. An ACK information field for a data unit satisfying a first condition among the plurality of ACK information fields includes a Traffic Identifier (TID) and a block ACK bitmap indicating whether the data unit has been successfully received. An ACK information field for a data unit satisfying a second condition and having been successfully received among the plurality of ACK information fields includes the first TID and does not include a block ACK bitmap.

16 Claims, 25 Drawing Sheets



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See application file for complete search history.

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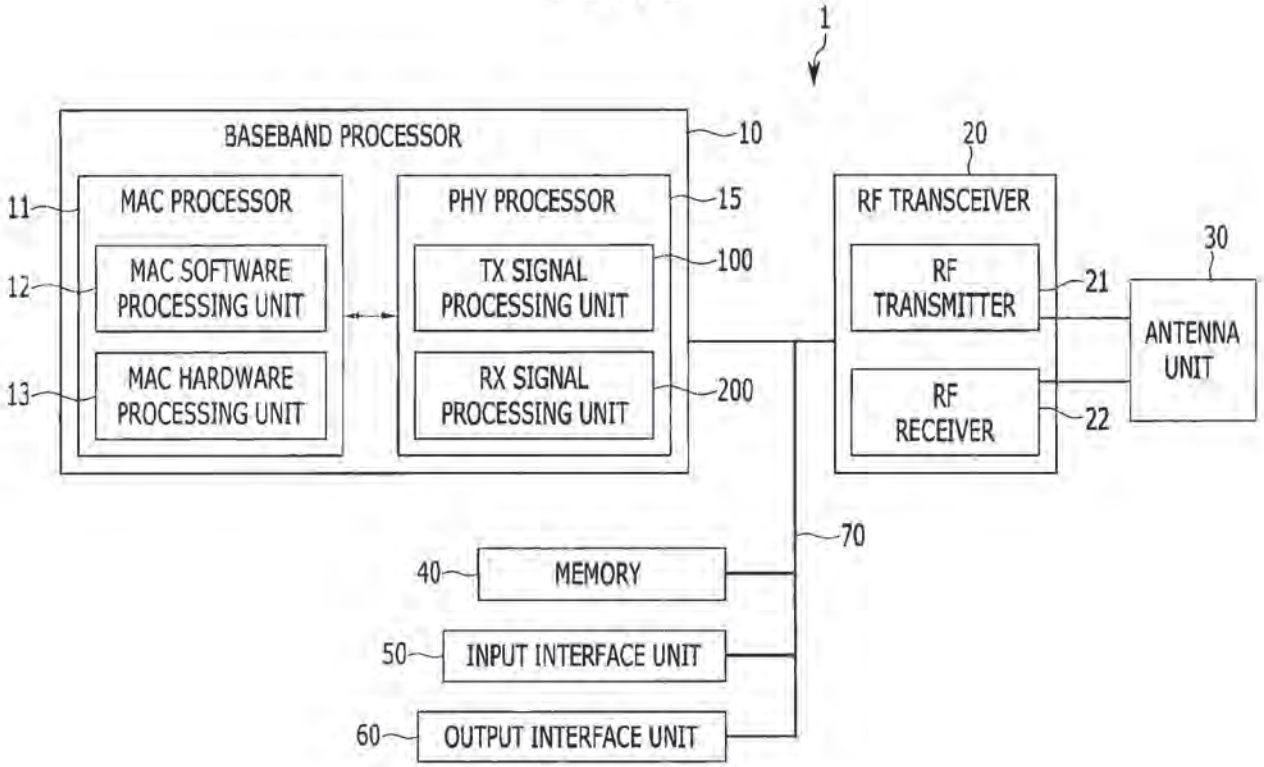
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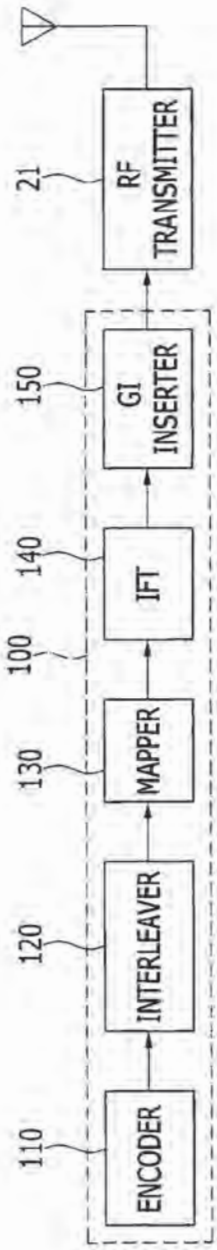
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FIG. 1



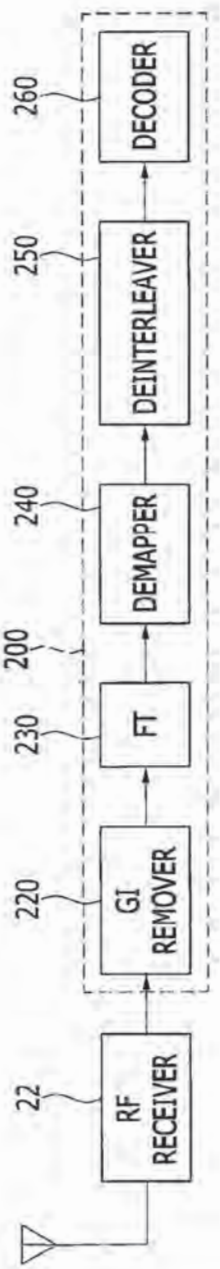
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FIG. 2



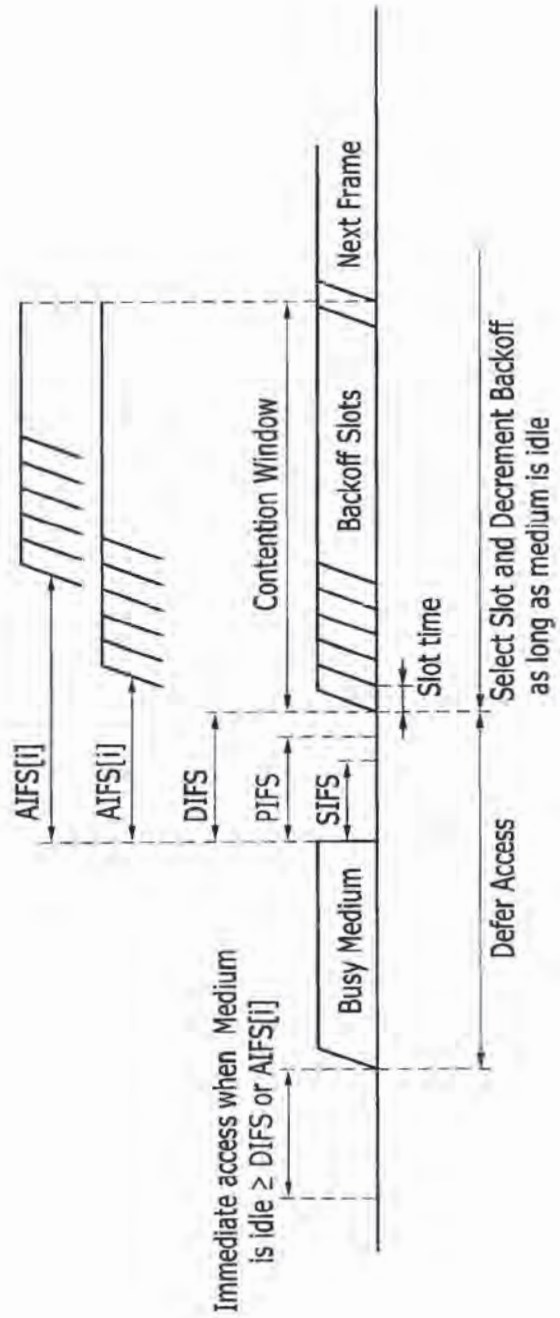
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FIG. 3



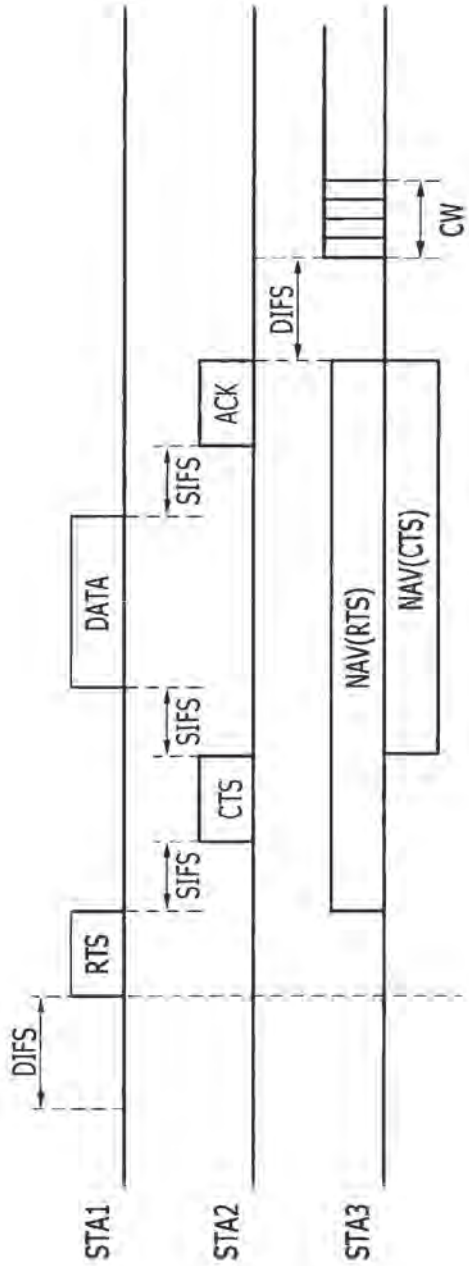
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FIG. 4



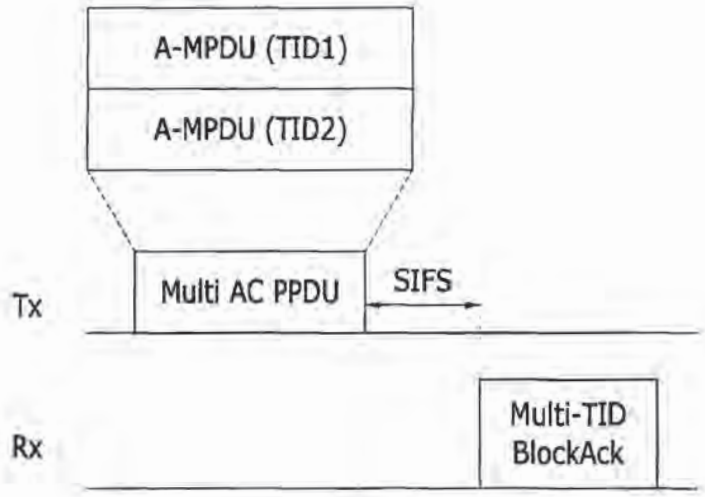
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FIG. 5



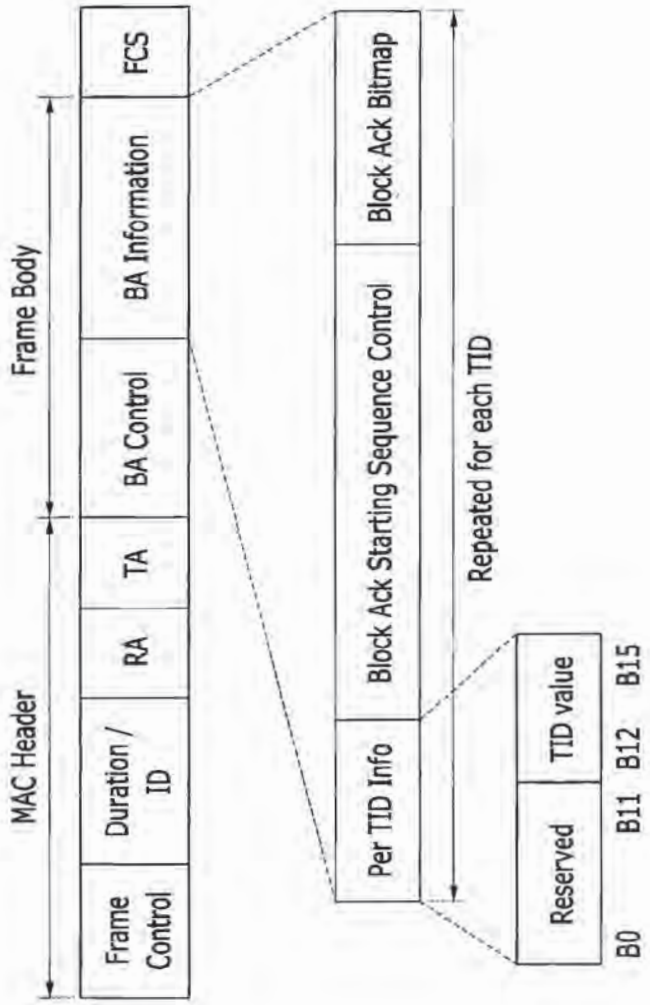
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FIG. 6



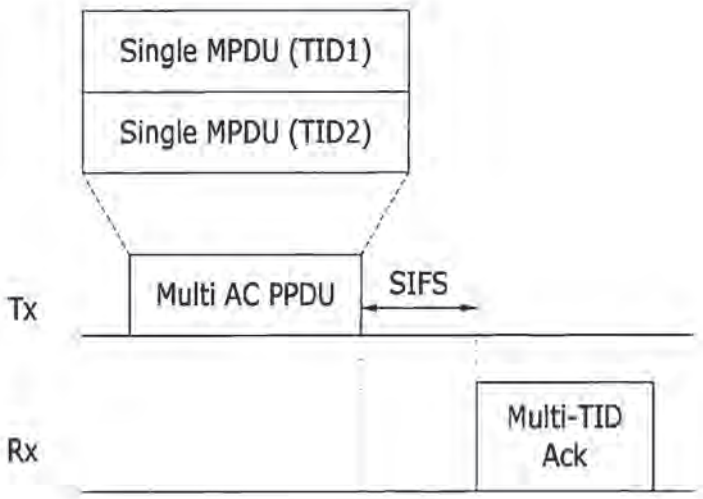
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FIG. 7



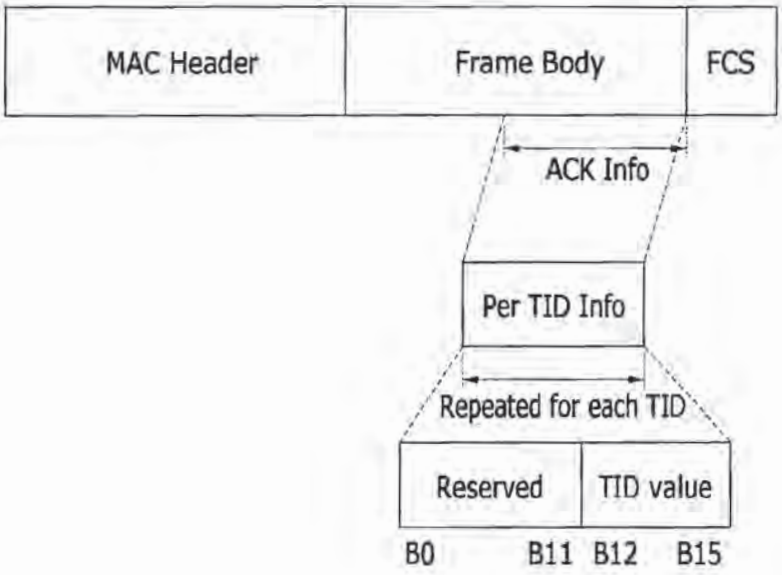
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FIG. 8



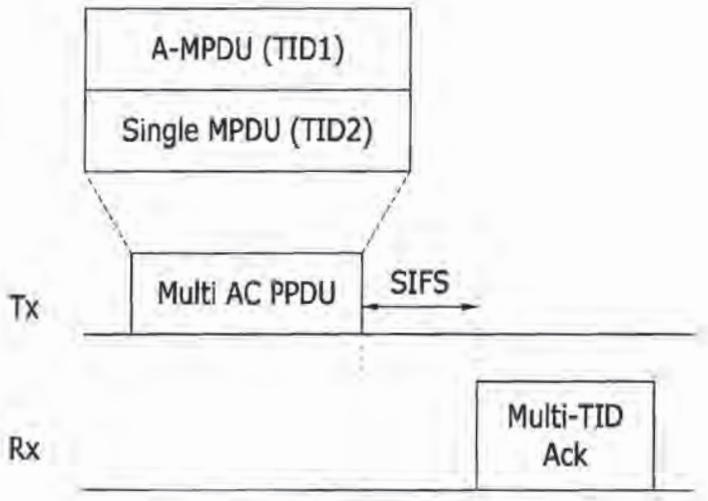
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FIG. 9



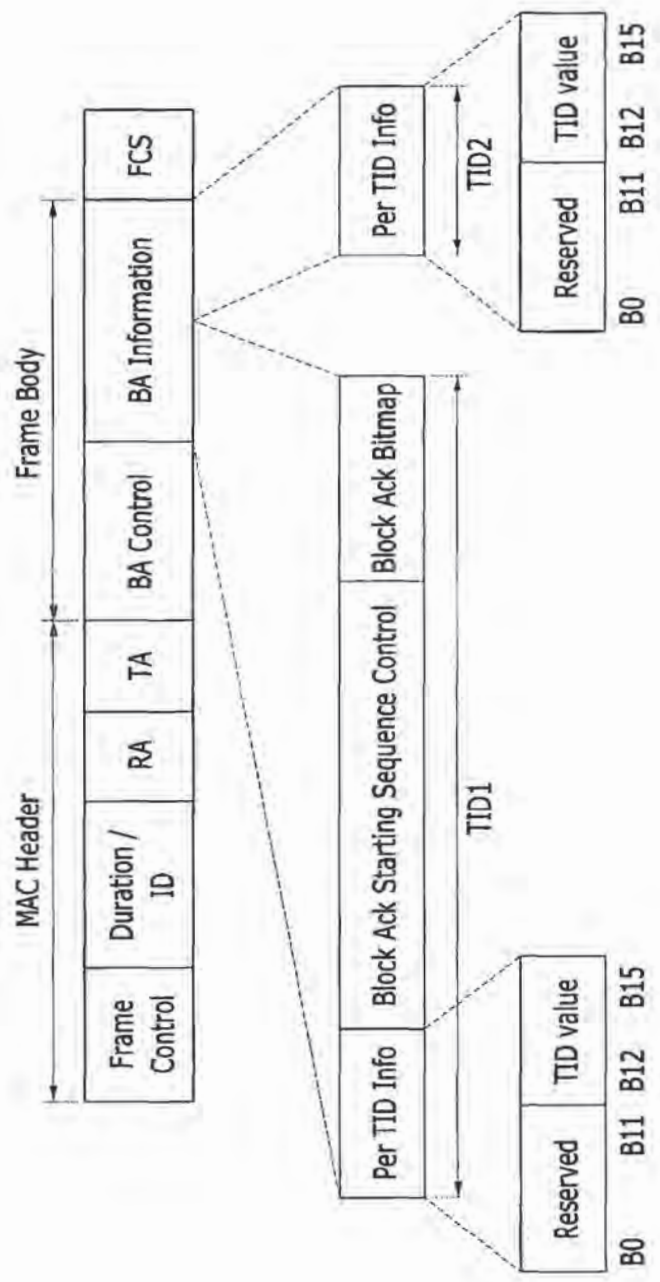
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FIG. 10



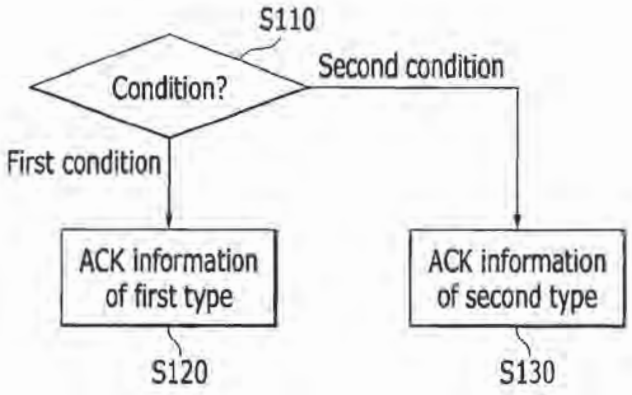
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FIG. 11



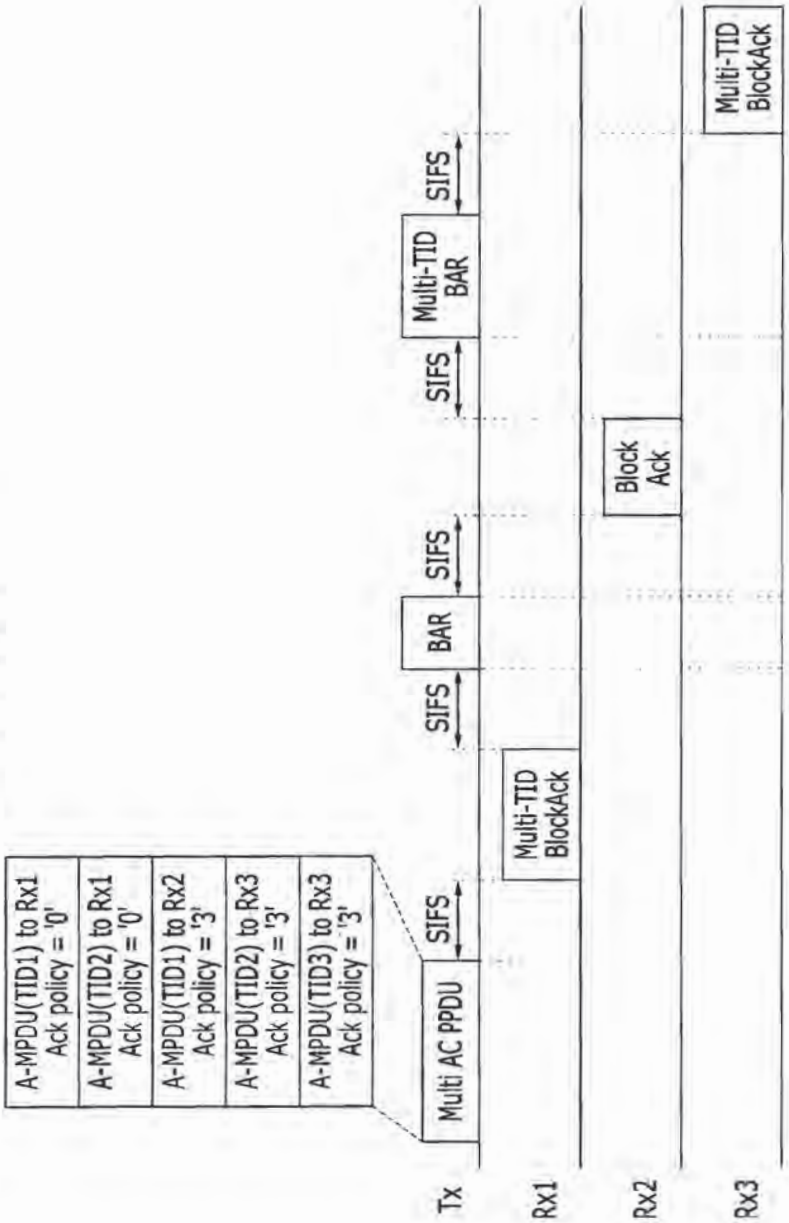
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FIG. 12



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FIG. 13



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FIG. 14

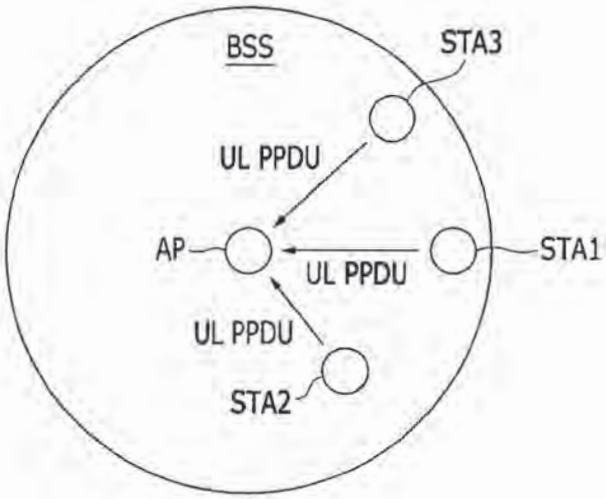
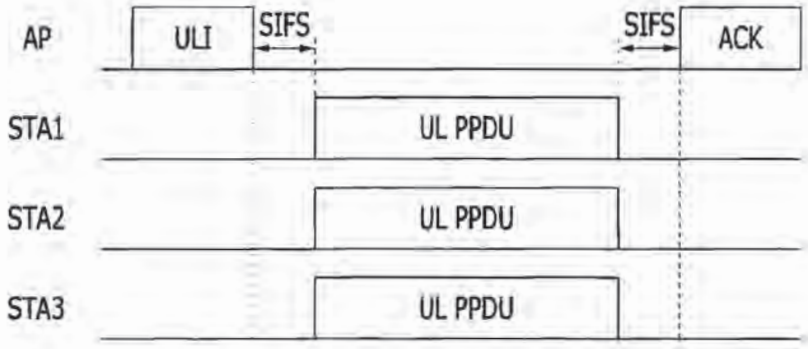
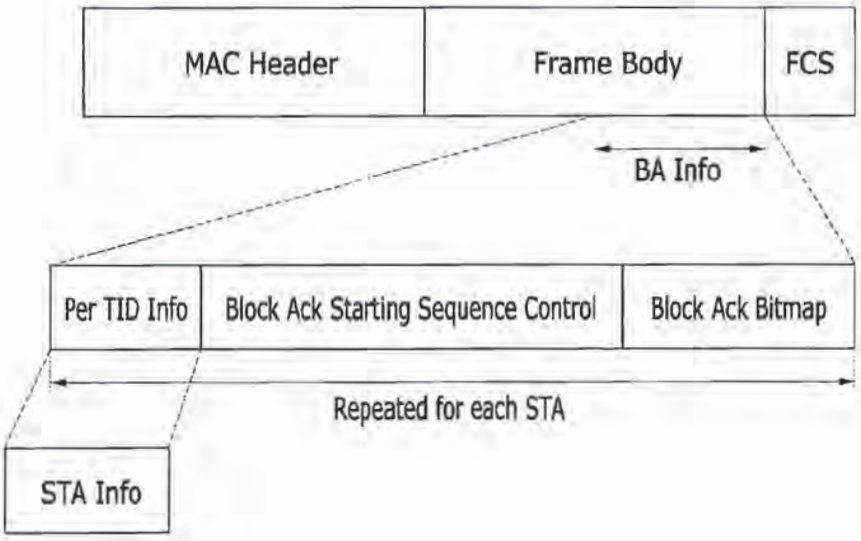


FIG. 15



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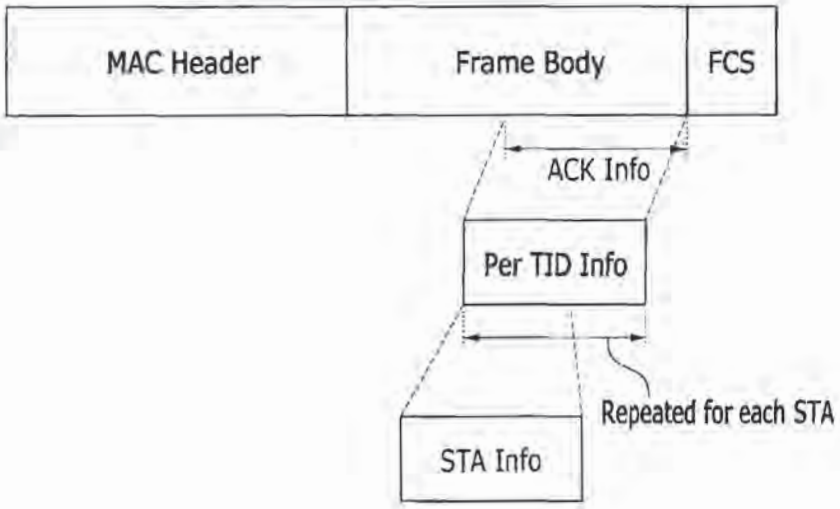
FIG. 16



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FIG. 17



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FIG. 18

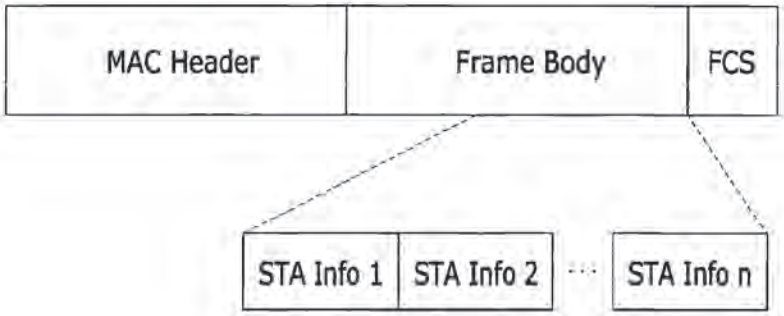
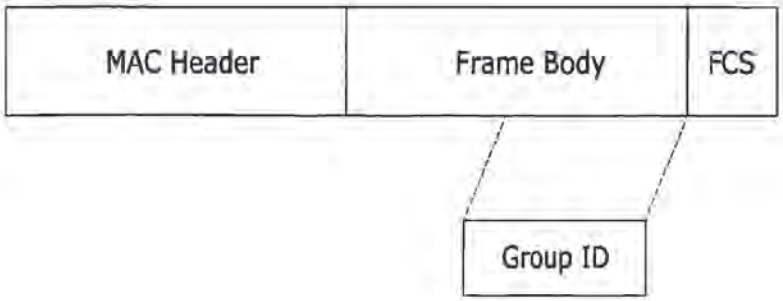
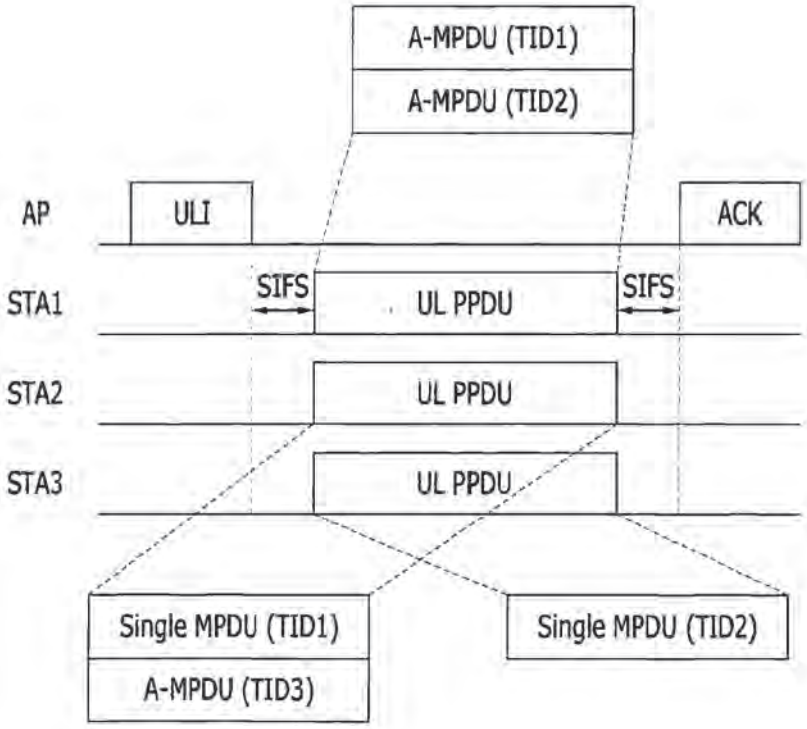


FIG. 19



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FIG. 20



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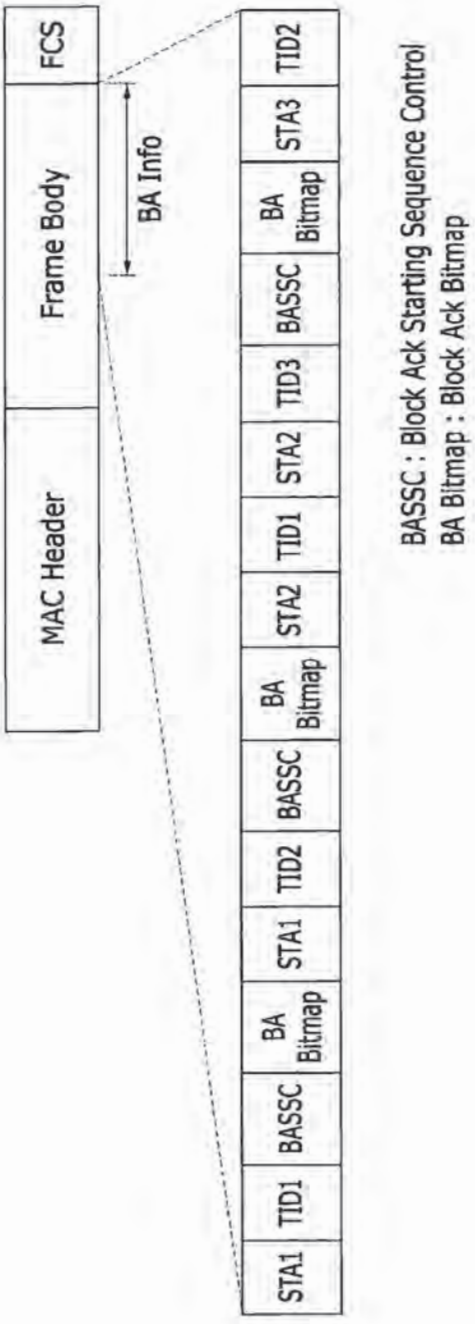


FIG. 21

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FIG. 22

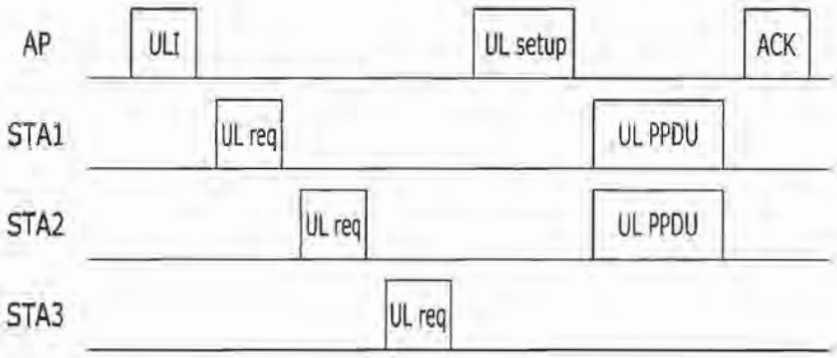
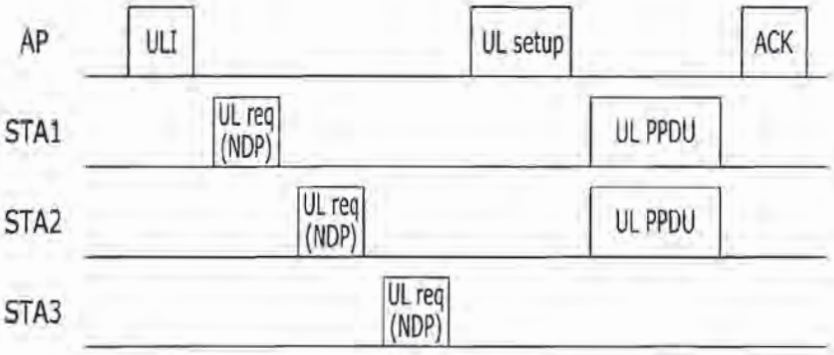
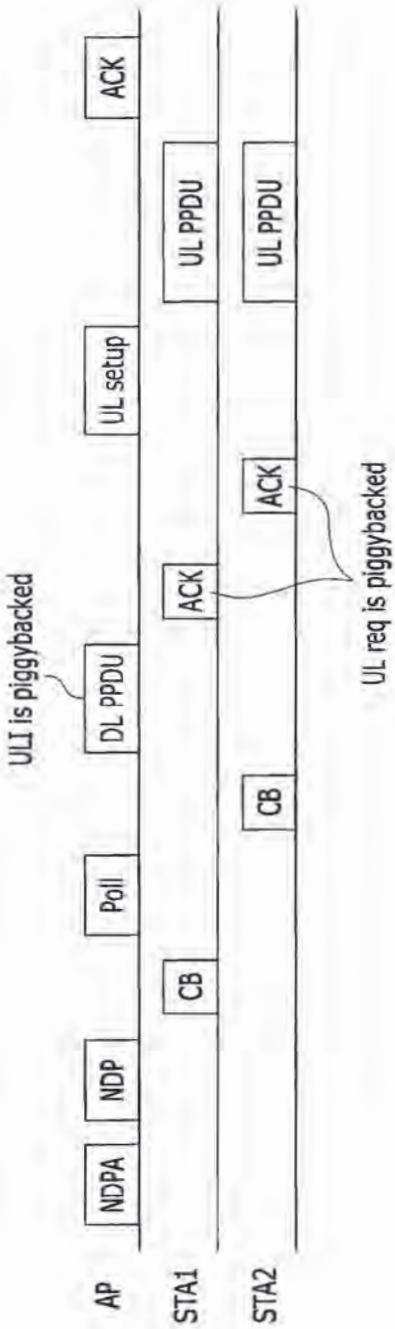


FIG. 23



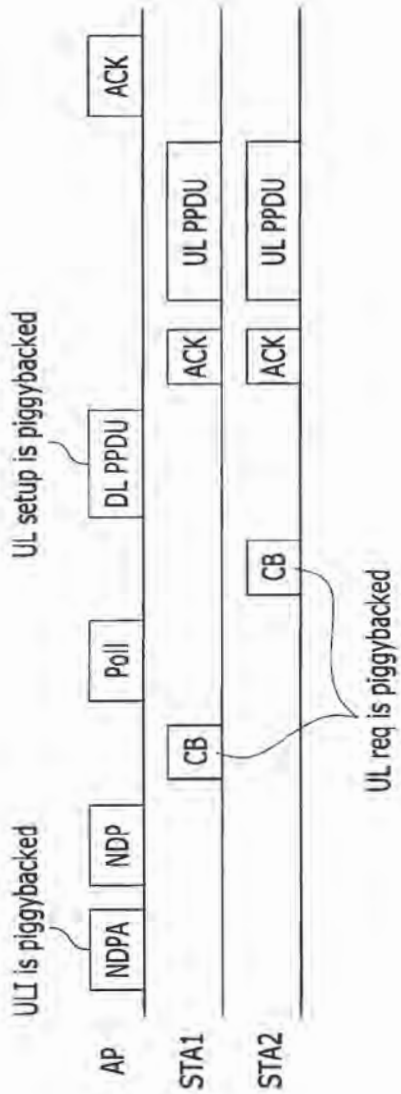
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FIG. 24



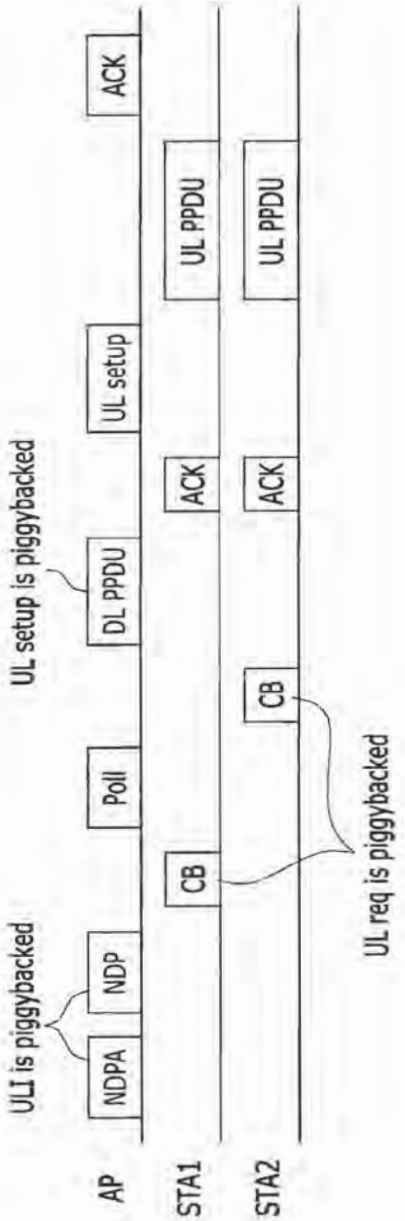
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FIG. 25



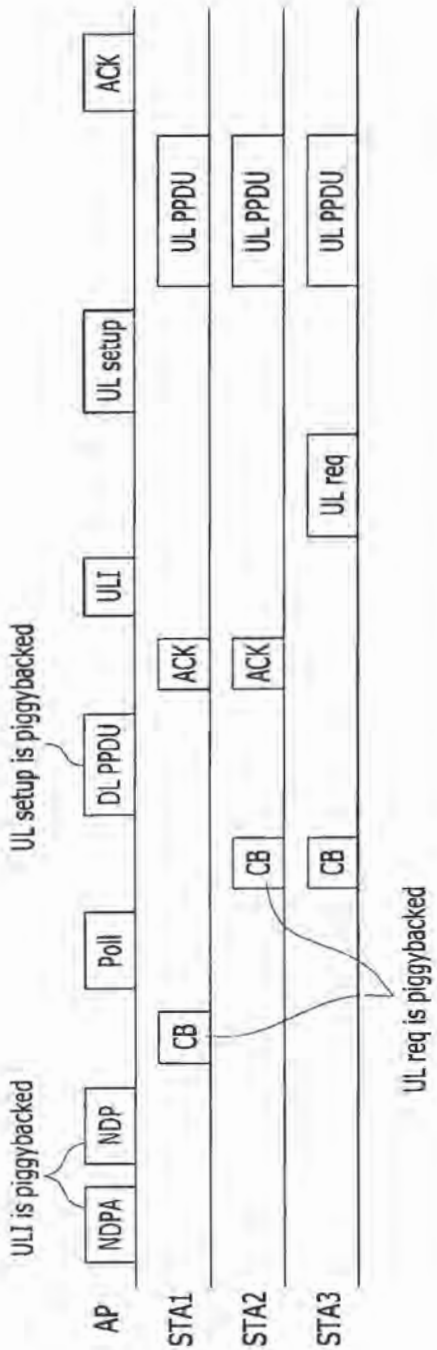
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FIG. 26



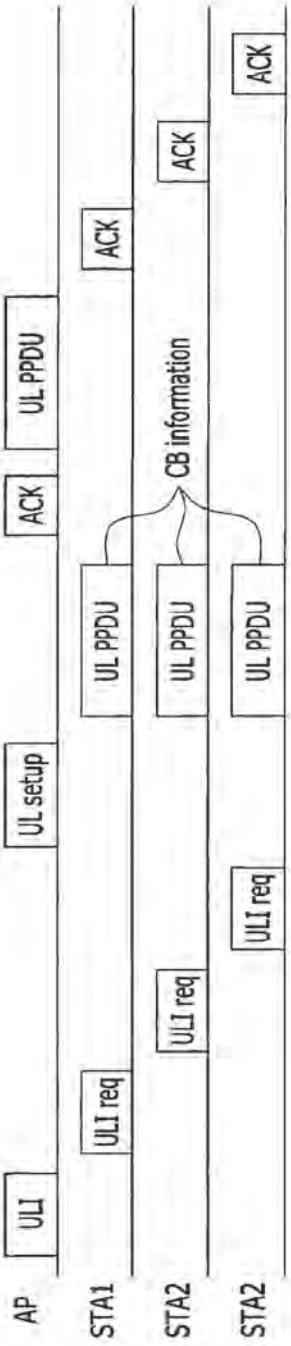
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FIG. 27



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FIG. 28



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ACKNOWLEDGEMENT METHOD AND MULTI USER TRANSMISSION METHOD

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority to and the benefit of U.S. Provisional Application Nos. 61/975,622 and 61/981,427, filed on Apr. 4, 2014 and Apr. 18, 2014 in the U.S. Patent and Trademark Office, the entire contents of which are incorporated herein by reference.

BACKGROUND

(a) Field

The described technology relates generally to an acknowledgement (ACK) method and an uplink multi-user transmission method. More particularly, the described technology relates generally to an acknowledgement (ACK) method and an uplink multi-user transmission method in a wireless local area network (WLAN).

(b) Description of the Related Art

In a WLAN, data are transmitted and received by using unlicensed band such as 2.4 GHz or 5 GHz. The WLAN is being standardized by the IEEE (Institute of Electrical and Electronics Engineers) Part 11 under the name of "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications."

After an original standard was published on 1999, new version standards are continuously published by amendments. The IEEE standard 802.11a (IEEE Std 802.11a-1999) supporting 2.4 GHz band was published on 1999, and the IEEE standard 802.11g (IEEE Std 802.11g-2003) supporting 5 GHz band was published on 2003. These standards are called legacy. Subsequently, the IEEE standard 802.11n (IEEE Std 802.11n-2009) for enhancements for higher throughput (HT) was published on 2009, and the IEEE standard 802.11ac (IEEE 802.11ac-2013) for enhancements for very high throughput (VHT) was published on 2013. Recently, a high efficiency WLAN (HEW) for enhancing the system throughput in high density scenarios is being developed by the IEEE 802.11 ax task group.

A multiple input multiple output (MIMO) has been introduced by the HT WLAN, and a downlink multi-user MIMO (MU-MIMO) has been introduced by the VHT WLAN. Accordingly, a transmitting device with multiple antennas can simultaneously transmit downlink data to a plurality of receiving devices. However, an uplink MU-MIMO has not been introduced by the previous WLANs, but the HEW or a later WLAN may use the uplink MU-MIMO such that a plurality of transmitting devices can simultaneously transmit data to a single receiving device.

The HEW or later WLAN may use a scheme such as an orthogonal frequency division multiple access (OFDMA) for simultaneously transmitting data to a plurality of devices or for data being simultaneously transmitted by the plurality of devices.

A single physical layer convergence procedure (PLCP) protocol data unit (PPDU) including MAC protocol data units (MPDUs) having a plurality of access categories (ACs) can be transmitted in the VHT WLAN. In this case, an MPDU corresponding to one AC is transmitted to a single receiving device. However, the single device may receive MPDUs having the plurality of ACs in the HEW or later WLAN.

As such, since the single device may simultaneously receive data from the plurality of devices or may receive data with the plurality of ACs in the HEW or later WLAN, an ACK procedure for the received data is required.

SUMMARY

An embodiment of the present invention provides an ACK method for acknowledging data received from a plurality of devices or data with a plurality of ACs and an uplink multi-user transmission method for transmitting uplink data by a plurality of devices.

According to another embodiment, a method of receiving an ACK is provided by a first transmitting device in a WLAN. The method includes transmitting a first data unit having a first traffic identifier (TID) when a plurality of data units, having a plurality of TIDs respectively, are transmitted by a plurality of transmitting devices including the first transmitting device. The method further includes receiving an ACK frame including a plurality of ACK information fields for at least part of the plurality of data units. When the first data unit satisfies a first condition, an ACK information field for the first data unit among the plurality of ACK information fields includes the first TID and a block ACK bitmap indicating whether the first data unit has been successfully received. When the first data unit satisfies a second condition and has been successfully received, an ACK information field for the first data unit among the plurality of ACK information fields includes the first TID and does not include a block ACK bitmap.

The first condition may be a condition that a data unit includes no single MAC (medium access protocol) protocol data unit (MPDU), and the second condition may be a condition that a data unit includes a single MPDU.

An ACK information field for a data unit satisfying the first condition among the plurality of ACK information fields may further include block ACK starting sequence control information. The block ACK starting sequence control information may indicate a sequence number of the first MPDU among a plurality of MPDUs included in the data unit, and a plurality of bits in the block ACK bitmap may indicate whether the plurality of MPDUs have been successfully received in an order of sequence number.

The ACK frame may further include identification information of the plurality of transmitting devices.

The identification information of each transmitting device may be included in a corresponding ACK information field among the plurality of ACK information fields.

When the first data unit satisfies the second condition and has been not successfully received, the ACK frame may not include the first TID.

According to yet another embodiment, an ACK receiving apparatus of a first transmitting device is provided in a WLAN. The ACK receiving apparatus includes a processor and a transceiver. The processor generates a first data unit having a first TID. The transceiver transmits the first data unit when a plurality of data units, having a plurality of TIDs respectively, are transmitted by a plurality of transmitting devices including the first transmitting device. The transceiver receives an ACK frame including a plurality of ACK information fields for at least part of the plurality of data units. When the first data unit satisfies a first condition, an ACK information field for the first data unit among the plurality of ACK information fields includes the first TID and a block ACK bitmap indicating whether the first data unit has been successfully received. When the first data unit satisfies a second condition and has been successfully received, an ACK information field for the first data unit

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among the plurality of ACK information fields includes the first TID and does not include a block ACK bitmap.

According to yet another embodiment of the present invention, an ACK method is provided by a receiving device in a WLAN. The method includes receiving a plurality of data units having a plurality of TIDs respectively, and transmitting an ACK frame including a plurality of ACK information fields for at least part of the plurality of data units. An ACK information field for a data unit satisfying a first condition among the plurality of ACK information fields includes a TID and a block ACK bitmap indicating whether the data unit has been successfully received. An ACK information field for a data unit satisfying a second condition and having been successfully received among the plurality of ACK information fields includes the first TID and does not include a block ACK bitmap.

The first condition may be a condition that a data unit includes no MPDU, and the second condition may be a condition that a data unit includes a single MPDU.

The ACK information field for the data unit satisfying the first condition among the plurality of ACK information fields may further include block ACK starting sequence control information. The block ACK starting sequence control information may indicate a sequence number of the first MPDU among a plurality of MPDUs included in the data unit, and a plurality of bits in the block ACK bitmap may indicate whether the plurality of MPDUs have been successfully received in an order of sequence number.

Receiving the plurality of data units may include receiving the plurality of data units from the plurality of transmitting devices, respectively.

The ACK frame may further include identification information of the plurality of transmitting devices.

The identification information of each transmitting device may be included in a corresponding ACK information field among the plurality of ACK information fields.

The ACK frame may not include a TID of a data unit satisfying the second condition and having been not successfully received.

According to still another embodiment of the present invention, an ACK apparatus of a receiving device is provided in a WLAN. The ACK apparatus includes a processor and a transceiver. The transceiver receives a plurality of data units having a plurality of TIDs respectively, and transmits an ACK frame. The processor generates the ACK frame including a plurality of ACK information fields for at least part of the plurality of data units. An ACK information field for a data unit satisfying a first condition among the plurality of ACK information fields includes a TID and a block ACK bitmap indicating whether the data unit has been successfully received. An ACK information field for a data unit satisfying a second condition and having been successfully received among the plurality of ACK information fields includes the first TID and does not include a block ACK bitmap.

According to further embodiment of the present invention, a method of receiving an ACK is provided by a transmitting device in a WLAN. The method includes transmitting a data unit having a TID and receiving an AKC frame including an ACK information field. When the data unit satisfies a first condition, the ACK information field includes the TID and a block ACK bitmap indicating whether the data unit has been successfully received. When the data unit satisfies a second condition and has been successfully received, the ACK information includes the TID and does not include a block ACK bitmap.

The first condition may be a condition that the data unit includes no single MPDU, and the second condition may be a condition that the data unit includes a single MPDU.

When the ACK information field satisfies the first condition, the ACK information field may further include block ACK starting sequence control information. The block ACK starting sequence control information may indicate a sequence number of the first MPDU among a plurality of MPDUs included in the data unit, and a plurality of bits in the block ACK bitmap may indicate whether the plurality of MPDUs have been successfully received in an order of sequence number.

The ACK frame may further include identification information of the transmitting device.

According to further embodiment of the present invention, an ACK receiving apparatus of a transmitting device is provided in a WLAN. The ACK receiving apparatus includes a processor and a transceiver. The processor generates a data unit having a TID. The transceiver transmits the data unit and receives an AKC frame including an ACK information field. When the data unit satisfies a first condition, the ACK information field includes the TID and a block ACK bitmap indicating whether the data unit has been successfully received. When the data unit satisfies a second condition and has been successfully received, the ACK information includes the TID and does not include a block ACK bitmap.

According to further embodiment of the present invention, an ACK method is provided by a receiving device in a WLAN. The method includes receiving a data unit having a TID and transmitting an ACK frame including an ACK information field. When the data unit satisfies a first condition, the ACK information field includes the TID and a block ACK bitmap indicating whether the data unit has been successfully received. When the data unit satisfies a second condition and has been successfully received, the ACK information includes the TID and does not include a block ACK bitmap.

The first condition may be a condition that the data unit includes no MPDU, and the second condition may be a condition that the data unit includes a single MPDU.

When the ACK information field satisfies the first condition, the ACK information field may further include block ACK starting sequence control information. The block ACK starting sequence control information may indicate a sequence number of the first MPDU among a plurality of MPDUs included in the data unit, and a plurality of bits in the block ACK bitmap may indicate whether the plurality of MPDUs have been successfully received in an order of sequence number.

The ACK frame may further include identification information of the transmitting device.

According to further embodiment of the present invention, an ACK apparatus of a receiving device is provided in a WLAN. The ACK apparatus includes a processor and a transceiver. The transceiver receives a data unit having a TID and transmits an ACK frame. The processor generates the ACK frame including an ACK information field. When the data unit satisfies a first condition, the ACK information field includes the TID and a block ACK bitmap indicating whether the data unit has been successfully received. When the data unit satisfies a second condition and has been successfully received, the ACK information includes the TID and does not include a block ACK bitmap.

According to further embodiment of the present invention, a multi-user transmission method is provided by an access point in a WLAN. The method includes transmitting

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an initiation frame indicating an initiation of uplink multi-user transmission, receiving a plurality of data frames from a plurality of stations, respectively, and transmitting an ACK frame indicating whether the plurality of data frames have been successfully received.

The initiation frame, the data frames, and the ACK frame may be transmitted on an unlicensed band.

An interval between temporally consecutive frames in a plurality of frames including the initiation frame, the data frames, and the ACK frame may be an SIFS (short inter-frame space) interval defined in a WLAN standard.

The ACK frame may include information for identifying each station and a block ACK bitmap for indicating whether the data frame transmitted by each station has been successfully received, and the block ACK bitmap may be provided for each station.

The ACK frame may further include block ACK starting sequence control information for each station. The block ACK starting sequence control information may indicate a sequence number of the first MPDU among a plurality of MPDUs included in a data frame transmitted by a corresponding station, and each bit in the block ACK bitmap may indicate whether the MPDU has successfully received in an order of sequence number.

The ACK frame may further include information for identifying a station that has transmitted a data frame which has been successfully received from among the plurality of stations.

The method may further include sequentially receiving request frame including feedback information from the plurality of stations as a response of the initiation frame, and transmitting a setup frame including setup information for the uplink multi-user transmission to at least part of the plurality of stations as a response of the request frame.

The feedback information may include transmission power information.

The setup information may include information that is common to the at least part of the plurality of stations and dedicate information that is specific to each of the at least part of the plurality of stations, for the uplink multi-user transmission.

According to further embodiment of the present invention, a multi-user transmission apparatus of an access point is provided in a WLAN. The multi-user transmission apparatus includes a processor and a transceiver. The transceiver received a plurality of data frames and transmits an ACK frame. The transceiver transmits an initiation frame indicating an initiation of uplink multi-user transmission, and receives a plurality of data frames from a plurality of stations, respectively. The processor generates an ACK frame indicating whether the plurality of data frames have been successfully received, and the transceiver transmits the ACK frame.

According to further embodiment of the present invention, a multi-user transmission method is provided by a station in a WLAN. The method includes receiving an initiation frame indicating an initiation of uplink multi-user transmission, transmitting a data frame, and receiving an ACK frame indicating whether a plurality of data frames including the data frame have been successfully received. The plurality of data frames are transmitted by a plurality of stations including the station, respectively.

According to further embodiment of the present invention, an ACK apparatus of a station is provided in a WLAN. The ACK apparatus includes a processor and a transceiver. The transceiver receives an initiation frame indicating an initiation of uplink multi-user transmission, and the processor generates a data frame. The transceiver transmits the data frame, and receives an ACK frame indicating whether a plurality of data frames including the data frame have been successfully received. The plurality of data frames are transmitted by a plurality of stations including the station, respectively.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic block diagram exemplifying a WLAN device.

FIG. **2** is a schematic block diagram exemplifying a transmitting signal processor in a WLAN.

FIG. **3** is a schematic block diagram exemplifying a receiving signal processing unit in the WLAN.

FIG. **4** exemplifies IFS relationships.

FIG. **5** is a schematic diagram explaining CSMA/CA based frame transmission procedure for avoiding collision between frames in a channel.

FIG. **6**, FIG. **8**, and FIG. **10** exemplify an ACK procedure in a wireless communication network according to embodiments of the present invention.

FIG. **7**, FIG. **9**, and FIG. **11** exemplify an ACK frame in a wireless communication network according to embodiments of the present invention.

FIG. **12** is a flowchart exemplifying information selection of an ACK frame in a wireless communication network according to an embodiment of the present invention.

FIG. **13** exemplifies an ACK procedure in a wireless communication network according to another embodiment of the present invention.

FIG. **14** shows an example of a wireless communication network according to another embodiment of the present invention.

FIG. **15** exemplifies a UL MU transmission procedure in a wireless communication network according to another embodiment of the present invention.

FIG. **16** and FIG. **17** exemplify an ACK frame in a wireless communication network according to embodiments of the present invention.

FIG. **18** and FIG. **19** exemplify a UL initiation frame in a wireless communication network according to embodiments of the present invention.

FIG. **20** exemplifies a UL MU transmission procedure in a wireless communication network according to yet another embodiment of the present invention.

FIG. **21** exemplifies an ACK frame in a wireless communication network according to yet another embodiment of the present invention.

FIG. **22**, FIG. **23**, FIG. **24**, FIG. **25**, FIG. **26**, FIG. **27**, and FIG. **28** exemplify a UL MU procedure in a wireless communication network according to various embodiments of the present invention.

DETAILED DESCRIPTION OF THE EMBODIMENTS

In the following detailed description, only certain embodiments of the present invention have been shown and described, simply by way of illustration. As those skilled in the art would realize, the described embodiments may be modified in various different ways, all without departing from the spirit or scope of the present invention. Accordingly, the drawings and description are to be regarded as illustrative in nature and not restrictive. Like reference numerals designate like elements throughout the specification.

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In a wireless local area network (WLAN), a basic service set (BSS) includes a plurality of WLAN devices. The WLAN device may include a medium access control (MAC) layer and a physical (PHY) layer according to the IEEE (Institute of Electrical and Electronics Engineers) standard 802.11. The plurality of WLAN devices may include a WLAN device that is an access point and the other WLAN devices that are non-AP stations (non-AP STAs). Alternatively, all the plurality of WLAN devices may be non-AP STAs in Ad-hoc networking. In general, the AP STA and the non-AP STA may be collectively called the STA. However, for easy description, only the non-AP STA may be called the STA.

FIG. **1** is a schematic block diagram exemplifying a WLAN device.

Referring to FIG. **1**, the WLAN device **1** includes a baseband processor **10**, a radio frequency (RF) transceiver **20**, an antenna unit **30**, a memory **40**, an input interface unit **50**, an output interface unit **60**, and a bus **70**.

The baseband processor **10** performs baseband signal processing, and includes a MAC processor **11** and a PHY processor **15**.

In one embodiment, the MAC processor **11** may include a MAC software processing unit **12** and a MAC hardware processing unit **13**. The memory **40** may store software (hereinafter referred to as "MAC software") including at least some functions of the MAC layer. The MAC software processing unit **12** executes the MAC software to implement the some functions of the MAC layer, and the MAC hardware processing unit **13** may implement remaining functions of the MAC layer as hardware (hereinafter referred to "MAC hardware"). However, the MAC processor **11** is not limited to this.

The PHY processor **15** includes a transmitting signal processing unit **100** and a receiving signal processing unit **200**.

The baseband processor **10**, the memory **40**, the input interface unit **50**, and the output interface unit **60** may communicate with each other via the bus **70**.

The RF transceiver **20** includes an RF transmitter **21** and an RF receiver **22**.

The memory **40** may further store an operating system and applications. The input interface unit **50** receives information from a user, and the output interface unit **60** outputs information to the user.

The antenna unit **30** includes one or more antennas. When multiple-input multiple-output (MIMO) or multi-user MIMO (MU-MIMO) is used, the antenna unit **30** may include a plurality of antennas.

FIG. **2** is a schematic block diagram exemplifying a transmitting signal processor in a WLAN.

Referring to FIG. **2**, a transmitting signal processing unit **100** includes an encoder **110**, an interleaver **120**, a mapper **130**, an inverse Fourier transformer (IFT) **140**, and a guard interval (GI) inserter **150**.

The encoder **110** encodes input data. For example, the encoder **100** may be a forward error correction (FEC) encoder. The FEC encoder may include a binary convolutional code (BCC) encoder followed by a puncturing device, or may include a low-density parity-check (LDPC) encoder.

The transmitting signal processing unit **100** may further include a scrambler for scrambling the input data before the encoding to reduce the probability of long sequences of 0s or 1s. If BCC encoding is used in the encoder, the transmitting signal processing unit **100** may further include an encoder parser for demultiplexing the scrambled bits among a plurality of BCC encoders. If LDPC encoding is used in the encoder, the transmitting signal processing unit **100** may not use the encoder parser.

The interleaver **120** interleaves the bits of each stream output from the encoder to change order of bits. Interleaving may be applied only when BCC encoding is used. The mapper **130** maps the sequence of bits output from the interleaver to constellation points. If the LDPC encoding is used in the encoder, the mapper **130** may further perform LDPC tone mapping besides the constellation mapping.

When the MIMO or the MU-MIMO is used, the transmitting signal processing unit **100** may use a plurality of interleavers **120** and a plurality of mappers corresponding to the number of N_{SS} of spatial streams. In this case, the transmitting signal processing unit **100** may further include a stream parser for dividing outputs of the BCC encoders or the LDPC encoder into blocks that are sent to different interleavers **120** or mappers **130**. The transmitting signal processing unit **100** may further include a space-time block code (STBC) encoder for spreading the constellation points from the N_{SS} spatial streams into N_{STS} space-time streams and a spatial mapper for mapping the space-time streams to transmit chains. The spatial mapper may use direct mapping, spatial expansion, or beamforming.

The IFT **140** converts a block of the constellation points output from the mapper **130** or the spatial mapper to a time domain block (i.e., a symbol) by using an inverse discrete Fourier transform (IDFT) or an inverse fast Fourier transform (IFFT). If the STBC encoder and the spatial mapper are used, the inverse Fourier transformer **140** may be provided for each transmit chain.

When the MIMO or the MU-MIMO is used, the transmitting signal processing unit **100** may insert cyclic shift diversities (CSDs) to prevent unintentional beamforming. The CSD insertion may occur before or after the inverse Fourier transform. The CSD may be specified per transmit chain or may be specified per space-time stream. Alternatively, the CSD may be applied as a part of the spatial mapper.

When the MU-MIMO is used, some blocks before the spatial mapper may be provided for each user.

The GI inserter **150** prepends a GI to the symbol. The transmitting signal processing unit **100** may optionally perform windowing to smooth edges of each symbol after inserting the GI. The RF transmitter **21** converts the symbols into an RF signal and transmits the RF signal via the antenna unit **30**. When the MIMO or the MU-MIMO is used, the GI inserter **150** and the RF transmitter **21** may be provided for each transmit chain.

FIG. **3** is a schematic block diagram exemplifying a receiving signal processing unit in the WLAN.

Referring to FIG. **3**, a receiving signal processing unit **200** includes a GI remover **220**, a Fourier transformer (FT) **230**, a demapper **240**, a deinterleaver **250**, and a decoder **260**.

An RF receiver **22** receives an RF signal via the antenna unit **30** and converts the RF signal into the symbols. The GI remover **220** removes the GI from the symbol. When the MIMO or the MU-MIMO is used, the RF receiver **22** and the GI remover **220** may be provided for each receive chain.

The FT **230** converts the symbol (i.e., the time domain block) into a block of the constellation points by using a discrete Fourier transform (DFT) or a fast Fourier transform (FFT). The Fourier transformer **230** may be provided for each receive chain.

When the MIMO or the MU-MIMO is used, the receiving signal processing unit **200** may a spatial demapper for converting the Fourier transformed receiver chains to con-

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stellation points of the space-time streams, and an STBC decoder for despreading the constellation points from the space-time streams into the spatial streams.

The demapper **240** demaps the constellation points output from the Fourier transformer **230** or the STBC decoder to the bit streams. If the LDPC encoding is used, the demapper **240** may further perform LDPC tone demapping before the constellation demapping. The deinterleaver **250** deinterleaves the bits of each stream output from the demapper **240**. Deinterleaving may be applied only when BCC encoding is used.

When the MIMO or the MU-MIMO is used, the receiving signal processing unit **200** may use a plurality of demappers **240** and a plurality of deinterleavers **250** corresponding to the number of spatial streams. In this case, the receiving signal processing unit **200** may further include a stream deparser for combining the streams output from the deinterleavers **250**.

The decoder **260** decodes the streams output from the deinterleaver **250** or the stream deparser. For example, the decoder **100** may be an FEC decoder. The FEC decoder may include a BCC decoder or an LDPC decoder. The receiving signal processing unit **200** may further include a descrambler for descrambling the decoded data. If BCC decoding is used in the decoder, the receiving signal processing unit **200** may further include an encoder deparser for multiplexing the data decoded by a plurality of BCC decoders. If LDPC decoding is used in the decoder, the receiving signal processing unit **100** may not use the encoder deparser.

FIG. **4** exemplifies interframe space (IFS) relationships.

A data frame, a control frame, or a management frame may be exchanged between WLAN devices.

The data frame is used for transmission of data forwarded to a higher layer. The WLAN device transmits the data frame after performing backoff if a distributed coordination function IFS (DIFS) has elapsed from a time when the medium has been idle. The management frame is used for exchanging management information which is not forwarded to the higher layer. Subtype frames of the management frame include a beacon frame, an association request/response frame, a probe request/response frame, and an authentication request/response frame. The control frame is used for controlling access to the medium. Subtype frames of the control frame include a request to send (RTS) frame, a clear to send (CTS) frame, and an acknowledgement (ACK) frame. In the case that the control frame is not a response frame of the other frame, the WLAN device transmits the control frame after performing backoff if the DIFS has elapsed. In the case that the control frame is the response frame of the other frame, the WLAN device transmits the control frame without performing backoff if a short IFS (SIFS) has elapsed. The type and subtype of frame may be identified by a type field and a subtype field in a frame control field.

On the other hand, a Quality of Service (QoS) STA may transmit the frame after performing backoff if an arbitration IFS (AIFS) for access category (AC), i.e., AIFS[AC], has elapsed. In this case, the data frame, the management frame, or the control frame which is not the response frame may use the AIFC[AC].

FIG. **5** is a schematic diagram explaining a CSMA (carrier sense multiple access)/CA (collision avoidance) based frame transmission procedure for avoiding collision between frames in a channel.

Referring to FIG. **5**, STA**1** is a transmit WLAN device for transmitting data, STA**2** is a receive WLAN device for receiving the data, and STA**3** is a WLAN device which may be located at an area where a frame transmitted from the STA**1** and/or a frame transmitted from the STA**2** can be received by the WLAN device.

The STA**1** may determine whether the channel is busy by carrier sensing. The STA**1** may determine the channel occupation based on an energy level on the channel or correlation of signals in the channel, or may determine the channel occupation by using a network allocation vector (NAV) timer.

When determining that the channel is not used by other devices during DIFS (that is, the channel is idle), the STA**1** may transmit an RTS frame to the STA**2** after performing backoff. Upon receiving the RTS frame, the STA**2** may transmit a CTS frame as a response of the CTS frame after SIFS.

When the STA**3** receives the RTS frame, it may set the NAV timer for a transmission duration of subsequently transmitted frames (for example, a duration of SIFS+CTS frame duration+SIFS+data frame duration+SIFS+ACK frame duration) by using duration information included in the RTS frame. When the STA**3** receives the CTS frame, it may set the NAV timer for a transmission duration of subsequently transmitted frames (for example, a duration of SIFS+data frame duration+SIFS+ACK frame duration) by using duration information included in the RTS frame. Upon receiving a new frame before the NAV timer expires, the STA**3** may update the NAV timer by using duration information included in the new frame. The STA**3** does not attempt to access the channel until the NAV timer expires.

When the STA**1** receives the CTS frame from the STA**2**, it may transmit a data frame to the STA**2** after SIFS elapses from a time when the CTS frame has been completely received. Upon successfully receiving the data frame, the STA**2** may transmit an ACK frame as a response of the data frame after SIFS elapses.

When the NAV timer expires, the STA**3** may determine whether the channel is busy by the carrier sensing. Upon determining that the channel is not used by the other devices during DIFS after the NAV timer has expired, the STA**3** may attempt the channel access after a contention window according to random backoff elapses.

Now, a signaling method in a wireless communication network according to various embodiments of the present invention is described with reference to the drawings.

FIG. **6**, FIG. **8**, and FIG. **10** exemplify an ACK procedure in a wireless communication network according to embodiments of the present invention, and FIG. **7**, FIG. **9**, and FIG. **11** exemplify an ACK frame in a wireless communication network according to embodiments of the present invention.

Referring to FIG. **6**, FIG. **8**, and FIG. **10**, a transmitting device transmits a PHY frame, for example a PLCP (physical layer convergence procedure) protocol data unit (PPDU).

The PPDU is a multi-AC PPDU corresponding to a plurality of access categories (ACs). The multi-AC PPDU includes a plurality of aggregate MAC protocol data units (A-MPDUs) that correspond to the plurality of ACs, respectively. Each A-MPDU may include a single MPDU or may include a plurality of MPDUs. One example of the single MPDU may be a VHT single MPDU defined in the IEEE Std 802.11ac. In the IEEE Std 802.11ac, an MPDU that is the only MPDU in an A-MPDU and is carried in an A-MPDU with an end-of-frame (EOF) subfield set to 1 is called a "VHT single MPDU." In one embodiment, the multi-AC PPDU may, as shown in FIG. **6**, include a plurality of A-MPDUs each including no single MPDU. In another embodiment, the multi-AC PPDU may, as shown in FIG. **8**, include a plurality of A-MPDUs each including a single MPDU. In yet another embodiment, the multi-AC PPDU

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may, as shown in FIG. **10**, include a plurality of A-MPDUs. The plurality of A-MPDUs includes an A-MPDU including a single MPDU and an A-MPDU including no single MPDU.

In some embodiments, the AC corresponds to a traffic identifier (TID). The TID associates the MPDU with an appropriate AC. Hereinafter, the AC is described as the TID for convenience.

Referring to FIG. **6** again, a transmitting device may transmit a PPDU including A-MPDUs for the plurality of ACs. FIG. **6** shows an example where the PPDU includes an A-MPDU to which "TID1" is assigned as the TID and an A-MPDU to which "TID2" is assigned as the TID. A receiving device receiving the PPDU transmits an ACK frame to the transmitting device after a predetermined IFS interval. The predetermined IFS may be an SIFS. Alternatively, the predetermined IFS may be an IFS having the different duration from the SIFS.

As shown in FIG. **7**, the ACK frame is defined by using a multi-TID block ACK frame format that is defined for a power save multi-poll operation in the HT WLAN.

Referring to FIG. **7**, the ACK frame includes an MAC header, a frame body field, and a frame check sequence (FCS) field like the multi-TID block ACK frame defined in the HT WLAN.

The MAC header includes an address field, and the address field may include a transmitter address (TA) field and a receiver address (RA) field. The MAC header may further include a frame control field and a duration/ID field. The FCS field includes a cyclic redundancy check (CRC). Since the MAC header and the FCS field are fields included in a control frame of a previous WLAN, detailed descriptions thereof are omitted.

The frame body field includes a block ACK (BA) information field. The BA information field has a variable length according to the number of TIDs and includes an information per TID (per TID info) subfield, a block ACK starting sequence control subfield, and a block ACK bitmap subfield, for each TID. The information per TID subfield, the block ACK starting sequence control subfield, and the block ACK bitmap subfield are repeated for each TID.

The information per TID subfield indicates a value of a corresponding TID. The information per TID subfield may have two octets whose first 12 bits B**0**-B**11** are reserved and last 4 bits B**12**-B**15** indicate the TID value.

The block ACK starting sequence control subfield includes a starting sequence number subfield. The starting sequence number subfield indicates a sequence number of the first MPDU, i.e., a MSDU or an aggregate MSDU (A-MSDU) included in the first MPDU, for which the ACK frame is sent. The block ACK starting sequence control subfield may have two octets whose last 12 bits B**4**-B**15** correspond to the starting sequence number subfield. The first 4 bits B**0**-B**3** of the block ACK starting sequence control subfield may correspond to a fragment number subfield set to 0.

The block ACK bitmap subfield includes a block ACK bitmap. Each bit that is equal to 1 in the block ACK bitmap acknowledges successful reception of an MPDU in the order of sequence number. The first bit of the Block ACK bitmap corresponds to the MPDU with the sequence number that matches the starting sequence number of the block ACK starting sequence control subfield. The bit position n of the block ACK bitmap, if equal to 1, indicates the successful reception of the MPDU with the sequence number equal to (a value of the block ACK starting sequence control subfield+n). The bit position n of the block ACK bitmap, if equal to 0, indicates that the MPDU with the sequence number equal to (a value of the block ACK starting sequence control subfield+n) has not been successfully received.

The first instance of the information per TID subfield, the block ACK starting sequence control subfield, and the block ACK bitmap subfield corresponds to the lowest TID value with subsequent instances ordered by increasing values of the information per TID subfield.

Accordingly, the receiving device receiving the multi-AC PPDU may set each bit of the block ACK bitmap according to whether MPDUs aggregated in the A-MPDU corresponding to the TID with the lowest TID value has been successfully received in the order of sequence number. Subsequently, the receiving device may set each bit of the block ACK bitmap according to whether MPDUs aggregated in the A-MPDU corresponding to the TID with the next TID value has been successfully received in the order of sequence number. Assuming that TID1 is less than TID2 in the example shown in FIG. **6**, the receiving device may set the information per TID subfield, the block ACK starting sequence control subfield, and the block ACK bitmap subfield for TID1, and then may set the information per TID subfield, the block ACK starting sequence control subfield, and the block ACK bitmap subfield for TID**2**. The transmitting device receiving the multi-TID block ACK frame can identify whether the MPDUs aggregated in the A-MPDU have been successfully received based on the TID value and the block ACK bitmap.

In some embodiments, the frame body field may further include a BA control field for controlling the block ACK.

Referring to FIG. **8** again, the transmitting device may transmit a PPDU including single MPDUs for the plurality of ACs. FIG. **8** shows an example where the PPDU includes a single MPDU to which "TID1" is assigned as the TID and a single MPDU to which "TID2" is assigned as the TID. A receiving device receiving the PPDU transmits an ACK frame to the transmitting device after a predetermined IFS interval.

The ACK frame is a multi-TID ACK frame and uses a normal ACK not the block ACK as shown in FIG. **9**.

Referring to FIG. **9**, the multi-TID ACK includes an MAC header, a frame body field, and an FCS field.

The MAC header includes an address field. In some embodiments, the address field may not include a TA field and may include an RA field. The MAC header may further include a frame control field and a duration/ID field. The FCS field includes a CRC.

The frame body field includes a BA information field. The BA information field has a variable length according to the number of TIDs and includes information per TID (per TID info) subfield for each TID. The information per TID subfield is repeated for each TID. In some embodiments, the BA information field may include the information per TID subfields for TIDs of single MPDUs that have been successfully received. That is, the ACK may be transmitted for only the single MPDUs that have been successfully received. Differently from an embodiment shown in FIG. **7**, the BA information field does not include a block ACK starting sequence control subfield and a block ACK bitmap subfield. Accordingly, the BA information field shown in FIG. **9** may be called an ACK information field. In some embodiments, the ACK frame may use a format that is a multi-TID block ACK frame format defined in the HT WLAN having an ACK information filed excluding a block ACK starting sequence control subfield and a block ACK bitmap subfield.

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The information per TID subfield indicates information, for example a TID value, on a TID for which an ACK is transmitted.

The information per TID subfield may have two octets whose first 12 bits **B0-B11** are reserved and last 4 bits **B12-B15** indicate the TID value.

The first instance of the information per TID subfield corresponds to the lowest TID value from among TIDs for which the ACK is transmitted, with subsequent instances ordered by increasing values of the information per TID subfield.

Accordingly, the receiving device receiving the multi-AC PPDU may input TID values of single MPDUs, which have been successfully received from among single MPDUs corresponding to a plurality of TIDs, to the ACK information field in the increasing order of TID value. The transmitting device receiving the multi-TID ACK frame can identify whether the single MPDUs have been successfully received based on the TID values input to the ACK information field. If the information per TID subfield is transmitted for the single MPDU that has been successfully received, the overhead of the ACK frame can be reduced.

In one embodiment, a bit of the reserved bits **B0-B11** of the information per TID subfield in the ACK frame shown in FIG. **9** may indicate whether the ACK frame includes the block ACK bitmap, i.e., is the block ACK. For example, the last bit **B11** of the reserved bits **B0-B11** may indicate the block ACK. In another embodiment, a bit of the reserved bits **B0-B11** of the information per TID subfield in the ACK frame shown in FIG. **7** may indicate whether the ACK frame is the block ACK.

Referring to FIG. **10**, a transmitting device may transmit a PPDU including a plurality of A-MPDUs. In the plurality of A-MPDUs, an A-MPDU for a certain AC includes a single MPDU and an A-MPDU for other AC includes no single MPDU. FIG. **10** shows an example where the PPDU includes an A-MPDU to which "TID**1**" is assigned as the TID and a single MPDU to which "TID**2**" is assigned as the TID. A receiving device receiving the PPDU transmits an ACK frame to the transmitting device after a predetermined IFS interval.

The ACK frame is an ACK frame into which a multi-TID block ACK frame and a multi-TID ACK frame are multiplexed, and may use a multi-TID block ACK frame format defined in the HT WLAN.

Referring to FIG. **11**, for the TID on which the A-MPDU is transmitted, the BA information field includes an information per TID subfield, a block ACK starting sequence control subfield, and a block ACK bitmap subfield as shown in FIG. **7**. For the TID on which the single MPDU is transmitted, the BA information field includes an information per TID subfield as shown in FIG. **9**. That is, the information per TID subfield, the block ACK starting sequence control subfield, and the block ACK bitmap subfield are repeated for each TID on which the A-MPDU is transmitted, and the information per TID subfield is repeated for each TID on which the single MPDU is transmitted. Since the A-MPDU is transmitted for TID**1** and the single MPDU is transmitted for TID**2** in an example shown in FIG. **10**, the ACK frame includes the information per TID subfield, the block ACK starting sequence control subfield, and the block ACK bitmap subfield for TID**1** and includes the information per TID for TID**2**.

The transmitting device receiving the ACK frame can identify whether the MPDUs aggregated in the A-MPDU have been successfully received based on the TID value and the block ACK bitmap for the TID on which the A-MPDU is transmitted, and can identify whether the single MPDU has been successfully received based on the TID value for the TID on which the single MPDU is transmitted.

In one embodiment, for each TID, a bit of the reserved bits **B0-B11** of the information per TID subfield may indicate whether the ACK frame for a corresponding TID is the block ACK. In another embodiment, for only the TID on which the block ACK is not used, a bit of the reserved bits **B0-B11** of the information per TID subfield may indicate that the ACK frame is not the block ACK.

While it has been described in the above embodiments that the ACK frame uses the information per TID subfield, the block ACK starting sequence control subfield, and the block ACK bitmap subfield or uses the information per TID subfield in accordance with whether the multi-AC PPDD includes the A-MPDU or the single MPDU, the other conditions may be used.

In some embodiments, when a data unit does not include an A-MPDU and a single MPDU, i.e., includes MPDUs that are not aggregated, an information per TID subfield, a block ACK starting sequence control subfield, and a block ACK bitmap subfield may be used as ACK information.

In some embodiments, when a data unit includes one MPDU that is not a single MPDU, an information per TID subfield, a block ACK starting sequence control subfield, and a block ACK bitmap subfield may be used as ACK information.

FIG. **12** is a flowchart exemplifying information selection of an ACK frame in a wireless communication network according to an embodiment of the present invention.

As shown in FIG. **12**, a device determines a condition (**S110**). When the determined condition is a first condition, the device inputs ACK information of a first type to an ACK frame (**S120**). When the determined condition is a second condition, the device inputs ACK information of a second type to the ACK frame (**S130**). The ACK information of the first type may correspond to an information per TID subfield, a block ACK starting sequence control subfield, and a block ACK bitmap subfield as described with reference to FIG. **7**. The ACK information of the second type may correspond to an information per TID subfield as described with reference to FIG. **9**. As such, the type of the ACK information inputted for a TID may be determined depending on the condition of the TID.

In some embodiments, the first condition may be a condition that an A-MPDU does not include a single MPDU, and the second condition may be a condition that an A-MPDU includes a single MPDU.

In some embodiments, the first condition may be a condition that an A-MPDU is not indicated to a single MPDU by information such as an EOF field, and the second condition may be a condition that an A-MPDU is indicated to a single MPDU by information such as an EOF field.

In some embodiments, the first condition may be a condition that an A-MPDU includes a plurality of MPDUs, and the second condition may be a condition that an A-MPDU includes one MPDU.

In some embodiments, the device may input the ACK information of the second type to the ACK frame when the data unit satisfies the second condition and has been successfully received in the step **S130**.

In another embodiment of the present invention, a transmitting device may set an ACK policy and a receiving device may transmit an ACK in accordance with the ACK policy. This embodiment is described with reference to Table 1 and FIG. **13**.

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Table 1 shows an ACK policy in a wireless communication network according to another embodiment of the present invention, and FIG. **13** exemplifies an ACK procedure in a wireless communication network according to another embodiment of the present invention.

TABLE 1

	Single AC transmission		Multi-AC transmission	
Value	Non A-MPDU or single MPDU	A-MPDU	Single MPDU	Non single MPDU
0	Normal ACK (ACK)	Implicit Block Ack (block ACK)	Normal ACK (Multi-TID ACK)	Implicit block Ack (Multi-TID block ACK)
1	No explicit acknowledgement or PSMP Ack			—
2	No Ack (No response)	No Ack (No response)	No Ack (No response)	No Ack (No response)
3	—	Block Ack Wait for receiving BlockAck Request (BAR)	—	Block Ack Wait for receiving Multi-TID BlockAck Request (BAR)

In some embodiments, the ACK policy may have a setting value of 2 bits, and may be included in, for example, a QoS (quality of service) control field of a data frame.

As shown in Table 1, the ACK policy setting value of 0 indicates to respond as a normal ACK, i.e., a multi-TID ACK frame for a single MPDU and to respond as a block ACK, i.e., a multi-TID block ACK frame for an A-MPDU. The ACK policy setting value of 2 indicates that no ACK needs to be transmitted as a response. The setting value of the ACK policy of 3 indicates to respond as the multi-TID block ACK frame after receiving a multi-TID block ACK request (BAR) for the A-MPDU.

Accordingly, when the multi-AC PPDU is used, the ACK procedure can be performed by setting the ACK policy.

In some embodiments, as shown in Table 1, the ACK policy setting value may be applied to a PPDU using a single AC not a plurality of ACs. The ACK policy setting value of 0 indicates to respond as an ACK frame for a non A-MPDU or an MPDU and to respond as a block ACK frame for an A-MPDU. The setting value of the ACK policy of 1 indicates that no explicit acknowledgement or PSMP ACK is required. The ACK policy setting value of 2 indicates that no ACK needs to be transmitted as a response. The setting value of the ACK policy of 3 indicates to respond as the block ACK frame after receiving a block ACK request (BAR) for the A-MPDU.

Next, referring to FIG. **13**, a transmitting device may transmit a PPDU including A-MPDUs. FIG. **13** shows an example where the PPDU include A-MPDUs **121**, **122**, **123**, **124**, and **125**. The A-MPDU **121** is assigned "TID**1**" as the TID, is toward a receiving device Rx**1**, and has an ACK policy set to 0. The A-MPDU **122** is assigned "TID**2**" as the TID, is toward the receiving device Rx**1**, and has an ACK policy set to 0. The A-MPDU **123** is assigned "TID**1**" as the TID, is toward a receiving device Rx**2**, and has an ACK policy set to 3. The A-MPDU **124** is assigned "TID**2**" as the TID, is toward a receiving device Rx**3**, and has an ACK policy set to 3. The A-MPDU **125** is assigned "TID**3**" as the TID, is toward the receiving device Rx**3**, and has an ACK policy set to 3.

The receiving device Rx**1** receiving the A-MPDUs **121** and **122** with the ACK policy of 0 transmits a multi-TID block ACK frame after the SIFS interval. The receiving device Rx**1** sets whether the A-MPDU has been received for each TID as a block ACK bitmap. The receiving device Rx**2** or Rx**3** receiving the A-MPDU **123**, **124**, or **125** with the ACK policy of 3 waits without transmitting an ACK.

The transmitting device receives the multi-TID block ACK frame from the receiving device Rx**1** and then transmits a BAR frame to the receiving device Rx**2** after the SIFS interval. Since the A-MPDU **123** transmitted to the receiving device Rx**2** has a single TID (TID**1**), the transmitting device transmits a normal BAR frame thereby requesting the receiving device Rx**2** to transmit a block ACK. The BAR frame uses a BlockAckReq frame format defined in the previous WLAN. The receiving device Rx**2** receiving the BAR frame transmits a block ACK frame after the SIFS interval. The block ACK frame sets whether the A-MPDU **123** has been received as a block ACK bitmap.

Next, the transmitting device receives the block ACK frame from the receiving device Rx**2** and then transmits a multi-TID BAR frame to the receiving device Rx**3** after the SIFS interval. Since the A-MPDUs **124** and **125** transmitted to the receiving device Rx**3** have multi TIDs (TID**2** and TID**3**), the transmitting device transmits a multi-TID BAR frame thereby requesting the receiving device Rx**3** to transmit a multi-TID block ACK. The receiving device Rx**3** receiving the multi-TID BAR frame transmits the block ACK frame after the SIFS interval. The receiving device Rx**3** sets whether the A-MPDU has been received for each TID as a block ACK bitmap.

Each receiving device can transmit the ACK in accordance with its ACK policy through the above procedure.

While the ACK for a frame having a plurality of ACs has been described above, an embodiment of the present invention may be applied to an ACK on frames that are simultaneously transmitted to a plurality of receiving devices. In a wireless communication network according to an embodiment of the present invention, a multi-user (MU), i.e., a plurality of stations may simultaneously transmit uplink (UL) frames (for example, PPDUs) using UL MU-MIMO or OFDMA transmission. In this case, a method in which a device, i.e., an AP, receiving the UL PPDUs transmits an ACK is described.

FIG. **14** shows an example of a wireless communication network according to another embodiment of the present invention, FIG. **15** exemplifies a UL MU transmission procedure in a wireless communication network according to another embodiment of the present invention, FIG. **16** and FIG. **17** exemplify an ACK frame in a wireless communication network according to embodiments of the present invention, and FIG. **18** and FIG. **19** exemplify a UL initia-

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tion frame in a wireless communication network according to embodiments of the present invention.

Referring to FIG. **14**, a basic service set (BSS) includes a plurality of WLAN devices. The WLAN devices include a device that is an AP and a device that is a non-AP station. i.e., a station. In FIG. **14** and FIG. **15**, three stations STA**1**, STA**2**, and STA**3** are shown for convenience, but the number of stations is not limited thereto.

Referring to FIG. **15**, the AP first transmits a UL initiation (ULI) frame to perform UL MU transmission with a plurality of stations STA**1**, STA**2**, and STA**3**. The AP may transmit the ULI frame whose recipient is a group including the stations STA**1**, STA**2**, and STA**3**. The ULI frame indicates the stations STA**1**, STA**2**, and STA**3** to initiate the UL MU transmission. In some embodiments, the ULI frame may include setup information to be used for the UL MU transmission by each station.

Each of the stations STA**1**, STA**2**, and STA**3** receiving the ULI frame transmits a UL data frame, for example a UL PPDU. The AP receiving the UL PPDUs from the stations STA**1**, STA**2**, and STA**3** transmits an ACK frame on the UL PPDUs to the stations STA**1**, STA**2**, and STA**3**. In one embodiment, the ACK frame may include information of each station and information about whether the UL PPDU from the corresponding station has been received to allow each station to check an acknowledgement on its UL PPDU. In another embodiment, the ACK frame may include information about whose UL PPDU has been successfully received from among the stations.

The stations STA**1**, STA**2**, and STA**3** can transmit the UL PPDUs to the AP through the above procedure.

In some embodiments, the ACK frame may use a block ACK frame described with reference to FIG. **7**. Referring to FIG. **16**, the block ACK frame includes a MAC header, a frame body field, and an FCS field, and the frame body field includes a BA information field, like a multi-TID block ACK frame shown in FIG. **7**.

Differently from an embodiment described with reference to FIG. **7**, since the AP transmits the ACK on the UL PPDUs received from the stations STA**1**, STA**2**, and STA**3**, the BA information field may have a variable length according to the number of stations. Accordingly, the BA information field may include an information per TID subfield, a block ACK starting sequence control subfield, and a block ACK bitmap subfield, for each station. The information per TID subfield may include information of a corresponding station, for example identification information of the corresponding station. Therefore, the information per TID subfield may be called an information per station subfield. The block ACK bitmap subfield may indicate whether MPDUs aggregated in an A-MPDU included in the UL PPDU of the corresponding station have been received.

In some embodiments, when the multi-TID block ACK frame format is used, a part or whole of reserved bits B**0**-B**11** in the information per TID subfield may indicate the identification information of the station. In this case, some bits of an association identifier (AID) between the station and the AP may be used as the identification information of the station.

In some embodiment, a part of the reserved bits B**0**-B**11** may indicate whether the ACK for the station is a block ACK.

Accordingly, each station can check the ACK on its UL PPDU from bitmap information of the block ACK corresponding to the station.

In some embodiments, the ACK frame described with reference to FIG. **16** may be applied to a case that the UL PPDU includes no single MPDU.

In another embodiment, the ACK frame may use an ACK frame described with reference to FIG. **9**. Referring to FIG. **17**, the ACK frame includes a MAC header, a frame body field, and an FCS field like a multi-TID ACK frame shown in FIG. **9**.

Differently from an embodiment described with reference to FIG. **9**, since the AP transmits the ACK on the UL PPDUs received from the stations STA**1**, STA**2**, and STA**3**, the BA information field (i.e., an ACK information field) may have a variable length according to the number of stations. Accordingly, the ACK information field may include an information per TID subfield for each station. The information per TID subfield may include information of a corresponding station, for example identification information of the corresponding station. Therefore, the information per TID subfield may be called an information per station subfield. Differently from an embodiment shown in FIG. **16**, a block ACK starting sequence control subfield and a block ACK bitmap subfield are not included in the ACK information field.

In some embodiments, the ACK information may include the information per TID subfield for only a station for which the ACK is transmitted.

In some embodiments, when the multi-TID ACK frame is used, a part or whole of reserved bits B**0**-B**11** of the information per TID subfield may indicate the identification information of the station. In this case, some bits of an AID between the station and the AP may be used as the identification information of the station.

In some embodiment, a part of the reserved bits B**0**-B**11** may indicate whether the ACK for the station is not a block ACK.

Accordingly, each station can check the ACK on its UL PPDU by determining whether its information exists in the ACK information field. In some embodiments, the ACK frame described with reference to FIG. **17** may be applied to a case that the UL PPDU includes a single MPDU.

In some embodiments, an interval between two frames shown in FIG. **15** may be a predetermined IFS interval. The predetermined IFS may be an SIFS. Alternatively, the predetermined IFS may be a PIFS or an IFS having the different duration from the SIFS and the PIFS. Accordingly, a plurality of devices can transmit frames without a collision in an unlicensed band.

In some embodiments, the ULI frame may include identification information (for example, address information) of each of the stations STA**1**, STA**2**, and STA**3** for joining in the UL MU transmission. Each station can transmit a UL request (UL req) frame when it corresponds to any one of the plurality of station identification information included in the ULI frame. In another embodiment, the ULI frame may include group information to which candidate stations STA**1**, STA**2**, and STA**3** belong. The group information may be a group ID. Then, each station can transmit the UL req frame when a group to which it belongs corresponds to the group information included in the ULI frame.

In some embodiments, the ULI frame may be a control frame or a management frame. That is, as shown in FIG. **18** and FIG. **19**, the ULI frame may include a MAC header, a frame body field, and an FCS field. The MAC header includes an address, and the address field may include a TA field indicating an address of the AP.

As shown in FIG. **18**, the frame body field may include information (STA Info **1**, STA Info **2**, . . . , STA Info n) of

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the stations STA1, STA2, and STA3. The information (STA Info i) of each station may indicate identification information of the station. In this case, some bits of an AID between the station and the AP may be used as the identification information of the station.

In another embodiment, as shown in FIG. 19, the frame body field may include group information to which the stations STA1, STA2, and STA3 belong. The group information may be an identifier (group ID) of the group.

In some embodiments, the UL PPDU transmitted by each device may have a plurality of ACs as described above. These embodiments are described with reference to FIG. 20 and FIG. 21.

FIG. 20 exemplifies a UL MU transmission procedure in a wireless communication network according to yet another embodiment of the present invention, and FIG. 21 exemplifies an ACK frame in a wireless communication network according to yet another embodiment of the present invention.

Referring to FIG. 20, an AP transmits a ULI frame to perform a UL MU transmission with a plurality of stations STA1, STA2, and STA3.

Each of the stations STA1, STA2, and STA3 receiving the ULI frame transmits a UL data frame, for example a UL PPDU. Each UL PPDU includes an A-MPDU corresponding to one or more ACs. The A-MPDU may be an A-MPDU including no single MPDU or an A-MPDU including a single MPDU. FIG. 20 shows an example where a UL PPDU transmitted to the station STA1 includes an A-MPDU to which "TID1" is assigned as the TID and an A-MPDU to which "TID2" is assigned as the TID, a UL PPDU transmitted to the station STA2 includes an A-MPDU to which "TID1" is assigned as the TID and an A-MPDU to which "TID3" is assigned as the TID, and a UL PPDU transmitted to the station STA3 includes an A-MPDU to which "TID2" is assigned as the TID. The A-MPDU of the station STA1 to which "TID1" is assigned and the A-MPDU of the station STA3 to which "TID2" is assigned include the single MPDU, and remaining A-MPDUs include no single MPDU.

The AP receiving the UL PPDUs from the stations STA1, STA2, and STA3 transmits an ACK frame on the UL PPDUs to the stations STA1, STA2, and STA3. The ACK frame may include information of each station and information about whether the UL PPDU from the corresponding station has been received to allow each station to check an acknowledgement on its UL PPDU.

The ACK frame may use an ACK frame described with reference to FIG. 11. Referring to FIG. 21, the ACK frame includes a MAC header, a frame body field, and an FCS field, and the frame body field includes a BA information field, like the ACK frame shown in FIG. 11.

Differently from an embodiment described with reference to FIG. 11, since the AP transmits the ACK on the UL PPDUs received from the stations STA1, STA2, and STA3, the BA information field may have a variable length according to the number of stations. Accordingly, the BA information field may include ACK information per TID for each station. For the TID on which the A-MPDU is transmitted, the ACK information per TID may an information per TID subfield, a block ACK starting sequence control subfield, and a block ACK bitmap subfield. For the TID on which the single MPDU is transmitted, the ACK information per TID field may include an information per TID subfield. That is, the ACK information per TID is repeated for each station and for each TID.

The information per TID subfield may include information (for example, identification information) of the corresponding station and TID information (for example, a TID value).

In the example shown in FIG. 20, the UL PPDU of the station STA1 includes A-MPDUs for TID1 and TID2 each including no single MPDU, the UL PPDU of the station STA2 includes an A-MPDU for TID1 including a single MPDU and an A-MPDU for TID3 including no single MPDU, and the UL PPDU of the station STA3 includes an A-MPDU for TID2 including a single MPDU. Therefore, the ACK frame includes the information per TID subfield, the block ACK starting sequence control subfield, and the block ACK bitmap subfield for TID1 of the station STA1 and includes the information per TID subfield, the block ACK starting sequence control subfield, and the block ACK bitmap subfield for TID2 of the station STA1. The ACK frame includes the information per TID subfield for TID1 of the station STA2, includes the information per TID subfield, the block ACK starting sequence control subfield, and the block ACK bitmap subfield for TID3 of the station STA2, and includes the information per TID subfield for TID2 of the station STA3.

In some embodiments, when the multi-TID block ACK frame format is used, a part or whole of reserved bits B0-B11 in the information per TID subfield may indicate the identification information of the station. In this case, some bits of an AID between the station and the AP may be used as the identification information of the station.

In some embodiments, a part of the reserved bits B0-B11 may indicate whether the corresponding ACK information per TID is a block ACK. In another embodiment, only when the block ACK is not used, a part of the reserved bits B0-B11 may indicate whether the corresponding ACK information per TID is not the block ACK.

Accordingly, each station can check whether its UL PPDU has been successfully received for each TID.

While it has been described above that the AP transmits one frame, for example one ULI frame, indicating the UL MU transmission for the UL MU transmission, the AP may the frames two or more times to indicate a UL MU-MIMO transmission when the UL MU transmission is the UL MU-MIMO transmission. Such embodiment is described below.

FIG. 22 exemplifies a UL MU procedure in a wireless communication network according to an embodiment of the present invention.

Referring to FIG. 22, an AP transmits a UL MU-MIMO initiation (ULI) frame to perform UL MU-MIMO with a plurality of stations STA1, STA2, and STA3. The ULI frame indicates the stations STA1, STA2, and STA3 to initiate the UL MU-MIMO transmission.

The stations STA1, STA2, and STA3 receiving the ULI frame sequentially transmit UL MU-MIMO request (UL req) frames to the AP. The UL req frame transmitted by each station includes feedback information for the UL MU-MIMO of the corresponding station.

The AP receiving the UL req frame from the stations STA1, STA2, and STA3 selects a station for joining in the UL MU-MIMO from among the stations STA1, STA2, and STA3 based on the feedback information carried by the UL req frame, and transmits a UL MU-MIMO setup (UL setup) frame to the selected stations STA1 and STA2. The UL setup frame includes setup information to be used for the UL MU-MIMO by each station. The setup information may include for example a transmission power, modulation and coding scheme (MCS) information, or a data length to be

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used by each station. The setup information may further include information on a structure of a long training field (LTF) to be used by each station.

Each of the stations STA1 and STA2 receiving the UL setup frame transmits a UL data frame, for example a UL MU PPDU, based on the setup information. The AP receiving the UL MU PPDUs transmits an ACK frame on the UL MU PPDUs to the stations STA1 and STA2.

The stations STA1 and STA2 can transmit the UL data frame to the AP in the MU-MIMO through the above procedure.

In some embodiments, an interval between two frames shown in FIG. 22 may be a predetermined IFS interval. The predetermined IFS may be an SIFS. Alternatively, the predetermined IFS may be a PIFS or an IFS having the different duration from the SIFS and the PIFS.

In some embodiments, the ULI frame may include identification information of each of the candidate stations STA1, STA2, and STA3 for joining in the UL MU transmission. Each station can transmit the UL req frame when it corresponds to any one of the plurality of station identification information included in the ULI frame. In another embodiment, the ULI frame may include group information to which candidate stations STA1, STA2, and STA3 belong. The group information may be a group ID. Then, each station can transmit the UL req frame when a group to which it belongs corresponds to the group information included in the ULI frame.

In yet another embodiment, the ULI frame may further including channel sounding indication information. The channel sounding indication information indicates whether to perform a channel sounding procedure between the AP and the stations STA1, STA2, and STA3. When the channel sounding indication information channel indicates to perform the channel sounding procedure, the AP may select the station for joining in the UL MU-MIMO based on channel information acquired through the channel sounding procedure of each station. When the channel sounding indication information indicates to perform the channel sounding procedure, beamforming may be supported at the data transmission.

In some embodiments, the stations STA1, STA2, and STA3 receiving the ULI frame may sequentially transmit the UL req frames in a predetermined order. The predetermined order may be for example an address order of the stations.

In some embodiments, the feedback information carried by the UL req frame may include transmission power information. The transmission power information may include information on a magnitude of a current transmission power of a corresponding station. The AP can determine a path loss between the AP and the corresponding station based on the information on the magnitude of the transmission power and a magnitude of a received power of the UL req frame. Accordingly, the transmission power information may be used when the AP determines whether to join the corresponding station in the UL MU-MIMO. The transmission power information may further include information on a magnitude of a maximum transmission power that can be used by the corresponding station.

In another embodiment, the feedback information may include information on a current state of a data queue of the corresponding station. The information on the data queue state may include information about whether data to be transmitted exist in the data queue and information on a size of the data if the data to be transmitted exist. Accordingly, the information on the data queue state may be used when the AP determines whether to include the corresponding in the UL MU-MIMO.

In yet another embodiment, each station may transmit the UL req frame by correcting a carrier frequency offset after receiving the ULI frame. Then, the AP can determine based on the UL req frame whether each station transmits a frame by correcting the carrier frequency offset to acceptable level. Accordingly, the carrier frequency offset that is corrected at the time of the UL req frame transmission may be used for determining whether to include the corresponding station in the UL MU-MIMO transmission. In this case, the stations STA1 and STA2 selected by the UL setup frame may transmit the UL data frames by applying the carrier frequency offsets that have been used at the time of the UL req frame transmission.

In yet another embodiment, when the ULI frame indicates to perform the channel sounding procedure, the number of long training fields used by the UL req frame may be the number of antennas of the corresponding station. That is, the long training field (LTF) is used for estimating a MIMO channel in a frame. For the MIMO channel estimation, the number of HEW long training fields (HEW-LTFs) may be determined in accordance with the number of antennas to be used for transmission, i.e., the number of space-time streams. For example, when the numbers of space-time streams are 1, 2, 3, 4, 5, 6, 7, and 8, the numbers of long training fields may be determined as 1, 2, 4, 4, 6, 6, 8, and 8, respectively. Accordingly, the AP can estimate the channel in each transmitting antennas from the long training fields.

In some embodiments, the UL setup frame that is transmitted by the AP, after the AP selects the stations for performing the MU-MIMO based on the UL req frames received from the candidate stations, includes setup information. The setup information may include common information that is common to all stations for joining in the UL MU-MIMO and dedicated information that is specific to each station.

In some embodiments, the common information is information to be commonly used for the UL MU-MIMO transmission by the station STA1 and STA2, and includes the total number of data streams, i.e., space-time streams to be transmitted by the stations STA1 and STA2 and a transmission length of the UL data frame. The transmission length of the UL data frame may be the number of symbols or a transmission time. Since the AP provides the transmission length, all of the stations STA1 and STA2 can transmit the data frames in accordance with the transmission length. When the transmission length is longer than a length of data to be actually transmitted, the station may add pad bits. Further, each station may determine the number of long training fields (HEW-LTFs) based on the number of space-time streams.

In some embodiments, the dedicated information is information dedicated to each station and is provided for each station. The dedicated information may include identification information of the corresponding station, the number of data streams (i.e., space-time streams) to be transmitted by the corresponding station, a transmission power of the corresponding station, an MCS of the corresponding station, or beam information for the corresponding station. The beam information may be provided as compressed beamforming information like the HT WLAN or the VHL WLAN. The compressed beamforming information may be provided in, for example, the form of angles representing compressed beamforming matrix. Then, the station may transmit the UL data frame by setting the number of space-

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time streams, a magnitude of the transmission power, the MCS, or a steering matrix in accordance with the dedicated information.

The dedicated information may further include information on the long training fields (HEW-LTF) to be used by the corresponding station. The information on the long training fields (HEW-LTF) may include an index of a row to be used by the corresponding station in a long training field mapping matrix. Accordingly, the station may set codes of the long training fields (HEW-LTF) in accordance with a row vector of the long training field mapping matrix.

In some embodiments, the ACK frame transmitted by the AP may use the ACK frame described with reference to FIG. **16**, FIG. **17** or FIG. **21**. The ACK frame may indicate whether there are more UL data to be transmitted by each station.

FIG. **23**, FIG. **24**, FIG. **25**, FIG. **26**, FIG. **27**, and FIG. **28** exemplify UL MU transmission procedure in a wireless communication network according to various embodiments of the present invention.

Referring to FIG. **23**, each station may transmit a UL req frame as a null data packet (NDP) type frame to perform a sounding procedure for beamforming. Then, an AP transmits a UL setup frame including compressed beamforming information to each station based on the received NDP type frame. A backoff contention window (CW) value may be determined based on the received signal-to-noise ratio (SNR) of the UL1 frame. Then, the higher received SNR is, the earlier the stations STA**1**, STA**2**, and STA**3** may transmit the UL req frames.

As shown in FIG. **24**, FIG. **25**, FIG. **26**, and FIG. **27**, downlink (DL) MU transmission may be performed together with the UL MU transmission.

Referring to FIG. **24**, an AP first transmits an NDP announcement (NDPA) frame to a plurality of stations STA STA**1** and STA**2**, and then transmits an NDP frame to the stations STA**1** and STA**2** after the SIFS interval. Among the stations STA**1** and STA**2** receiving the NDP frame, the first station STA**1** feedbacks a compressed beamforming (CB) frame to the AP as a response of the NDPA frame. The AP receiving the CB frame from the station STA**1** transmits a beamforming report poll (BR-poll) frame to the second station STA**2**. The station STA**2** receiving the BR-poll frame feedbacks a CB frame to the AP as a response of the BR-poll frame.

Since the CB frame includes compressed beamforming information as feedback information, the AP may determine a steering matrix based on the compressed beamforming information and transmit DL data frame, for example a DL PPDU, to the stations STA**1** and STA**2** using the steering matrix. The stations STA**1** and STA**2** receiving the DL PPDU sequentially transmit ACK frames.

Information included in the UL1 frame may be piggybacked on the DL PPDU, and information included in the UL req frame may be piggybacked on the ACK frame. Then, the AP and the stations STA**1** and STA**2** may omit a procedure for exchanging the UL1 frame and the UL req frame.

Accordingly, the AP receiving the ACK frames transmits a UL setup frame to the stations STA**1** and STA**2**. The subsequent processes are the same as the processes described with reference to FIG. **22**.

Referring to FIG. **25**, information included in a UL1 frame is piggybacked on an NDPA frame, information included in a UL req frame is piggybacked on a CB frame, and information included in a UL setup frame is piggybacked on a DL PPDU. Then, the AP and the stations STA**1** and STA**2** may omit a procedure for exchanging the UL1 frame, the UL req frame, and the UL setup frame. Accordingly, the stations STA**1** and STA**2** may transmit ACK frames on the DL PPDU and then transmit UL MU PPDUs after the predetermined IFS interval.

Referring to FIG. **26**, if all setup information to be transmitted by a UL setup frame cannot be piggybacked on a DL PPDU, some setup information may be piggybacked on the DL PPDU and remaining setup information may be transmitted by a separate UL setup frame. After receiving the ACK frames on the DL PPDU from the stations STA**1** and STA**2**, the AP may transmit the UL setup frame including the remaining setup information to the stations STA**1** and STA**2**.

Referring to FIG. **27**, while information for UL MU-MIMO transmission is piggybacked on and is transmitted through a frame for DL transmission, an additional STA STA**4** may join in a group for the UL MU-MIMO transmission. In this case, an AP and the added station STA**4** may exchange a UL1 frame, a UL req frame, and a UL setup frame independently of the other stations STA**1** and STA**2**.

According to embodiments described with reference to FIG. **24** to FIG. **27**, the UL transmission can be performed subsequently to the DL transmission.

Referring to FIG. **28**, after stations STA**1**, STA**2**, and STA**3** perform UL MU-MIMO transmission with an AP as described with reference to FIG. **22**, the AP may perform DL MU-MIMO transmission with the stations STA**1**, STA**2**, and STA**3**. A UL PPDU may include compressed beamforming information for the DL MU-MIMO transmission. Then, the AP may transmit an ACK frame on the UL PPDU and then transmit a DL PPDU to the stations STA**1**, STA**2**, and STA**3** based on the compressed beamforming information after the predetermined IFS interval. The stations STA**1**, STA**2**, and STA**3** may sequentially transmit ACK frames on the DL PPDU to the AP.

Accordingly, the DL transmission can be performed subsequently to the UL transmission.

A frame transmitting method and a frame receiving method according to above embodiments of the present invention may be executed by a baseband processor **10** shown in FIG. **1** to FIG. **3**. In one embodiment, instructions for executing the frame transmitting method and the frame receiving method according to above embodiments of the present invention may be stored in a recording medium such as a memory **40**. In another embodiment, at least some of the instructions may be MAC software. In yet another embodiment, at least some of the instructions may be transmitted from a recording medium of a certain server and may be stored in the memory **40**.

While this invention has been described in connection with what is presently considered to be practical embodiments, it is to be understood that the invention is not limited to the disclosed embodiments, but, on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims. Further, two or more embodiments may be combined.

What is claimed is:

1. A method of operating an access point in a wireless communication network, the method comprising:

generating downlink data;

generating uplink setup information, the uplink setup information including a first information to be used for uplink multi-user transmission;

transmitting the downlink data and the uplink setup information in a single physical downlink frame to a plurality of stations;

simultaneously receiving multiple uplink frames from multiple stations of the plurality of stations; and

transmitting an acknowledgement frame to the multiple stations after a successful reception of the multiple uplink frames.

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wherein the uplink setup information includes a common information portion and a dedicated information portion, the common information portion includes a second information being common to all of the plurality of stations to receive the uplink setup information, and the dedicated information portion includes respective third information specific to each of the plurality of stations to receive the uplink setup information, and

wherein the second information is a function of a total number of space time streams to be used to transmit the multiple uplink frames.

2. The method of claim **1**, wherein the common information portion includes a length information associated with a length of the multiple uplink frames.

3. The method of claim **2**, wherein respective lengths of the multiple uplink frames are identical to a transmission length.

4. The method of claim **3**, wherein one or more of the multiple uplink frames include padding bits when the transmission length is longer than a length of a frame to be actually transmitted.

5. The method of claim **1**, wherein the dedicated information portion includes a station identification information, an information associated with a number of data streams, and MCS (Modulation and Coding Scheme).

6. The method of claim **1**, wherein the acknowledgement frame includes acknowledgement information for one or more of the plurality of stations.

7. The method of claim **1**, wherein an interframe space between the uplink setup frame and the multiple uplink frames is SIFS (short interframe space), and an interframe space between the multiple uplink frames and the acknowledgement frame is SIFS.

8. The method of claim **1**, wherein the multiple uplink frames are transmitted by the multiple stations using MU-MIMO (multi-user multiple-input multiple-output).

9. A method of operating a station in a wireless communication network, the method comprising:

receiving, from an access point, a physical downlink frame transmitted to a plurality of stations, the physical downlink frame comprising:

uplink setup information including a first information to be used for uplink multi-user transmission by the station, and

downlink data;

transmitting an uplink frame to the access point, the uplink frame being simultaneously transmitted with one or more uplink frames from one or more other stations of the plurality of stations, the uplink frame being generated based on the uplink setup information; and

receiving an acknowledgement frame from the access point after the uplink frame is successfully received in the access point,

wherein the uplink setup information includes a common information portion and a dedicated information portion, the common information portion includes a second information being common to all of the plurality of stations to receive the uplink setup frame, the dedicated information portion includes respective third information specific to each of the plurality stations to receive the uplink setup information, and

wherein the second information is a function of a total number of space time streams to be used to perform the simultaneous transmission of the uplink frame and the one or more uplink frames from the one or more other stations.

10. The method of claim **9**, wherein the common information portion includes a length information associated with a length of the uplink frame.

11. The method of claim **10**, wherein the length of the uplink frame is identical to the length of each of the one or more uplink frames transmitted from the one or more other stations.

12. The method of claim **11**, wherein further the uplink frame includes padding bits when the length of the uplink frame is longer than a length of a frame to be actually transmitted to the access point.

13. The method of claim **9**, wherein the dedicated information portion includes a station identification information, an information associated with a number of data streams, and MCS (Modulation and Coding Scheme).

14. The method of claim **9**, wherein the acknowledgement frame includes acknowledgement information for the station and one or more other stations of the plurality of stations.

15. The method of claim **9**, wherein an interframe space between the uplink setup frame and the uplink frame is SIFS (short interframe space), and an interframe space between the multiple frames and the acknowledgement frame is SIFS.

16. The method of claim **9**, wherein the uplink frame of the station and the one or more uplink frames of the one or more other stations are simultaneously transmitted using MU-MIMO (multi-user multiple-input multiple-output).

* * * * *

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EXHIBIT 4

U 8146575

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August 23, 2021

THIS IS TO CERTIFY THAT ANNEXED HERETO IS A TRUE COPY FROM THE RECORDS OF THIS OFFICE OF:

U.S. PATENT: *9,848,442*
ISSUE DATE: *December 19, 2017*

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Certifying Officer

ATLAS-00013900

US009848442B2

(12) **United States Patent**
Kwon et al.

(10) **Patent No.: US 9,848,442 B2**
(45) **Date of Patent: Dec. 19, 2017**

(54) **METHOD FOR TRANSMITTING AND RECEIVING FRAME IN WIRELESS LOCAL AREA NETWORK**

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(73) Assignee: **NEWRACOM INC.**, Irvine, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 76 days.

(21) Appl. No.: **14/937,284**

(22) Filed: **Nov. 10, 2015**

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Related U.S. Application Data

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(51) **Int. Cl.**
H04W 74/08 (2009.01)
H04W 84/12 (2009.01)

(52) **U.S. Cl.**
CPC ***H04W 74/0808*** (2013.01); ***H04W 74/085*** (2013.01); *H04W 74/0816* (2013.01); *H04W 84/12* (2013.01)

(58) **Field of Classification Search**
CPC H04W 74/0808; H04W 74/0816; H04W 74/085; H04W 74/0883; H04W 74/0891; H04W 84/12
See application file for complete search history.

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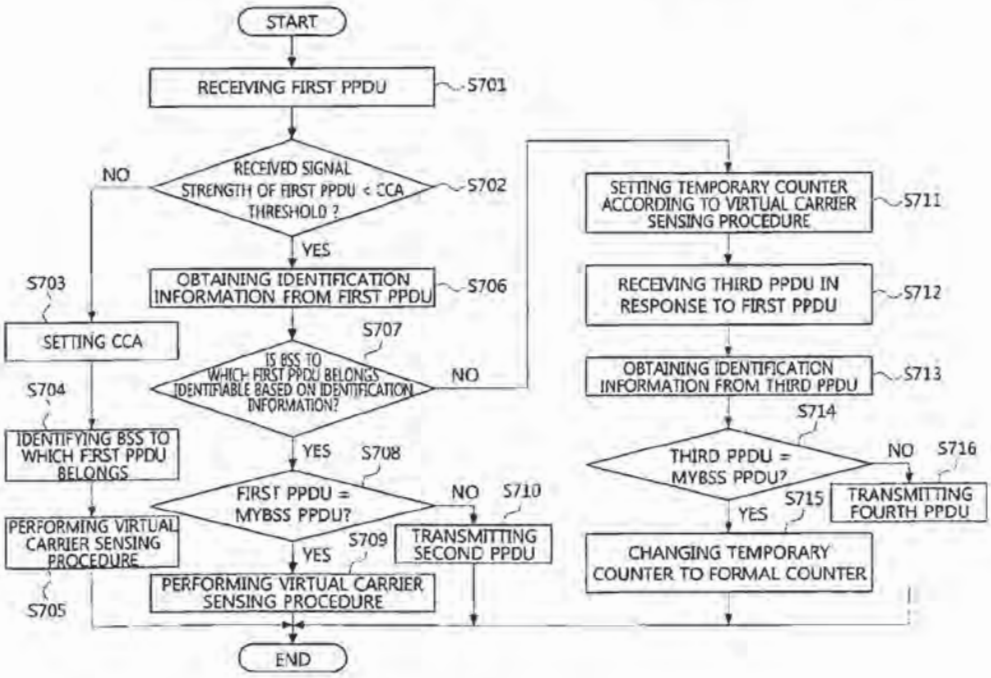
* cited by examiner

Primary Examiner — Khoa Huynh

(57) **ABSTRACT**

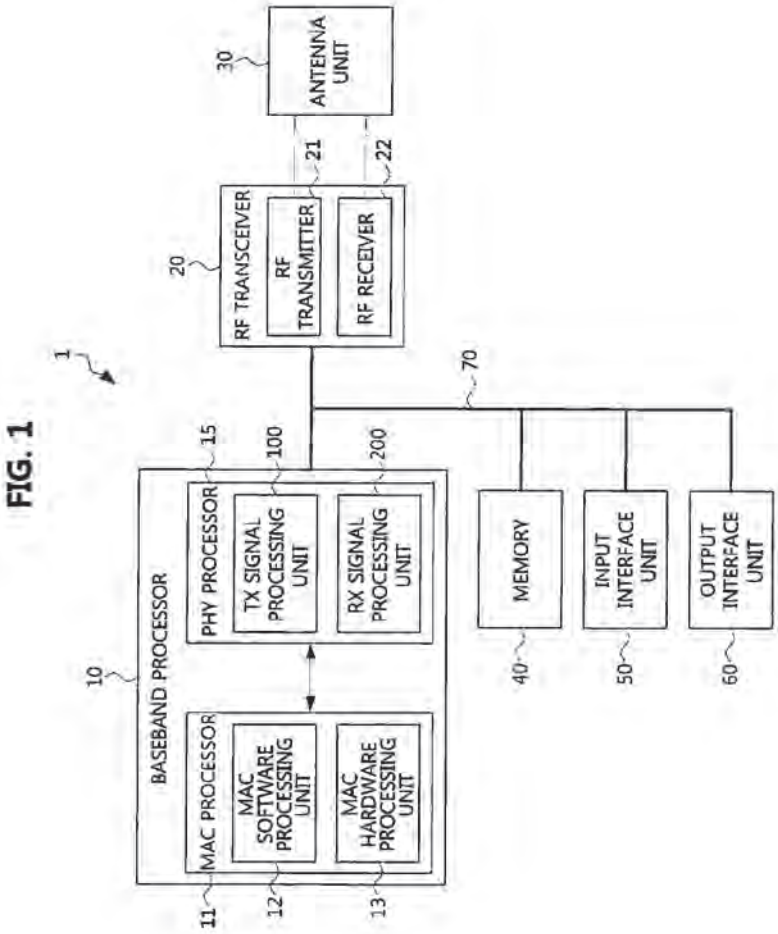
Disclosed are methods and apparatuses for transmitting and receiving a frame in a WLAN. A method for transmitting a frame, performed in a first station, may comprise receiving a first PPDU; determining whether a BSS of the first PPDU is a BSS to which the first station belongs or a BSS to which the first station does not belong; when the BSS of the first PPDU is the BSS to which the first station does not belong and a received signal strength of the first PPDU is higher than a first threshold, setting a virtual carrier sensing by using information included in a preamble of the first PPDU. Therefore, performance of the WLAN can be enhanced.

14 Claims, 9 Drawing Sheets



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FIG. 1


1
10
BASEBAND PROCESSOR
11
MAC PROCESSOR
12
MAC SOFTWARE PROCESSING UNIT
13
MAC HARDWARE PROCESSING UNIT
15
PHY PROCESSOR
100
TX SIGNAL PROCESSING UNIT
200
RX SIGNAL PROCESSING UNIT
20
RF TRANSCEIVER
21
RF TRANSMITTER
22
RF RECEIVER
30
ANTENNA UNIT
40
MEMORY
50
INPUT INTERFACE UNIT
60
OUTPUT INTERFACE UNIT
70

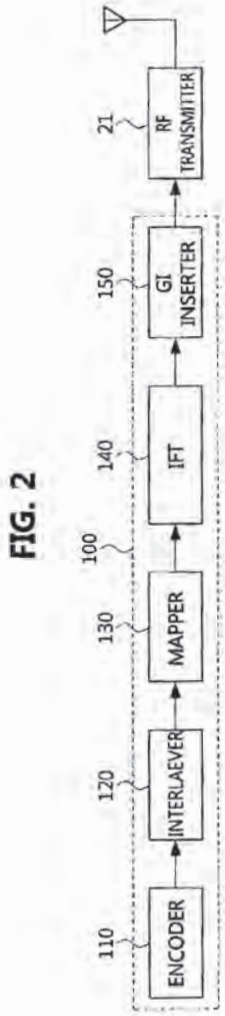


FIG. 2

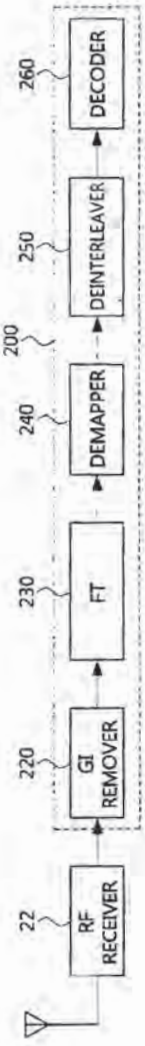


FIG. 3

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FIG. 4

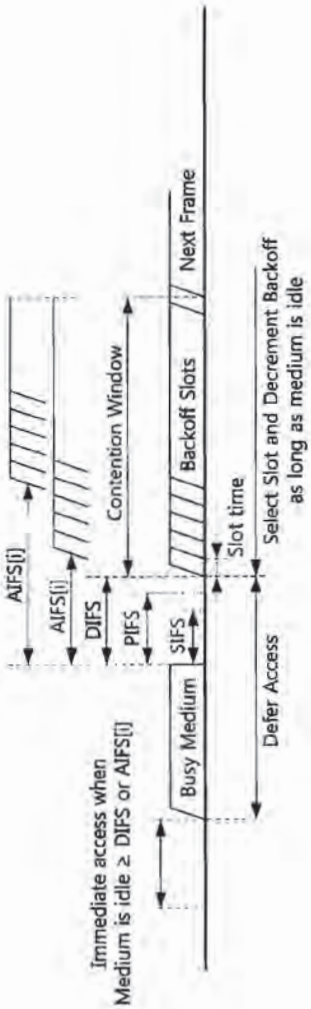
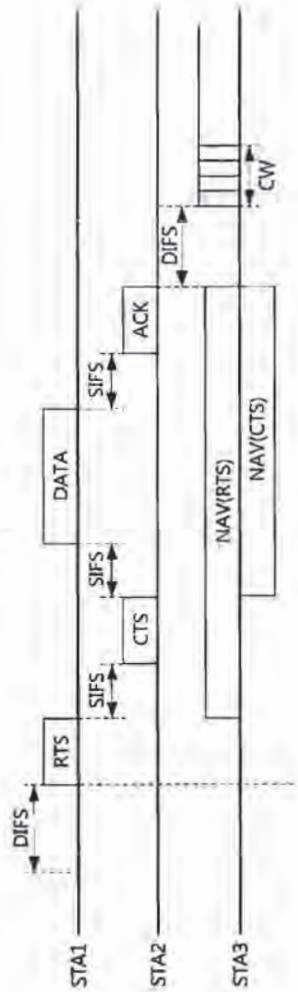


FIG. 5



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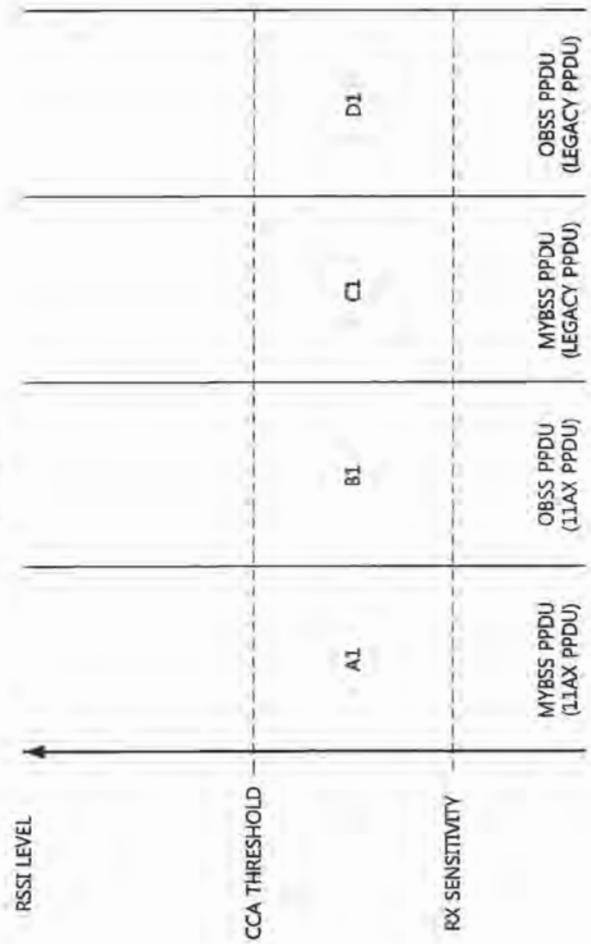


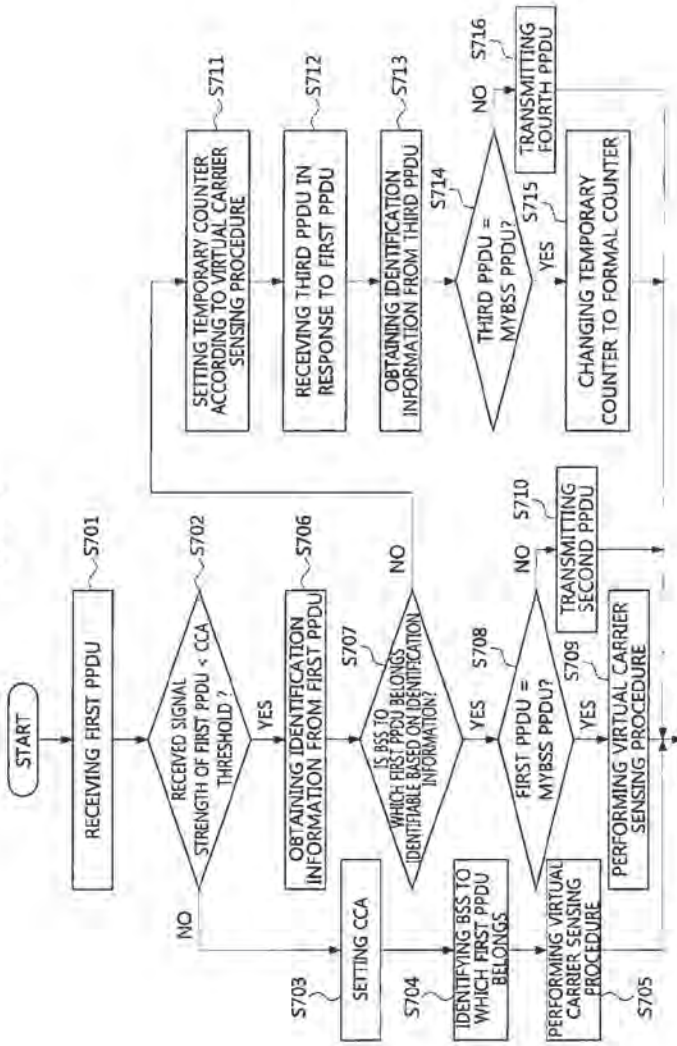
FIG. 6

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FIG. 7



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FIG. 8A

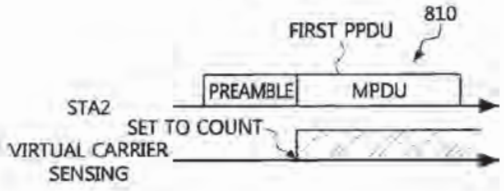


FIG. 8B

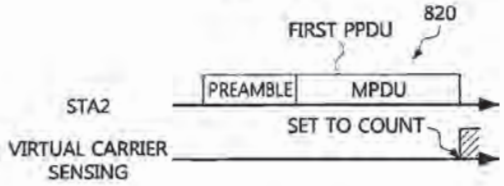
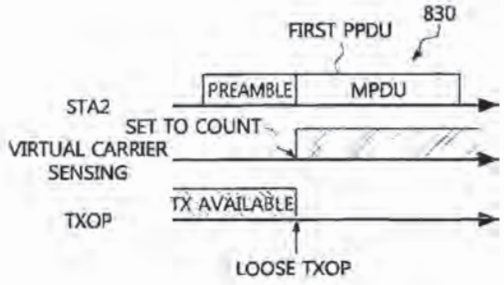


FIG. 8C



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FIG. 8D

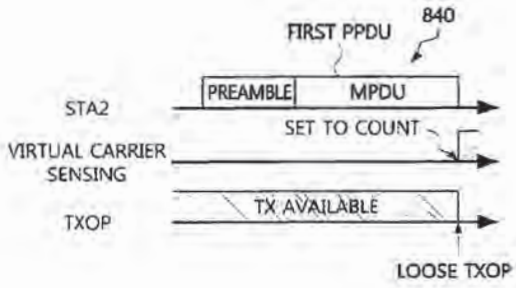
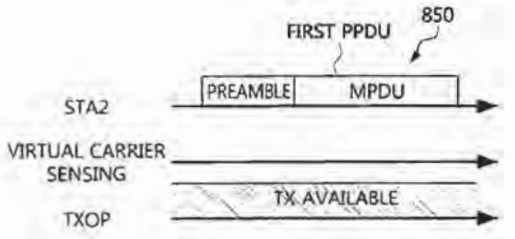


FIG. 8E



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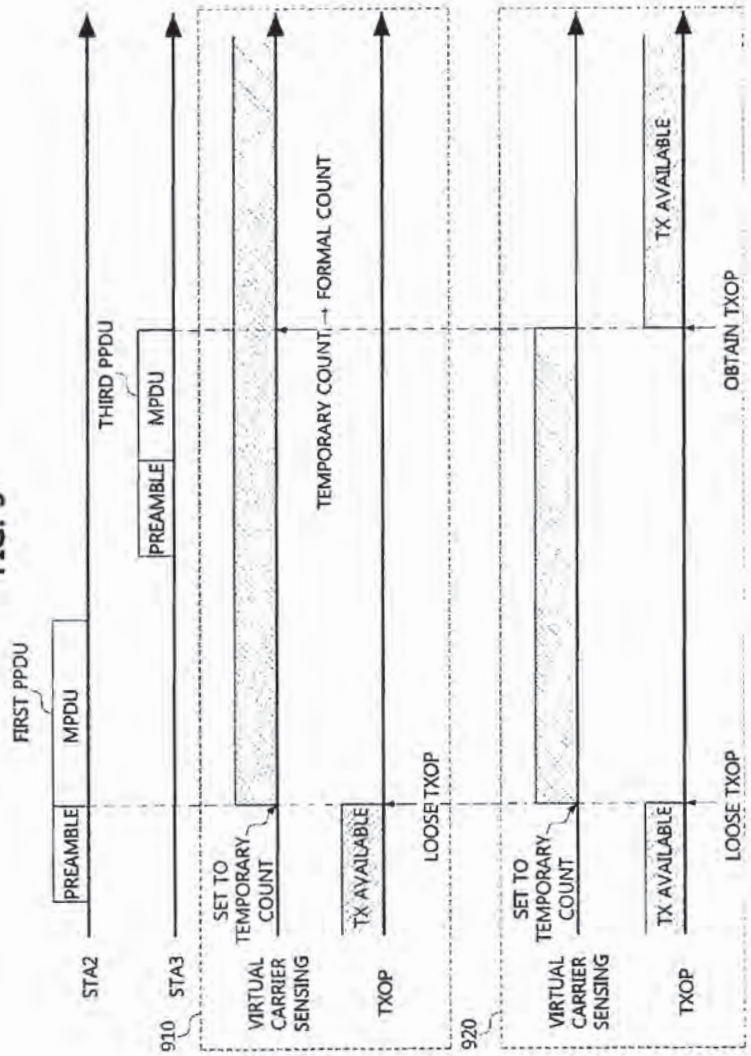


FIG. 9

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FIG. 10

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METHOD FOR TRANSMITTING AND RECEIVING FRAME IN WIRELESS LOCAL AREA NETWORK

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to U.S. Patent Application No. 62/077,771 filed on Nov. 10, 2014, and the entire contents of which are hereby incorporated by reference.

BACKGROUND

1. Technical Field

The present disclosure relates to a wireless local area network (WLAN) technology, and more particularly to methods for transmitting and receiving a frame in an overlapping basic service set (OBSS) environment.

2. Related Art

With the development of information communication technologies, a variety of wireless communication technologies have been developed. Among these technologies, wireless local area network (WLAN) is a technology that Internet access is possible in a wireless way in homes, business or specific service providing areas, using portable terminal such as personal digital assistant (PDA), a laptop computer, a portable multimedia player (PMP), or the like, based on wireless frequency technologies.

WLAN technologies are created and standardized by the IEEE 802.11 Working Group under IEEE 802 Standard Committee. As such WLAN technology becomes more prevalent and its applications become more diverse, there is increasing demand for new WLAN technology that can support a higher throughput than existing WLAN technologies. Very high throughput (VHT) WLAN technology is proposed to support a data rate of 1 Gbps and higher. A WLAN technology according to IEEE 802.11ac standard is a technology providing VHT in sub 6 GHz band, and A WLAN technology according to IEEE 802.11ad standard is a technology providing VHT in 60 GHz band.

In addition to the above-described standards, various standards on WLAN technologies have been developed, and are being developed. As representative recent technologies, a WLAN technology according to IEEE 802.11af standard is a technology which has been developed for WLAN operation in TV white space bands, and a WLAN technology according to IEEE 802.11ah standard is a technology which has been developed for supporting a great number of stations operating with low power in sub 1 GHz band, and a WLAN technology according to IEEE 802.11ai standard is a technology which has been developed for supporting fast initial link setup (FILS) in WLAN systems. Also, IEEE 802.11ax standard is being developed for enhancing frequency efficiency of dense environments in which numerous access points and stations exist.

In the system based on such the WLAN technologies, even in a situation in which a communication entity can transmit a frame, the communication entity may lose its transmission opportunity due to a frame transmitted by another communication entity belonging to an overlapping basic service set (OBSS).

SUMMARY

Accordingly, exemplary embodiments of the present disclosure are provided to substantially obviate one or more problems due to limitations and disadvantages of the related art. Exemplary embodiments of the present disclosure provide methods and apparatuses for transmitting and receiving a frame in the OBSS environment.

In order to achieve the objectives of the present disclosure, a method for transmitting a frame, performed in a first station, comprises receiving a first physical layer convergence procedure protocol data unit (PPDU); determining whether a basic service set (BSS) of the first PPDU is a BSS to which the first station belongs or a BSS to which the first station does not belong; when the BSS of the first PPDU is the BSS to which the first station does not belong and a received signal strength of the first PPDU is higher than a first threshold, setting a virtual carrier sensing by using information included in a preamble of the first PPDU; and when the BSS of the first PPDU is the BSS to which the first station does not belong and the received signal strength of the first PPDU is lower than the first threshold, trying to obtain a transmission opportunity.

In addition, the method may further comprises, when the BSS of the first PPDU is the BSS to which the first station belongs, setting a virtual carrier sensing by using information included in the preamble of the first PPDU.

Here, the BSS of the first PPDU may be determined based on at least one of a BSS identifier (BSSID), a transmitter address, a receiver address, and a version information included in the first PPDU.

Here, the first threshold may be a clear channel assessment (CCA) threshold.

Here, the first threshold may be different from a threshold which is used for determining reception possibility of the first PPDU when the BSS of the first PPDU is the BSS to which the first station belongs.

Here, the information included in the preamble of the first PPDU may indicate a duration which is set for the virtual carrier sensing.

Here, the trying to obtain the transmission priority may be performed without set of the virtual carrier sensing.

In order to achieve the objectives of the present disclosure, a station comprises a processor, and a memory storing at least one instruction executed by the processor, wherein the at least one instruction: receiving a first physical layer convergence procedure protocol data unit (PPDU); determining whether a basic service set (BSS) of the first PPDU is a BSS to which the first station belongs or a BSS to which the first station does not belong; when the BSS of the first PPDU is the BSS to which the first station does not belong and a received signal strength of the first PPDU is higher than a first threshold, setting a virtual carrier sensing by using information included in a preamble of the first PPDU; and when the BSS of the first PPDU is the BSS to which the first station does not belong and the received signal strength of the first PPDU is lower than the first threshold, trying to obtain a transmission opportunity.

In addition, the at least one instruction may further execute, when the BSS of the first PPDU is the BSS to which the first station belongs, setting the virtual carrier sensing by using information included in the preamble of the first PPDU.

Here, the BSS of the first PPDU may be determined based on at least one of a BSS identifier (BSSID), a transmitter address, a receiver address, and a version information included in the first PPDU.

Here, the first threshold may be a clear channel assessment (CCA) threshold.

Here, the first threshold may be different from a threshold which is used for determining reception possibility of the

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first PPDU when the BSS of the first PPDU is the BSS to which the first station belongs.

Here, the information included in the preamble of the first PPDU may indicate a duration which is set for the virtual carrier sensing.

Here, the trying to obtain the transmission priority may be performed without set of the virtual carrier sensing.

According to exemplary embodiments, the station receiving the first PPDU can identify whether the first PPDU is transmitted from a BSS to which the station belongs or an OBSS. In a case that the first PPDU is transmitted from the BSS to which the station belongs, the station may perform a virtual carrier sensing procedure. On the contrary, in a case that the first PPDU is transmitted from the OBSS, the station may obtain a transmission opportunity.

Meanwhile, if the station does not identify the BSS from which the first PPDU is transmitted, the station may set a temporary counter based on a virtual carrier sensing procedure, and receive a second PPDU in response to the first PPDU. Also, the station may identify whether the second PPDU is transmitted from the BSS to which the station belongs or the OBSS based on information included in the second PPDU. If the second PPDU is a PPDU transmitted from the BSS to which the station belongs, the station may change the temporary counter to a formal counter based on a virtual carrier sensing procedure. On the contrary, if the second PPDU is a PPDU transmitted from an OBSS, the station may obtain a transmission opportunity.

Therefore, the station can obtain more transmission opportunities, and efficiently utilize radio channels. Also, the station can easily obtain a transmission opportunity even in an environment where stations are deployed densely. Therefore, performance of WLAN can be enhanced.

BRIEF DESCRIPTION OF DRAWINGS

Exemplary embodiments of the present disclosure will become more apparent by describing in detail exemplary embodiments of the present disclosure with reference to the accompanying drawings, in which:

FIG. **1** is a block diagram illustrating a structure of a WLAN device according to an embodiment;

FIG. **2** is a schematic block diagram illustrating a transmitting signal processing unit **100** according to an embodiment suitable for use in a WLAN;

FIG. **3** is a schematic block diagram of a receiving signal processing unit according to an embodiment suitable for use in the WLAN;

FIG. **4** illustrates interframe space (IFS) relationships;

FIG. **5** is a timing diagram illustrating a frame transmission procedure based on a CSMA (carrier sense multiple access)/CA (collision avoidance) manner for avoiding collision between frames in a channel;

FIG. **6** is a conceptual diagram illustrating cases in which a PPDU can be transmitted;

FIG. **7** is a flow chart illustrating a method for transmitting a frame according to an exemplary embodiment of the present disclosure;

FIGS. **8**A to **8**E are timing diagrams illustrating exemplary embodiments of durations for which a frame can be transmitted;

FIG. **9** is timing diagram illustrating other exemplary embodiments of durations for which a frame can be transmitted; and

FIG. **10** is a diagram to explain a method for controlling transmission opportunities of a WLAN device according to an exemplary embodiment of the present disclosure.

DETAILED DESCRIPTION

In the following detailed description, only certain embodiments of the present disclosure have been shown and described, simply by way of illustration. As those skilled in the art would realize, the described embodiments may be modified in various different ways, all without departing from the spirit or scope of the present disclosure. Accordingly, the drawings and description are to be regarded as illustrative in nature and not restrictive. Like reference numerals designate like elements throughout the specification.

In a wireless local area network (WLAN), a basic service set (BSS) includes a plurality of WLAN devices. The WLAN device may include a medium access control (MAC) layer and a physical (PHY) layer according to IEEE (Institute of Electrical and Electronics Engineers) 802.11 standard. In the plurality of WLAN devices, at least one WLAN device may be an access point and the other WLAN devices may be non-AP stations (non-AP STAs). Alternatively, all of the plurality of WLAN devices may be non-AP STAs in Ad-hoc networking. In general, the AP STA and the non-AP STAs may be collectively called the STA. However, for ease of description herein, only the non-AP STAs are referred to as the STAs.

FIG. **1** is a block diagram illustrating a structure of a WLAN device according to an embodiment.

Referring to FIG. **1**, the WLAN device **1** may include a baseband processor **10**, a radio frequency (RF) transceiver **20**, an antenna unit **30**, a memory **40**, an input interface unit **50**, an output interface unit **60**, and a bus **70**. The baseband processor **10** may perform baseband signal processing, and may include a MAC processor **11** and a PHY processor **15**.

In one embodiment, the MAC processor **11** may include a MAC software processing unit **12** and a MAC hardware processing unit **13**. The memory **40** may store software (hereinafter referred to as "MAC software") including at least some functions of the MAC layer. The MAC software processing unit **12** executes the MAC software to implement the some functions of the MAC layer, and the MAC hardware processing unit **13** may implement remaining functions of the MAC layer as hardware (hereinafter referred to "MAC hardware"). However, embodiments of the MAC processor **11** are not limited to this. The PHY processor **15** may include a transmitting (Tx) signal processing unit **100** and a receiving (Rx) signal processing unit **200**.

The baseband processor **10**, the memory **40**, the input interface unit **50**, and the output interface unit **60** may communicate with each other via the bus **70**. The RF transceiver **20** may include an RF transmitter **21** and an RF receiver **22**. The memory may further store an operating system and applications. The input interface unit **50** receives information from a user, and the output interface unit **60** outputs information to the user.

The antenna unit **30** includes one or more antennas. When multiple-input multiple-output (MIMO) or multi-user MIMO (MU-MIMO) is used, the antenna unit **30** may include a plurality of antennas.

FIG. **2** is a schematic block diagram illustrating a transmitting signal processing unit **100** according to an embodiment suitable for use in a WLAN.

Referring to FIG. **2**, a transmitting signal processing unit **100** may include an encoder **110**, an interleaver **120**, a

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mapper **130**, an inverse Fourier transformer (IFT) **140**, and a guard interval (GI) inserter **150**.

The encoder **110** encodes input data. For example, the encoder **100** may be a forward error correction (FEC) encoder. The FEC encoder may include a binary convolutional code (BCC) encoder followed by a puncturing device, or may include a low-density parity-check (LDPC) encoder.

The transmitting signal processing unit **100** may further include a scrambler for scrambling the input data before the encoding to reduce the probability of long sequences of 0s or 1s. If BCC encoding is used in the encoder, the transmitting signal processing unit **100** may further include an encoder parser for demultiplexing the scrambled bits among a plurality of BCC encoders. If LDPC encoding is used in the encoder, the transmitting signal processing unit **100** may not use the encoder parser.

The interleaver **120** interleaves the bits of each stream output from the encoder to change an order of bits. Interleaving may be applied only when BCC encoding is used. The mapper **130** maps the sequence of bits output from the interleaver to constellation points. If the LDPC encoding is used in the encoder, the mapper **130** may further perform LDPC tone mapping besides the constellation mapping.

When the MIMO or the MU-MIMO is used, the transmitting signal processing unit **100** may use a plurality of interleavers **120** and a plurality of mappers **130** corresponding to a number of spatial streams Nss. In this case, the transmitting signal processing unit **100** may further include a stream parser for dividing outputs of the BCC encoders or the LDPC encoder into blocks that are sent to different interleavers **120** or mappers **130**. The transmitting signal processing unit **100** may further include a space-time block code (STBC) encoder for spreading the constellation points from the NSS spatial streams into NSTS space-time streams and a spatial mapper for mapping the space-time streams to transmit chains. The spatial mapper may use direct mapping, spatial expansion, or beamforming.

The IFT **140** converts a block of the constellation points output from the mapper **130** or the spatial mapper to a time domain block (i.e., a symbol) by using an inverse discrete Fourier transform (IDFT) or an inverse fast Fourier transform (IFFT). If the STBC encoder and the spatial mapper are used, the inverse Fourier transformer **140** may be provided for each transmit chain.

When the MIMO or the MU-MIMO is used, the transmitting signal processing unit **100** may insert cyclic shift diversities (CSDs) to prevent unintentional beamforming. The CSD insertion may occur before or after the inverse Fourier transform. The CSD may be specified per transmit chain or may be specified per space-time stream. Alternatively, the CSD may be applied as a part of the spatial mapper. When the MU-MIMO is used, some blocks before the spatial mapper may be provided for each user.

The GI inserter **150** prepends a guard interval (GI) to the symbol. The transmitting signal processing unit **100** may optionally perform windowing to smooth edges of each symbol after inserting the GI. The RF transmitter **21** converts the symbols into an RF signal and transmits the RF signal via the antenna unit **30**. When the MIMO or the MU-MIMO is used, the GI inserter **150** and the RF transmitter **21** may be provided for each transmit chain.

FIG. **3** is a schematic block diagram of a receiving signal processing unit according to an embodiment suitable for use in the WLAN.

Referring to FIG. **3**, a receiving signal processing unit **200** may include a GI remover **220**, a Fourier transformer (FT) **230**, a demapper **240**, a deinterleaver **250**, and a decoder **260**. An RF receiver **22** receives an RF signal via the antenna unit **30** and converts the RF signal into a symbol. The GI remover **220** removes the GI from the symbol. When the MIMO or the MU-MIMO is used, the RF receiver **22** and the GI remover **220** may be provided for each receive chain.

The FT **230** converts the symbol (i.e., the time domain block) into a block of the constellation points by using a discrete Fourier transform (DFT) or a fast Fourier transform (FFT). The Fourier transformer **230** may be provided for each receive chain. When the MIMO or the MU-MIMO is used, the receiving signal processing unit **200** may include a spatial demapper for converting the Fourier transformed receiver chains to constellation points of the space-time streams, and an STBC decoder for despreading the constellation points from the space-time streams into the spatial streams.

The demapper **240** demaps the constellation points output from the Fourier transformer **230** or the STBC decoder to the bit streams. If the LDPC encoding is used, the demapper **240** may further perform LDPC tone demapping before the constellation demapping. The deinterleaver **250** deinterleaves the bits of each stream output from the demapper **240**. Deinterleaving may be applied only when BCC encoding is used.

When the MIMO or the MU-MIMO is used, the receiving signal processing unit **200** may use a plurality of demappers **240** and a plurality of deinterleavers **250** corresponding to the number of spatial streams. In this case, the receiving signal processing unit **200** may further include a stream deparser for combining the streams output from the deinterleavers **250**.

The decoder **260** decodes the streams output from the deinterleaver **250** or the stream deparser. For example, the decoder **100** may be an FEC decoder. The FEC decoder may include a BCC decoder or an LDPC decoder. The receiving signal processing unit **200** may further include a descrambler for descrambling the decoded data. If BCC decoding is used in the decoder, the receiving signal processing unit **200** may further include an encoder deparser for multiplexing the data decoded by a plurality of BCC decoders. If LDPC decoding is used in the decoder **260**, the receiving signal processing unit **100** may not use the encoder deparser.

FIG. **4** illustrates interframe space (IFS) relationships.

Referring to FIG. **4**, a data frame, a control frame, or a management frame may be exchanged between WLAN devices. The data frame is used for transmission of data forwarded to a higher layer. The WLAN device transmits the data frame after performing backoff if a distributed coordination function IFS (DIFS) has elapsed from a time when the medium has been idle.

The management frame is used for exchanging management information which is not forwarded to the higher layer. Subtype frames of the management frame include a beacon frame, an association request/response frame, a probe request/response frame, and an authentication request/response frame. The control frame is used for controlling access to the medium. Subtype frames of the control frame include a request to send (RTS) frame, a clear to send (CTS) frame, and an acknowledgement (ACK) frame. When the control frame is not a response frame of a previous frame, the WLAN device transmits the control frame after performing backoff when the DIFS has elapsed. When the control frame is the response frame of the previous frame, the WLAN device transmits the control frame without performing backoff when a short IFS (SIFS) has elapsed. The type and subtype of frame may be identified by a type field and a subtype field in a frame control field.

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On the other hand, a Quality of Service (QoS) STA may transmit the frame after performing backoff when an arbitration IFS (AIFS) for access category (AC), i.e., AIFS[AC] has elapsed. In this case, the data frame, the management frame, or the control frame which is not the response frame may use the AIFS[AC].

FIG. **5** is a timing drawing illustrating a frame transmission procedure based on a CSMA (carrier sense multiple access)/CA (collision avoidance) manner for avoiding collision between frames in a channel.

Referring to FIG. **5**, STA1 is a transmit WLAN device for transmitting data, STA2 is a receive WLAN device for receiving the data, and STA3 is a third WLAN device which may be located at an area where a frame transmitted from the STA1 and/or a frame transmitted from the STA2 can be received by the third WLAN device STA3.

The STA1 may determine whether the channel is busy by carrier sensing. The STA1 may determine the channel occupation based on an energy level on the channel or correlation of signals in the channel, or may determine the channel occupation by using a network allocation vector (NAV) timer.

When it is determined that the channel is not in use by other devices during DIFS (that is, the channel is idle), the STA1 may transmit an RTS frame to the STA2 after performing backoff Upon receiving the RTS frame, the STA2 may transmit a CTS frame as a response of the CTS frame after a SIFS.

When the STA3 receives the RTS frame, it may set the NAV timer for a transmission duration of subsequently transmitted frames (for example, a duration of SIFS+CTS frame duration+SIFS+data frame duration+SIFS+ACK frame duration) by using duration information included in the RTS frame. When the STA3 receives the CTS frame, it may set the NAV timer for a transmission duration of subsequently transmitted frames (for example, a duration of SIFS+data frame duration+SIFS+ACK frame duration) by using duration information included in the CTS frame. Upon receiving a new frame before the NAV timer expires, the STA3 may update the NAV timer by using duration information included in the new frame. The STA3 does not attempt to access the channel until the NAV timer expires.

When the STA1 receives the CTS frame from the STA2, it may transmit a data frame to the STA2 after a SIFS elapses from a time when the CTS frame has been completely received. Upon successfully receiving the data frame, the STA2 may transmit an ACK frame as a response of the data frame after a SIFS elapses.

When the NAV timer expires, the STA3 may determine whether the channel is busy by the carrier sensing. Upon determining that the channel is not in use by the other devices during DIFS after the NAV timer has expired, the STA3 may attempt the channel access after a contention window according to random backoff operation.

FIG. **6** is a conceptual diagram illustrating cases in which a PPDU can be transmitted.

Referring to FIG. **6**, a reception sensitivity (RX sensitivity) may be set as a value less than a clear channel assessment (CCA) threshold. Also, according to an exemplary embodiment, the RX sensitivity may be set identically to the CCA threshold. Also, a CCA threshold for a 'MyBSS' may be set differently from a CCA threshold for an overlapping BSS (OBSS). Here, the 'MyBSS' may be a BSS to which the first station STA1 belongs, and the OBSS may be a BSS overlapping with the BSS to which the STA1 belongs. When a received signal strength (i.e., a received signal strength indicator (RSSI) level) of a physical layer convergence procedure protocol data unit (PPDU) is equal to or higher than the RX sensitivity, the STA1 can receive the PPDU. Also, when the received signal strength of the PPDU is equal to or higher than the CCA threshold, the STA1 may determine that a channel on which the CCA is performed is busy.

In a case that a PPDU transmitted by a station belonging to MyBSS is a PPDU specified in the IEEE 802.11ax (i.e., 11ax PPDU) and a received signal strength of the PPDU is equal to or higher than the RX sensitivity and equal to or lower than the CCA threshold (i.e., **A1** region), since collisions between PPDUs can occur when the STA1 transmits a PPDU, the STA1 may not obtain a transmission opportunity (TxOP). In a case that a PPDU transmitted by a station belonging to OBSS is an 11ax PPDU and a received signal strength of the PPDU is equal to or higher than the RX sensitivity and equal to or lower than the CCA threshold (i.e., **B1** region), since possibility of collisions between PPDUs is low when the STA1 transmits a PPDU, the STA1 may obtain a transmission opportunity.

In a case that a PPDU transmitted by a station belonging to MyBSS is a legacy PPDU (i.e., a PPDU specified by versions earlier than the IEEE 802.11ax) and a received signal strength of the PPDU is equal to or higher than the RX sensitivity and equal to or lower than the CCA threshold (i.e., **C1** region), since collisions between PPDUs can occur when the STA1 transmits a PPDU, the STA1 may not obtain a transmission opportunity. Also, in a case that a PPDU transmitted by a station belonging to OBSS is a legacy frame and a received signal strength of the PPDU is equal to or higher than the RX sensitivity and equal to or lower than the CCA threshold (i.e., a **D1** region), since possibility of collisions between PPDUs is low when the STA1 transmits a PPDU, the STA1 may obtain a transmission opportunity.

Therefore, in order to enhance transmission efficiency in WLAN, it may be permitted to obtain transmission opportunities in the **B1** region and the **D1** region. For this, the STA1 should identify a region (e.g., **A1**, **B1**, **C1**, or **D1**) to which a received PPDU belongs. However, if the received PPDU is a legacy PPDU, it is not easy to identify the region (e.g., **C1** region or **D1** region) to which the received PPDU belongs.

FIG. **7** is a flow chart illustrating a method for transmitting a frame according to an exemplary embodiment of the present disclosure, FIGS. **8**A to **8**E are timing diagrams illustrating exemplary embodiments of durations for which a frame can be transmitted, and FIG. **9** is timing diagram illustrating other exemplary embodiments of durations for which a frame can be transmitted.

Referring to FIG. **7**, FIGS. **8**A to **8**E, and FIG. **9**, the STA1 may receive a first PPDU transmitted by the STA2 (**S701**). That is, when a received signal strength of the first PPDU is equal to or higher than the RX sensitivity, the STA1 can receive the first PPDU. The BSS to which the STA1 belongs may be identical to the BSS to which the STA2 belongs or may be a BSS (i.e. OBSS) overlapping the BSS to which the STA2 belongs. The STA1 may determine whether a received signal strength of the first PPDU is equal to or lower than the CCA threshold (**S702**). Here, the CCA threshold for MyBSS may be set differently from the CCA threshold for OBSS.

In a case that the received signal strength of the first PPDU is equal to or higher than the CCA threshold, the STA1 may perform a CCA procedure (**S703**). That is, a PHY processor of the STA1 may transmit a CCA indication indicating that a channel is busy to a MAC processor. Then, the MAC processor may determine that the channel is busy if it receives the CCA indication for a CCA time.

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Then, the STA1 may determine whether the BSS of the first PPDU is MyBSS or OBSS (S704). For example, the STA1 may obtain, from the first PPDU, identification information indicating a BSS (i.e., a BSS to which a station transmitting or receiving the first PPDU belongs) from which the first PPDU is transmitted, and identify the BSS of the first PPDU based on the identification information. The identification information may include at least one of a color bit, a BSS identifier (BSSID), a transmitter address, a receiver address, and a version information.

The color bit may be a color bit defined in the IEEE 802.11ah, and be included in a signal field of the first PPDU. The STA1 may obtain the color bit from the signal field of the first PPDU, and identify the BSS of the first PPDU based on the color bit. The BSSID, the transmitter address, and the receiver address may be included in a MAC header of the first PPDU. The STA1 may obtain at least one of the BSSID, the transmitter address, and the receiver address from the MAC header of the first PPDU, and determine that the BSS of the first PPDU is MyBSS when an access point indicated by the obtained information is same as an access point with which the STA1 is associated. On the contrary, when the access point indicated by the obtained information is different from the access point with which the STA1 is associated, the STA1 may determine the BSS of the first PPDU as an OBSS. The version information may indicate a WLAN version (e.g., non-HT, HT, VHT, HE, etc.) supported by the STA2 transmitting the first PPDU, and be included in the preamble or the MAC header of the first PPDU. The STA1 may obtain the version information from the preamble or MAC header of the first PPDU, and determine the BSS of the first PPDU as an OBSS when the obtained version information indicates that the STA2 supports HT or VHT.

On the basis of information included in the first PPDU, a virtual carrier sensing may be performed (S705). The virtual carrier sensing may be classified into a PHY-level virtual carrier sensing, a MAC-level virtual carrier sensing, etc. The PHY-level virtual carrier sensing may be performed based on information included in the preamble of the first PPDU (e.g., a response indication parameter (RESPONSE_INDICATION parameter), a duration field, etc.). Also, the MAC-level virtual carrier sensing may be performed based on information included in the MAC header of the first PPDU (e.g., a duration field, etc.).

In a case that the first PPDU is an 11ax PPDU and the BSS of the first PPDU is MyBSS (e.g., an A2 region in FIG. 10 to be explained later), the STA1 may perform the PHY-level virtual carrier sensing based on the information included in the preamble of the first PPDU. For example, the STA1 may set to count according to a response indication deferral (RID) or the duration field for the PHY-level virtual carrier sensing. The STA1 may set to count after the preamble of the first PPDU as illustrated in a timing diagram of FIG. 8A or after the end of the first PPDU as illustrated in a timing diagram of FIG. 8B. If the first PPDU belongs to the A2 region, the STA1 may perform the MAC-level virtual carrier sensing based on the information included in the MAC header of the first PPDU. For example, the STA1 may set a NAV based counter based on the information indicated by the duration field included in the MAC header of the first PPDU. The NAV based counter may be set after the end of the first PPDU as illustrated in the timing diagram of FIG. 8B.

In a case that the first PPDU is an 11ax PPDU and the BSS of the first PPDU is MyBSS (e.g., a B2 region in FIG. 10 to be explained later), the STA1 may perform the PHY-level virtual carrier sensing based on the information included in the preamble of the first PPDU.

In a case that the first PPDU is a legacy PPDU and the BSS of the first PPDU is MyBSS (e.g., a C2 region in FIG. 10 to be explained later), the STA1 may perform the MAC-level virtual carrier sensing based on the information included in the MAC header of the first PPDU. In a case that the first PPDU is a legacy PPDU and the BSS of the first PPDU is OBSS (e.g., a D2 region in FIG. 10 to be explained later), the STA1 may perform the MAC-level virtual carrier sensing based on the information included in the MAC header of the first PPDU. In a case that the first PPDU is a legacy PPDU and the BSS of the first PPDU is not identifiable (e.g., an E2 region in FIG. 10 to be explained later), the STA1 may perform the MAC-level virtual carrier sensing based on the information included in the MAC header of the first PPDU.

Meanwhile, in a case that a received signal strength of the first PPDU is equal to or lower than the CCA threshold, the STA1 may obtain identification information indicating a BSS from which the first PPDU is transmitted (i.e., a BSS to which a station transmitting or receiving the first PPDU belongs) from the first PPDU (S706). The identification information may be identical to those explained in the step S704.

The STA1 may determine whether the BSS from which the first PPDU is transmitted is identifiable or not based on the identification information of the first PPDU (S707). When the BSS from which the first PPDU is transmitted is identifiable based on the identification information of the first PPDU, the STA1 may determine whether the first PPDU is transmitted from the BSS to which the STA1 belongs (i.e., MyBSS) (S708). In the case that the first PPDU is an 11ax PPDU, the STA1 may identify the BSS from which the first PPDU is transmitted by using at least one of a color bit, a BSSID, a transmitter address, a receiver address, and a version information included in the first PPDU. In cases that the first PPDU is a non-HT PPDU, a HT PPDU, or a VHT PPDU, the STA1 may identify the BSS from which the first PPDU is transmitted by using at least one of a BSSID, a transmitter address, a receiver address, and a version information included in the first PPDU.

In the case that the BSS from which the first PPDU is transmitted is the BSS to which the STA1 belongs, the STA1 may perform a virtual carrier sensing (S709). The STA1 may additionally perform a CCA before performing the virtual carrier sensing. In the case that first PPDU is an 11ax PPDU (e.g., the A1 region of FIG. 10 to be explained later), the STA1 may perform the PHY-level virtual carrier sensing or the MAC-level virtual carrier sensing. When the PHY-level virtual carrier sensing is performed, the STA1 may obtain a transmission opportunity (TxOP) until the end point of the preamble of the first PPDU as illustrated in a timing diagram of FIG. 8C. However, the STA1 may lose the transmission opportunity after the preamble of the first PPDU. The STA1 may obtain a transmission opportunity until the end point of the first PPDU as illustrated in a timing diagram of FIG. 8D. However, the STA1 may lose the transmission opportunity after the first PPDU. When the MAC-level virtual carrier sensing is performed, the STA1 may obtain a transmission opportunity until the end of the first PPDU as illustrated in the timing diagram of FIG. 8D. However, the STA1 may lose the transmission opportunity after the first PPDU.

In the case that the first PPDU is a legacy PPDU (e.g., the C1 region of FIG. 10 to be explained later), the STA1 may perform the MAC-level virtual carrier sensing. For example, the STA1 may obtain a transmission opportunity until the

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end point of the first PPDU as illustrated in the timing diagram of FIG. **8**D. However, the STA**1** may lose the transmission opportunity after the first PPDU.

That is, in the case that the BSS from which the first PPDU is transmitted is the BSS to which the STA**1** belongs, since collisions between PPDUs can occur when the STA**1** transmits a PPDU, the STA**1** may not obtain a transmission opportunity.

On the contrary, in the case that the BSS from which the first PPDU is transmitted is OBSS (e.g., the B**1** region or D**1** region of FIG. **10** to be explained later), the STA**1** may not lose a transmission opportunity, and accordingly can transmit a second PPDU (S**710**). That is, since the virtual carrier sensing is not performed as illustrated in a timing diagram of FIG. **8**E, the STA**1** may not lose the transmission opportunity.

Meanwhile, in the case that the BSS from which the first PPDU is transmitted is not identifiable based on the identification information of the first PPDU (e.g., the E**1** region of FIG. **10**), the STA**1** may set a temporary counter according to a virtual carrier sensing based on the information included in the first PPDU (S**711**). For example, in a case that the first PPDU is a CTS frame in response to a RTS frame, since the CTS frame includes only a receiver address among a transmitter address and a receiver address, the STA**1** may not identify the BSS from which the first PPDU is transmitted. Although the STA**1** may obtain a transmission opportunity until the end of the preamble of the first PPDU as illustrated in a timing diagram of FIG. **9**, the STA**1** may lose the transmission opportunity from a time point when the temporary counter is set. Here, the temporary counter may be changed to a formal counter, reset to **0**, or canceled according to a BSS from which a third PPDU in response to the first PPDU is transmitted. The formal counter may be a counter which is set based on a virtual carrier sensing procedure defined in the IEEE 802.11.

Then, the STA**1** may receive the third PPDU in response to the first PPDU (S**712**). For example, if the first PPDU is a CTS frame in response to a RTS frame, the third PPDU may be a data frame in response to the CTS frame. The STA**1** may obtain identification information indicating a BSS from which the third PPDU is transmitted from the third PPDU (S**713**), and identify whether the third PPDU is transmitted from the BSS to which the STA**1** belongs based on the obtained identification information (S**714**). That is, in the case that the BSS from which the current PPDU is transmitted is not identifiable based on the identification information of the current PPDU, the STA**1** can identify the BSS from which the current PPDU is transmitted based on identification information of a PPDU subsequent to the current PPDU.

In the case that the BSS from which the third PPDU is transmitted is the BSS to which the STA**1** belongs, the STA**1** may change the temporary counter to a formal counter (e.g., a counter based on a MAC-level virtual carrier sensing procedure) based on the information included in the first PPDU or the third PPDU (S**715**). That is, as illustrated in the timing diagram of FIG. **9**, the STA**1** may change the temporary counter to the formal counter at the end point of the third PPDU (or, at the end point of the preamble of the third PPDU). On the contrary, in the case that the BSS from which the third PPDU is transmitted is OBSS, the STA**1** may obtain a transmission opportunity, and accordingly can transmit the fourth PPDU (S**716**). That is, as illustrated in the timing diagram of FIG. **9**, the STA**1** may cancel the temporary counter or set the temporary counter as 0 at the end point of the third PPDU (or, at the end point of the preamble of the third PPDU), and accordingly can obtain a transmission opportunity.

FIG. **10** is a diagram to explain a method for controlling transmission opportunities of a WLAN device according to an exemplary embodiment of the present disclosure. Although the CCA thresholds for OBSS and MyBSS are illustrated as identical, they may be different from each other. Especially, the CCA threshold for OBSS may be higher than the CCA threshold for MyBSS.

A PHY header (e.g., a preamble) of a frame defined in the IEEE 802.11ax (hereinafter, referred to as '11ax frame' or 'HE frame') may include BSS identification information (field) such as a BSS color field (or, a color bit) and information (field) for setting a duration for a virtual carrier sensing. Here, a frame may be a PPDU which has been explained. In the present description, the 11 ax frame may include a frame according to versions after the IEEE 802.11ax. A PHY header of a legacy frame (e.g., a non-HT frame, a HT frame, a VHT frame, etc.) does not include a BSS color field and information (field) for setting a duration for a virtual carrier sensing.

The fact that a received signal strength of a received frame is lower than a RX sensitivity may mean that a station cannot receive a frame having a valid PHY header. Also, the fact that a received signal strength of a received frame is higher than a RX sensitivity may mean that a station can receive a frame having a valid PHY header.

The set of the PHY-level virtual carrier sensing performed by a station may mean that the station sets a duration for the virtual carrier sensing by using information (field) of a valid PHY header. Also, the set of the MAC-level virtual carrier sensing performed by a station may mean that the station sets a duration for the virtual carrier sensing by using information (duration/ID field) of a MAC header in a MAC PDU (MPDU). The duration for the virtual carrier sensing may mean a duration in which a station deems a channel as busy regardless of a received signal strength.

If the received signal strength of the received frame is lower than the RX sensitivity, the station may obtain a transmission opportunity.

If the received signal strength of the received frame is higher than the RX sensitivity, the station may obtain a valid PHY header and MAC header from the received frame, and identify version information of the received frame. For example, the station may identify the received frame as one of a non-HT frame, a HT frame, a VHT frame, and a HE frame (11ax frame).

The MAC headers of the non-HT frame, the HT frame, the VHT frame, and the HE frame may include a MAC address. Especially, they may include at least one of a transmitter address (TA) and a receiver address (RA).

Also, the station may identify a BSS of the received frame based on version information of at least one of the PHY header, the MAC header, and the received frame. Also, a case that the BSS of the received frame cannot be identified even though the version information of the PHY header, the MAC header, and the received frame is used may exist.

For example, if the received frame is an 11ax frame and the PHY header of the received frame has BSS identification information such as a BSS color field, the station may identify whether the received frame is a MyBSS frame or an OBSS frame based on the PHY header, specifically based on the BSS identification information of the PHY header.

If the received frame is not an 11ax frame and the PHY header of the received frame does not have BSS identification information, the station may identify whether the

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received frame is a MyBSS frame or an OBSS frame by using the MAC address of the MAC header of the received frame. For example, if the MAC header of the received frame includes both a TA address and a RA address, the HE station may compare a BSSID of its access point with the TA and RA of the received frame, and determine that the received frame is a MyBSS frame when at least one of the TA and RA coincides with the BSSID of its access point. The HE station may determine that the received frame is an OBSS frame when any one of the TA and RA does not coincide with the BSSID of its access point. However, since a frame such as a CTS frame has only a RA, the HE station cannot identify whether the received frame is a MyBSS frame or an OBSS frame, for all non-HE frames.

In order to identify whether the received frame is a MyBSS frame or not, the HE station may also use a version of the received frame. When the PHY header of the received frame does not have BSS identification information and the received frame is a HT frame or a VHT frame, the HE station may determine that the received frame is an OBSS frame.

If the PHY header of the received frame does not have BSS identification information and the received frame is a non-HT frame, the HE station may not determine whether the received frame is a MyBSS frame or an OBSS frame with easiness. The reason is that the HE station also uses non-HT control frames such as a RTS frame and a CTS frame. As described above, in the case that a non-HT frame such as a RTS frame has both a TA address and a RA address, it can be determined whether the received frame is a MyBSS frame or an OBSS frame. However, since a frame such as a CTS frame has not a TA but a RA, the HE station cannot identify whether the received frame is a MyBSS frame or an OBSS frame for all non-HE frames.

If the received frame is an 11ax frame and a MyBSS frame, and the received signal strength of the received frame is higher than the RX sensitivity and lower than the CCA threshold for MyBSS, the station may not obtain a transmission opportunity, and may set a PHY-level virtual carrier sensing or a MAC-level virtual carrier sensing (A1 region). Since the received frame is an 11ax frame, the HE station may easily identify whether the received frame is a MyBSS frame based on the BSS color field of the PHY header. In a case that the station can obtain a MAC header, the station may set the MAC-level virtual carrier sensing. On the contrary, in a case that the station cannot obtain a MAC header, the station may set the PHY-level virtual carrier sensing. Since the received frame is an 11ax frame including a PHY header comprising information for setting a virtual carrier sensing, the station may set the PHY-level virtual carrier sensing without necessity of reading the MAC header for power saving.

If the received frame is an 11ax frame and a MyBSS frame, and the received signal strength of the received frame is higher than the CCA threshold for MyBSS, the station may not obtain a transmission opportunity, and may set a PHY-level virtual carrier sensing or a MAC-level virtual carrier sensing (A2 region). Since the received frame is an 11ax frame, the HE station may easily identify whether the received frame is a MyBSS frame based on the BSS color field of the PHY header. In a case that the station can obtain a MAC header, the station may set the MAC-level virtual carrier sensing. On the contrary, in a case that the station cannot obtain a MAC header, the station may set the PHY-level virtual carrier sensing. Since the received frame is an 11ax frame including a PHY header comprising information for setting a virtual carrier sensing, the station may set the PHY-level virtual carrier sensing without necessity of reading the MAC header for power saving.

If the received frame is an 11ax frame and an OBSS frame, and the received signal strength of the received frame is higher than the RX sensitivity and lower than the CCA threshold for OBSS, the station may try to obtain a transmission opportunity (B1 region). That is, the station may try to obtain a transmission opportunity based on a spatial reuse scheme.

If the received frame is an 11ax frame and an OBSS frame, and the received signal strength of the received frame is higher than the CCA threshold for OBSS, the station may not obtain a transmission opportunity, and may set a virtual carrier sensing (B2 region). Since the received frame is an 11ax frame including a PHY header comprising information for setting a virtual carrier sensing, the station may set the PHY-level virtual carrier sensing without necessity of reading the MAC header for power saving.

Even when the received frame is a legacy frame, if the received frame is identified as a MyBSS frame, and the received signal strength of the received frame is higher than the RX sensitivity and lower than the CCA threshold for MyBSS, the station may not obtain a transmission opportunity, and may set a MAC-level virtual carrier sensing (C1 region). Since the received frame is a legacy frame which does not include a PHY header comprising information for setting a virtual carrier sensing, the station may set the MAC-level virtual carrier sensing.

Even when the received frame is a legacy frame, if the received frame is identified as a MyBSS frame, and the received signal strength of the received frame is higher than the CCA threshold for MyBSS, the station may not obtain a transmission opportunity, and may set a PHY-level virtual carrier sensing or a MAC-level virtual carrier sensing (C2 region). Since the received frame is a legacy frame which does not include a PHY header comprising information for setting a virtual carrier sensing, the station may set the MAC-level virtual carrier sensing.

Even when the received frame is a legacy frame, if the received frame is identified as an OBSS frame, and the received signal strength of the received frame is higher than the RX sensitivity and lower than the CCA threshold for OBSS, the station may try to obtain a transmission opportunity (D1 region). That is, the station may try to obtain a transmission opportunity based on a spatial reuse scheme.

Even when the received frame is a legacy frame, if the received frame is identified as an OBSS frame, and the received signal strength of the received frame is higher than the CCA threshold for OBSS, the station may not obtain a transmission opportunity, and may set a virtual carrier sensing (D2 region). Since the received frame is a legacy frame which does not include a PHY header comprising information for setting a virtual carrier sensing, the station may set the MAC-level virtual carrier sensing.

If the station cannot identify whether the received frame is a MyBSS frame or an OBSS frame, and the received signal strength of the received frame is higher than the RX sensitivity and lower than the CCA threshold for MyBSS, the station cannot determine to set a virtual carrier sensing or to obtain a transmission opportunity for spatial reuse. Therefore, for this case, the station may set a temporary level virtual carrier sensing (E1 region). For example, the station may set a temporary duration for a virtual carrier sensing by using information (duration/ID field) of a MAC header in a MPDU. In this case, the temporary duration may be a temporary NAV. The temporary duration may be updated or reset based on information in a PHY header or a MAC

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header of a frame subsequent to the received frame. In an exemplary embodiment, when the station receives a frame such as a CTS frame, which cannot be identified as a MyBSS frame or an OBSS frame, the station may set a temporary duration for a virtual carrier sensing together with a MAC address of a receiving station. After then, if the station receives a subsequent frame having a MAC address identical to the MAC address which is set with the temporary duration, and the station can determine that the subsequent frame is a MyBSS frame since the subsequent frame belongs to regions A1, A2, B1, B2, C1, C2, D1, and D2, the station may set a PHY-level virtual carrier sensing or a MAC-level virtual carrier sensing. Also, if the station can identify that the subsequent frame is an OBSS frame, the station may reset the temporary duration, and obtain a transmission opportunity.

If the station cannot identify whether the received frame is a MyBSS frame or an OBSS frame, and the received signal strength of the received frame is higher than the CCA threshold for MyBSS, the station may set a virtual carrier sensing without necessity of identifying whether the received frame is a MyBSS frame or an OBSS frame (E2 region). Specifically, since a PHY header of a legacy frame does not include information (field) for setting a virtual carrier sensing, the station may set a MAC-level virtual carrier sensing.

While the example embodiments of the present disclosure and their advantages have been described in detail, it should be understood that various changes, substitutions and alterations may be made herein without departing from the scope of the disclosure.

What is claimed is:

1. A method for transmitting a frame, performed in a first station, the method comprising:

receiving a first physical layer (PHY) protocol data unit (PPDU);

determining whether a basic service set (BSS) of the first PPDU is a BSS to which the first station belongs or a BSS to which the first station does not belong;

when the BSS of the first PPDU is the BSS to which the first station does not belong, a received signal strength of the first PPDU is higher than a first threshold, and the first PPDU is a frame having a mode that is High Efficiency and having a PHY header that includes duration information for setting a virtual carrier sensing, setting a PHY-level virtual carrier sensing, wherein setting the PHY-level virtual carrier sensing includes setting a virtual carrier sensing by using the duration information included in a the PHY header of the first PPDU;

when the BSS of the first PPDU is the BSS to which the first station does not belong, the received signal strength of the first PPDU is higher than the first threshold, the first PPDU is a frame having a mode of a standard previous to a standard defining the High Efficiency mode, and the first PPDU is a frame having a PHY header that does not include duration information for setting the virtual carrier sensing, setting a medium access control (MAC)-level virtual carrier sensing, wherein setting the MAC-level virtual carrier sensing includes setting the virtual carrier sensing by using duration information included in a MAC header of the first PPDU; and

when the BSS of the first PPDU is the BSS to which the first station does not belong and the received signal strength of the first PPDU is lower than the first threshold, attempting to obtain a transmission opportunity.

2. The method according to claim 1, further comprising, when the BSS of the first PPDU is the BSS to which the first station belongs, setting a virtual carrier sensing by using information included in the PHY header of the first PPDU.

3. The method according to claim 1, wherein the BSS of the first PPDU is determined based on at least one of a BSS identifier (BSSID), a transmitter address, a receiver address, and a version information included in the first PPDU.

4. The method according to claim 1, wherein the first threshold is a clear channel assessment (CCA) threshold.

5. The method according to claim 1, wherein the first threshold is different from a threshold which is used for determining reception possibility of the first PPDU when the BSS of the first PPDU is the BSS to which the first station belongs.

6. The method according to claim 1, wherein the information included in the PHY header of the first PPDU indicates a duration which is set for the virtual carrier sensing.

7. The method according to claim 1, wherein attempting to obtain the transmission priority is performed without setting of the virtual carrier sensing.

8. A station comprising:

a processor; and

a memory storing at least one instruction executed by the processor, to perform:

receiving a first physical layer (PHY) protocol data unit (PPDU);

determining whether a basic service set (BSS) of the first PPDU is a BSS to which the first station belongs or a BSS to which the first station does not belong;

when the BSS of the first PPDU is the BSS to which the first station does not belong, a received signal strength of the first PPDU is higher than a first threshold, and the first PPDU is a frame having a mode that is High Efficiency and having a PHY header that includes duration information for setting a virtual carrier sensing, setting a PHY-level virtual carrier sensing, wherein setting the PHY-level virtual carrier sensing includes setting a virtual carrier sensing by using the duration information included in a PHY header of the first PPDU;

when the BSS of the first PPDU is the BSS to which the first station does not belong, the received signal strength of the first PPDU is higher than the first threshold, the first PPDU is a frame having a mode of a standard previous to a standard defining the High Efficiency mode, and the first PPDU is a frame having a PHY header that does not include duration information for setting the virtual carrier sensing, setting a medium access control (MAC)-level virtual carrier sensing, wherein setting the MAC-level virtual carrier sensing includes setting the virtual carrier sensing by using duration information included in a MAC header of the first PPDU; and

when the BSS of the first PPDU is the BSS to which the first station does not belong and the received signal strength of the first PPDU is lower than the first threshold, attempting to obtain a transmission opportunity.

9. The station according to claim 8, wherein the at least one instruction further executes, when the BSS of the first PPDU is the BSS to which the first station belongs, setting

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the virtual carrier sensing by using information included in the PHY header of the first PPDU.

10. The station according to claim **8**, wherein the BSS of the first PPDU is determined based on at least one of a BSS identifier (BSSID), a transmitter address, a receiver address, and a version information included in the first PPDU.

11. The station according to claim **8**, wherein the first threshold is a clear channel assessment (CCA) threshold.

12. The station according to claim **8**, wherein the first threshold is different from a threshold which is used for determining reception possibility of the first PPDU when the BSS of the first PPDU is the BSS to which the first station belongs.

13. The station according to claim **8**, wherein the information included in the PHY header of the first PPDU indicates a duration which is set for the virtual carrier sensing.

14. The station according to claim **8**, wherein attempting to obtain the transmission priority is performed without set of the virtual carrier sensing.

* * * * *

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EXHIBIT 5

U 9146575

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United States Patent and Trademark Office

August 23, 2021

THIS IS TO CERTIFY THAT ANNEXED HERETO IS A TRUE COPY FROM THE RECORDS OF THIS OFFICE OF:

U.S. PATENT: *9,912,513*
ISSUE DATE: *March 06, 2018*

By Authority of the
Under Secretary of Commerce for Intellectual Property
and Director of the United States Patent and Trademark Office

SYLVIA HOLLEY
Certifying Officer

ATLAS-00014189

US009912513B2

(12) United States Patent
Kwon

(10) Patent No.: US 9,912,513 B2
(45) Date of Patent: *Mar. 6, 2018

(54) **SYSTEM AND METHOD FOR SYNCHRONIZATION FOR OFDMA TRANSMISSION**

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(73) Assignee: **NEWRACOM, INC.**, Irvine, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

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(22) Filed: **Jul. 6, 2016**

(65) **Prior Publication Data**

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(Continued)

(51) **Int. Cl.**
H04W 4/00 (2009.01)
H04J 3/06 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H04L 27/2665*** (2013.01); ***H04B 7/0452*** (2013.01); ***H04L 5/0007*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC H04L 27/2665
See application file for complete search history.

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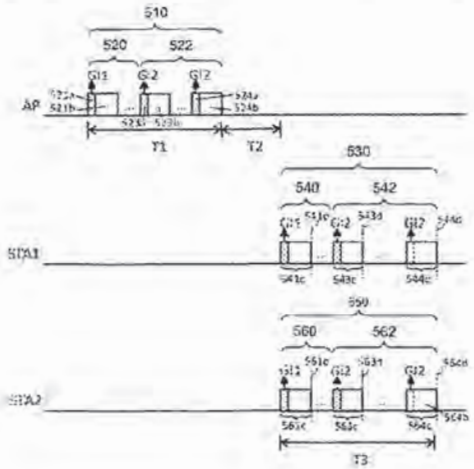
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Primary Examiner — Gerald Smarth
(74) *Attorney, Agent, or Firm* — McDermott Will & Emery LLP

(57) **ABSTRACT**

In an example of wireless communications, an access point may send a downlink frame to multiple stations. The downlink frame may include information indicative of a cyclic prefix length to be utilized by the stations. In response, some or all of the stations may transmit their respective uplink frames to the access point. A cyclic prefix for a portion of each respective uplink frame may have a cyclic prefix length corresponding to the information included in the downlink frame. The downlink frame may be, for example, a beacon frame or a trigger frame. A trigger frame may allocate resources for uplink orthogonal frequency division multiple access (OFDMA) transmission. Other methods, apparatus, and computer-readable media are also disclosed.

19 Claims, 10 Drawing Sheets



Related U.S. Application Data

(60) Provisional application No. 62/061,503, filed on Oct. 8, 2014.

(51) **Int. Cl.**

H04L 27/26	(2006.01)
H04W 56/00	(2009.01)
H04B 7/0452	(2017.01)
H04L 5/00	(2006.01)
H04W 84/12	(2009.01)

(52) **U.S. Cl.**
CPC ***H04L 27/2666*** (2013.01); ***H04W 56/00*** (2013.01); *H04W 84/12* (2013.01)

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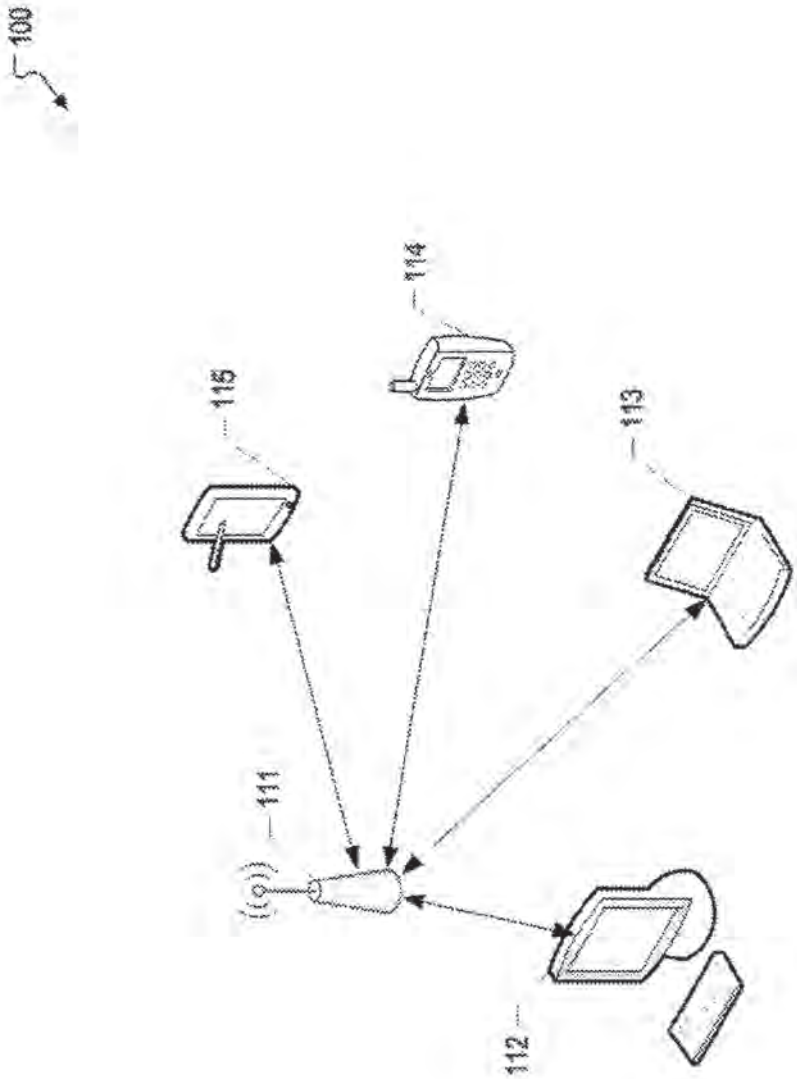


FIG. 1

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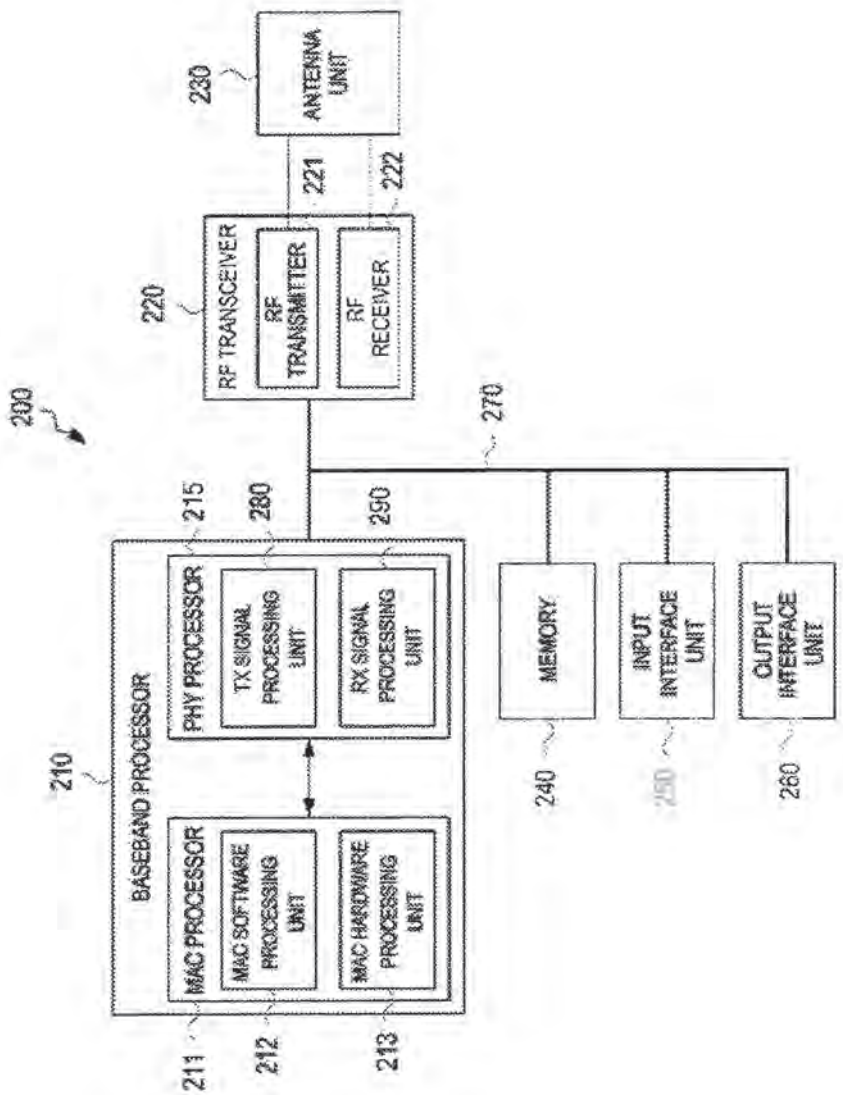


FIG. 2

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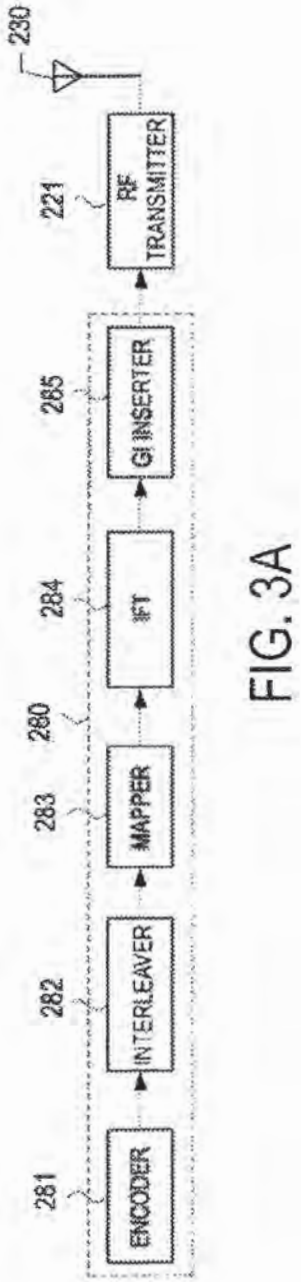


FIG. 3A

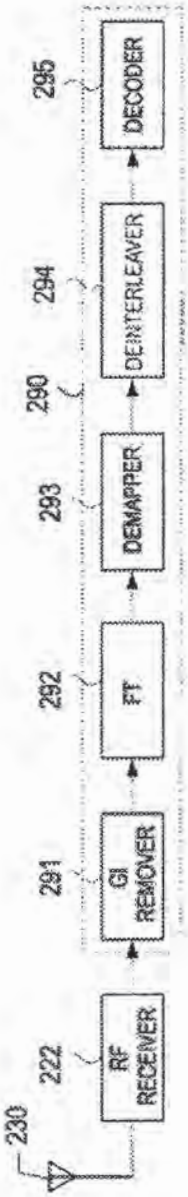


FIG. 3B

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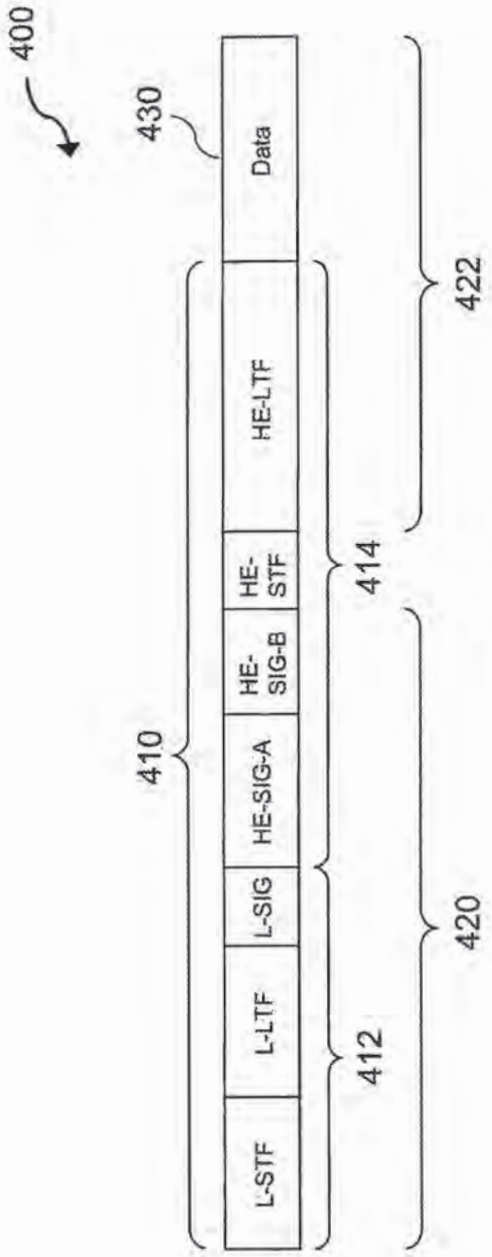


FIG. 4

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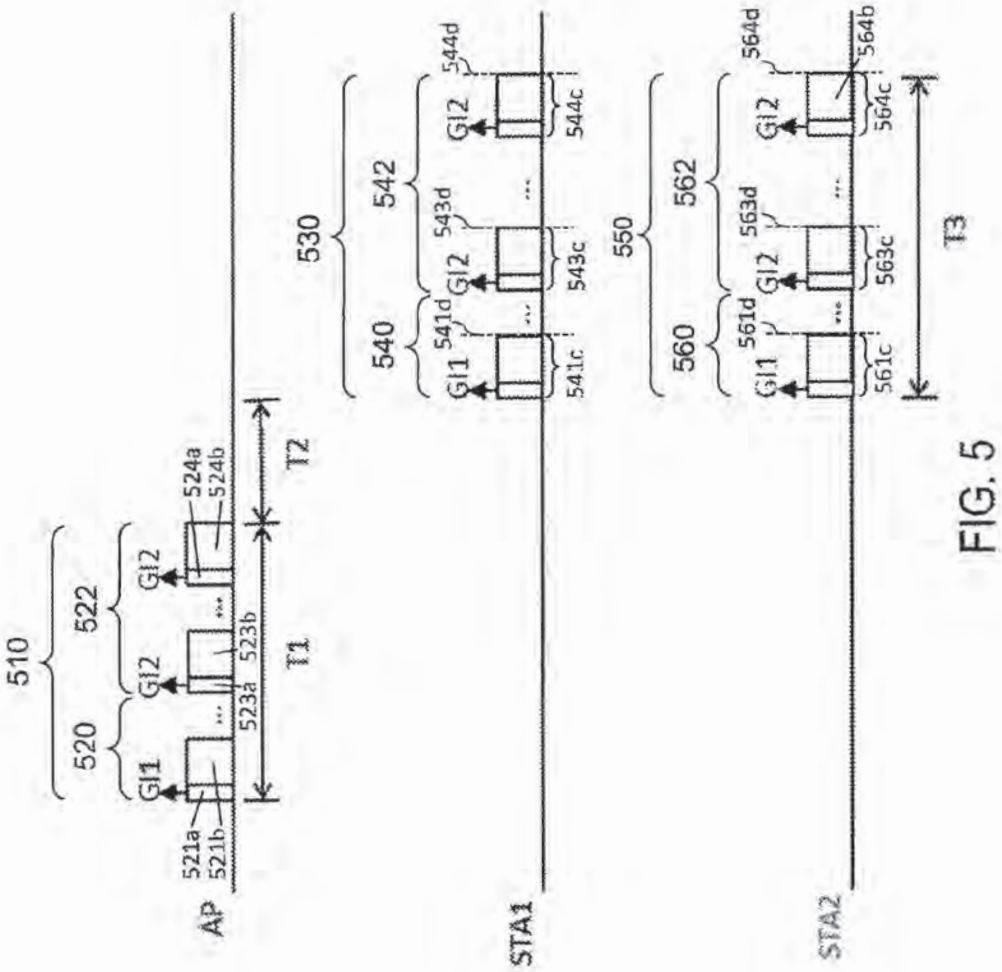


FIG. 5

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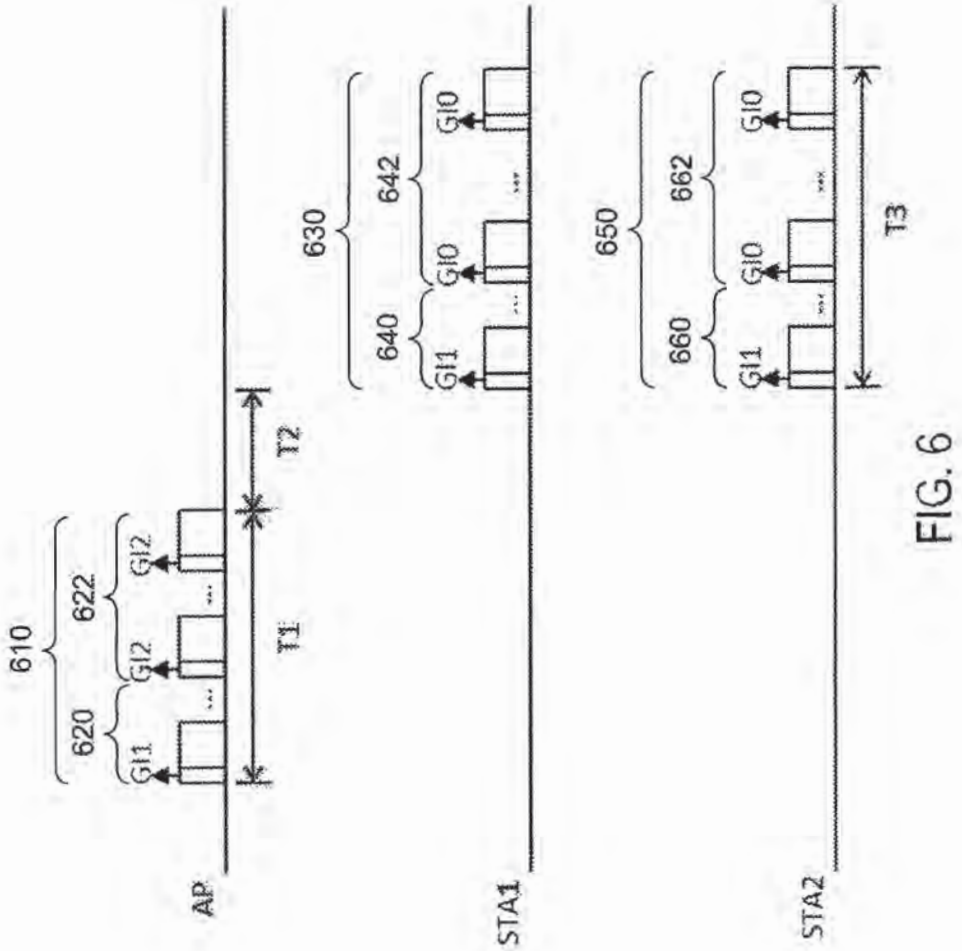


FIG. 6

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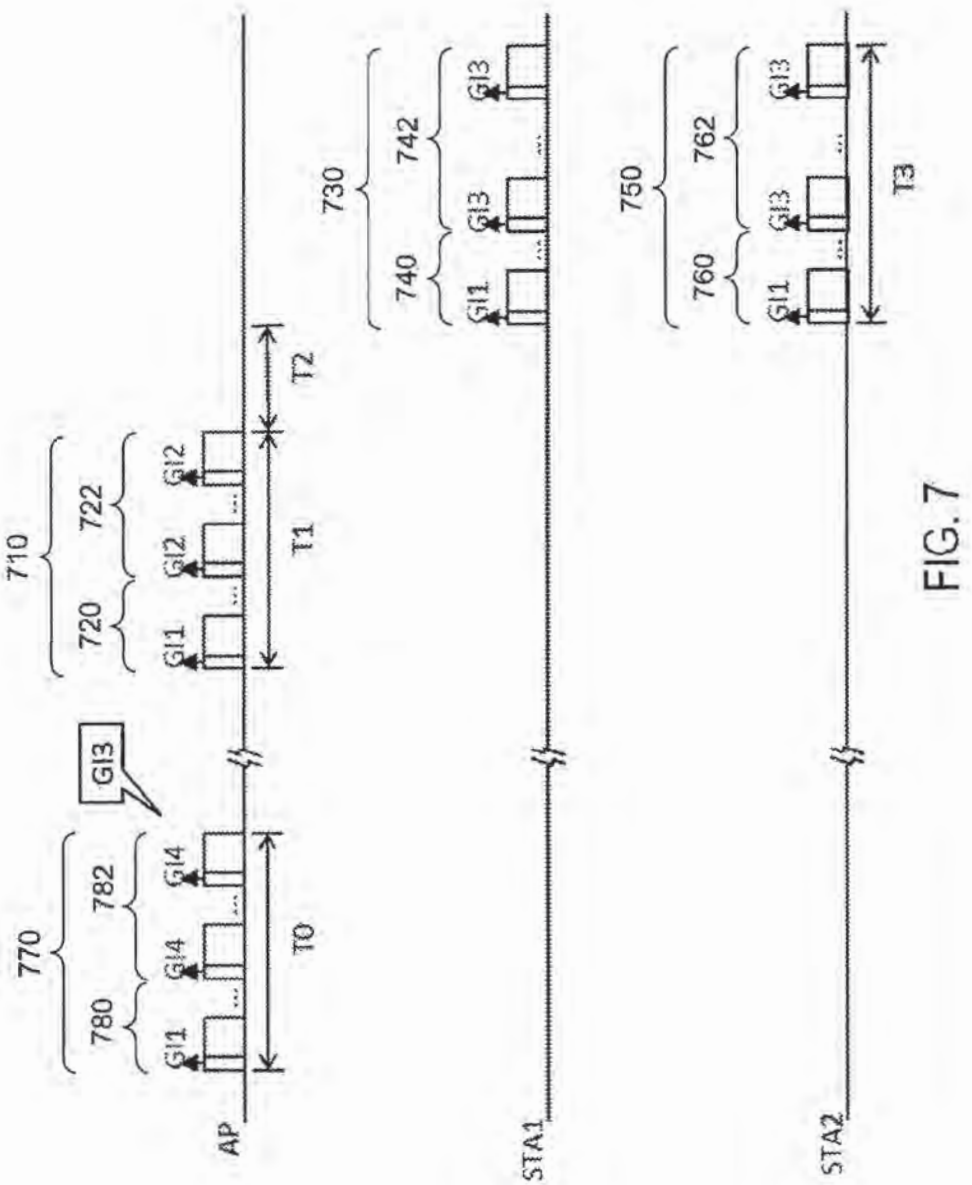


FIG. 7

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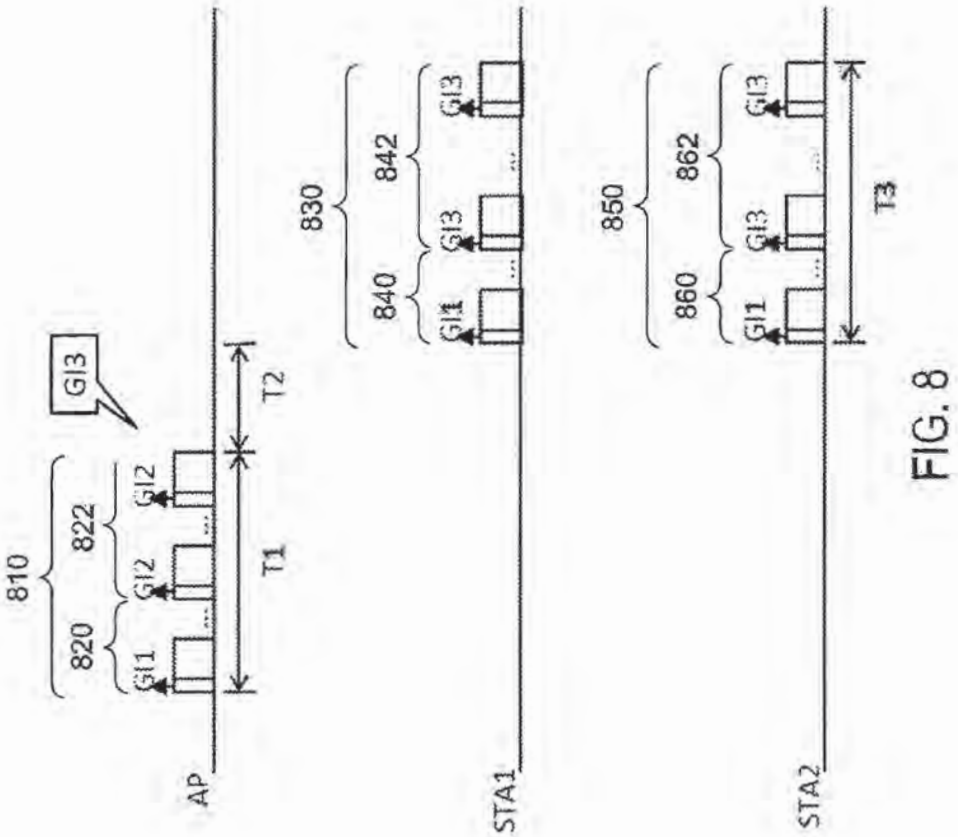


FIG. 8

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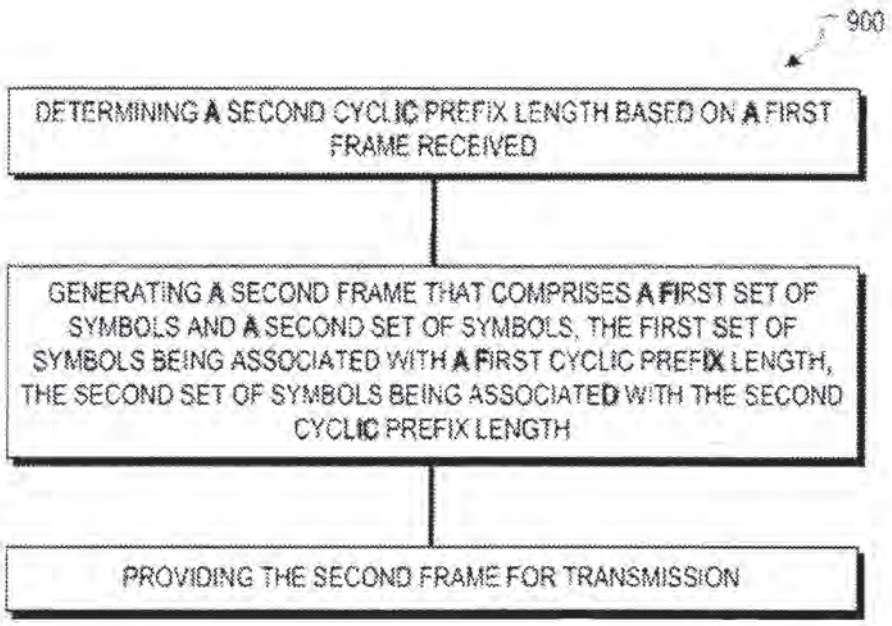


FIG. 9A

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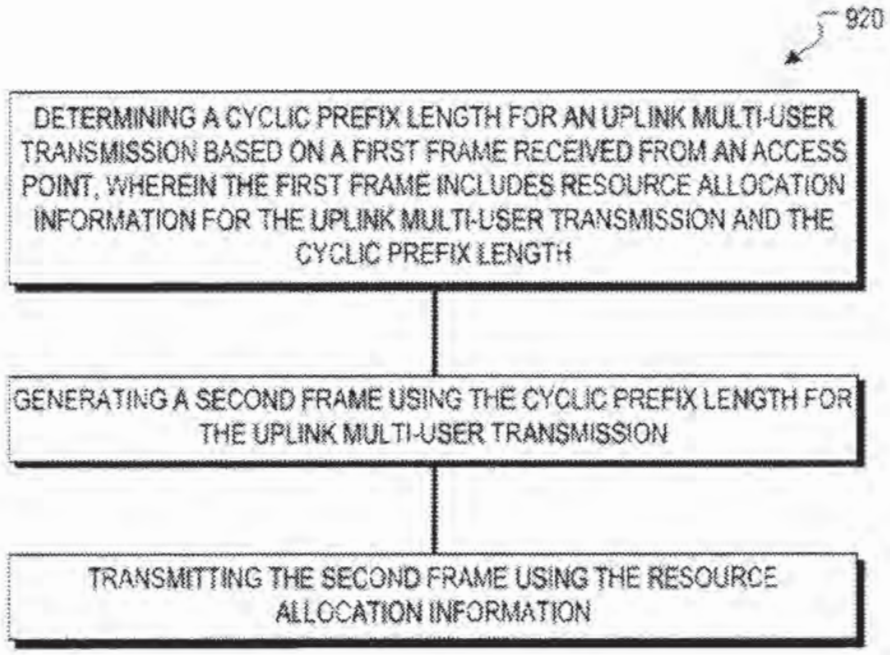


FIG. 9B

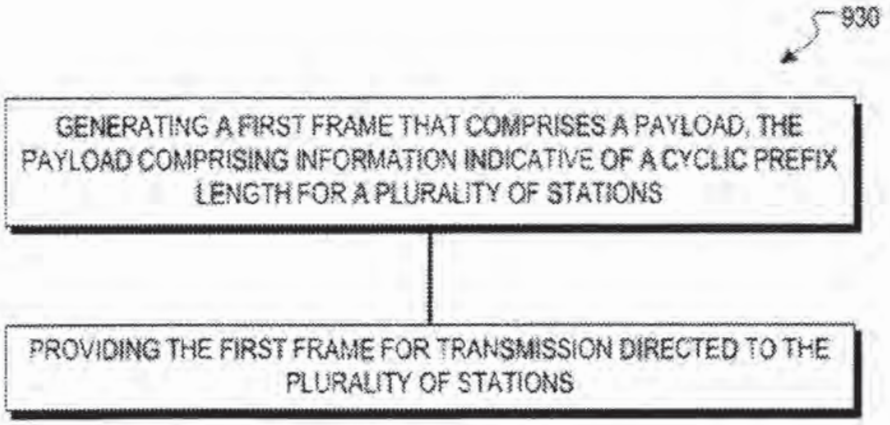


FIG. 9C

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SYSTEM AND METHOD FOR SYNCHRONIZATION FOR OFDMA TRANSMISSION

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 14/868,303, filed on Sep. 28, 2015, entitled "SYSTEM AND METHOD FOR SYNCHRONIZATION FOR OFDMA TRANSMISSION," which in turn claims the benefit of priority from U.S. Provisional Application No. 62/061,503, entitled "SYSTEM AND METHOD FOR SYNCHRONIZATION OF OFDMA TRANSMISSION," filed Oct. 8, 2014, each of which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

The present description relates in general to wireless communication systems and methods, and more particularly to, for example, without limitation, systems and methods for synchronization for orthogonal frequency division multiple access (OFDMA) transmission.

BACKGROUND

Wireless local area network (WLAN) devices are deployed in diverse environments. These environments are generally characterized by the existence of access points and non-access point stations. Increased interference from neighboring devices gives rise to performance degradation. Additionally, WLAN devices are increasingly required to support a variety of applications such as video, cloud access, and offloading. In particular, video traffic is expected to be the dominant type of traffic in many high efficiency WLAN deployments. With the real-time requirements of some of these applications, WLAN users demand improved performance in delivering their applications, including improved power consumption for battery-operated devices.

The description provided in the background section should not be assumed to be prior art merely because it is mentioned in or associated with the background section. The background section may include information that describes one or more aspects of the subject technology.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates a schematic diagram of an example of a wireless communication network.

FIG. **2** illustrates a schematic diagram of an example of a wireless communication device.

FIG. **3A** illustrates a schematic block diagram of an example of a transmitting signal processor in a wireless communication device.

FIG. **3B** illustrates a schematic block diagram of an example of a receiving signal processor in a wireless communication device.

FIG. **4** illustrates an example of a high efficiency frame.

FIG. **5** illustrates a schematic diagram of an example of an exchange of frames among wireless communication devices for OFDMA transmission.

FIG. **6** illustrates a schematic diagram of an example of an exchange of frames among wireless communication devices for OFDMA transmission.

FIG. **7** illustrates a schematic diagram of an example of an exchange of frames among wireless communication devices for OFDMA transmission.

FIG. **8** illustrates a schematic diagram of an example of an exchange of frames among wireless communication devices for OFDMA transmission.

FIGS. **9A** through **9C** illustrate flow charts of examples of methods for facilitating wireless communication.

In one or more implementations, not all of the depicted components in each figure may be required, and one or more implementations may include additional components not shown in a figure. Variations in the arrangement and type of the components may be made without departing from the scope of the subject disclosure. Additional components, different components, or fewer components may be utilized within the scope of the subject disclosure.

DETAILED DESCRIPTION

The detailed description set forth below is intended as a description of various implementations and is not intended to represent the only implementations in which the subject technology may be practiced. As those skilled in the art would realize, the described implementations may be modified in various different ways, all without departing from the scope of the present disclosure. Accordingly, the drawings and description are to be regarded as illustrative in nature and not restrictive.

Multi-user (MU) transmission in next-generation WLAN systems include techniques such as downlink/uplink (DL/UL) MU multiple-input/multiple-output (MIMO) and DL/UL orthogonal frequency division multiple access (OFDMA). During the standardization activities of the Institute of Electrical and Electronics Engineers (IEEE) 802.11, Task Group ax, OFDMA technology is introduced to provide a multiple access scheme to improve network efficiency. OFDMA is a technology that allows multiple stations (STAs) to transmit frames simultaneously using non-overlapping frequency-time resources.

In OFDMA transmission, if frames transmitted by different stations are not synchronized at a receiver side (e.g., at an access point), the receiver may have difficulty correctly decoding the frames. In one or more aspects, a trigger frame may be utilized to facilitate maintaining of synchronization among the participating stations for MU simultaneous transmission in OFDMA.

In one or more aspects, a trigger frame may be a frame sent by an access point (AP) that seeks data, control, or management frame response(s) from stations that participate in a subsequent uplink (UL) MU frame. The trigger frame may be utilized to initiate the MU simultaneous transmission in OFDMA. By way of non-limiting example, a trigger frame may include some or all of the following features: (a) a list of STAs that an AP seeks a response from; (b) resource allocation information for each STA (e.g., a sub-band assigned to each STA); and/or (c) attributes of the expected UL MU frame, such as the duration, bandwidth, etc., among other features. The term "resource" may refer to, for example, bandwidth, time/duration that the STAs expect to occupy a transmission medium, and/or possibly a number of spatial streams that the STAs may use. In one or more aspects, a trigger frame may include information for a guard interval (GI) duration and/or the fast Fourier transform (FFT) size to be used for at least some symbols of an UL frame.

In one or more aspects, a data transmission procedure using a trigger frame may be provided as follows. An AP

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sends a trigger frame to participating STAs, where the trigger frame includes resource allocation information for the participating STAs. Each of the participating STAs may send its respective UL frame in its assigned resource at a predetermined time after receiving the trigger frame. Each of the participating STAs may monitor frames transmitted by the AP, such as beacon frames, and compensate frequency offset before the participating STA transmits its respective UL frame. For example, the participating STAs may perform frequency/time offset compensation by aligning their respective clock to a clock associated with the AP. The alignment of the clocks may also allow for time synchronization between the participating STAs and the AP. Accordingly, the trigger frame for the AP may facilitate time/frequency synchronization, which in turn may facilitate synchronization for OFDMA transmission.

In one or more implementations, in addition to time/frequency synchronization, each participating STA may be configured to use the same orthogonal frequency division multiplexing (OFDM) symbol duration as the other participating STAs to further facilitate synchronization of the OFDMA transmission. The configuring of the participating STAs may be based on information (e.g., from the AP) indicative of guard interval durations to be utilized by the participating STAs. The OFDM symbol duration of the participating STAs may be referred to as being aligned when the OFDM symbol duration is the same among the participating STAs. Conversely, if the STAs have different OFDM symbol durations from one another (e.g., the OFDM symbol durations are not aligned between the various STAs), a receiver of the OFDM symbols (e.g., the AP) may have greater difficulty correctly decoding the frames received from the STAs.

In one or more aspects, to maintain the same OFDM symbol duration among the participating STAs, the GI periods, associated with the OFDM symbols of the participating STAs, are aligned. In one or more aspects, mechanisms are provided to enable all participating STAs to use the same GI duration (or the same OFDM symbol duration).

In one or more implementations, a method is provided for aligning the OFDM symbol durations from multiple STAs based on setting a guard interval utilized by the participating STAs. The aligning of the OFDM symbol durations allows synchronization of OFDM symbol boundaries when the multiple STAs transmit frames simultaneously, such as for OFDMA transmission. In some aspects, the aligning of the OFDM symbol durations of multiple STAs may be referred to as aligning the OFDM symbol boundaries of the multiple STAs, synchronizing the OFDM symbols of the multiple STAs, or synchronizing the OFDM symbol boundaries of the multiple STAs.

In one or more implementations, the method may include receiving at a first station a first frame (e.g., a downlink frame), where the first frame includes information on resource allocation that the first station is scheduled to transmit a frame (e.g., an uplink frame). The method may further include sending, by the first station, a second frame (e.g., an uplink frame), where the guard interval of each OFDM symbol of a portion (e.g., a payload portion) of the second frame is the same as that of a portion (e.g., the payload portion) of the first frame.

In one aspect, each of the first and second frames includes a respective first part and a respective second part. A guard interval duration associated with the second part of the second frame may be based on information (e.g., a value) contained in the first frame that is indicative of the guard interval duration.

In some aspects, the first part of the first frame is associated with a first FFT size, and the second part of the first frame is associated with a second FFT size different from the first FFT size. In some aspects, the first part of the second frame is associated with a third FFT size, and the second part of the second frame is associated with a fourth FFT size different from the third FFT size. In one aspect, the third FFT size is the same as the first FFT size. In one aspect, the fourth FFT size is the same as the second FFT size.

FIG. **1** illustrates a schematic diagram of an example of a wireless communication network **100**. In the wireless communication network **100**, such as a wireless local area network (WLAN), a basic service set (BSS) includes a plurality of wireless communication devices (e.g., WLAN devices). In one aspect, a BSS refers to a set of STAs that can communicate in synchronization, rather than a concept indicating a particular area. In the example, the wireless communication network **100** includes wireless communication devices **111-115**, which may be referred to as stations (STAs).

Each of the wireless communication devices **111-115** may include a media access control (MAC) layer and a physical (PHY) layer according to an IEEE 802.11 standard. In the example, at least one wireless communication device (e.g., device **111**) is an access point (AP). An AP may be referred to as an AP STA or an AP device. The other wireless communication devices (e.g., devices **112-115**) may be non-AP STAs. Alternatively, all of the wireless communication devices **111-115** may be non-AP STAs in an Ad-hoc networking environment.

An AP STA and a non-AP STA may be collectively called STAs. However, for simplicity of description, in some aspects, only a non-AP STA may be referred to as a STA. An AP may be, for example, a centralized controller, a base station (BS), a node-B, a base transceiver system (BTS), a site controller, a network adapter, a network interface card (NIC), a router, or the like. An non-AP STA (e.g., a client device operable by a user) may be, for example, a device with wireless communication capability, a terminal, a wireless transmit/receive unit (WTRU), a user equipment (UE), a mobile station (MS), a mobile terminal, a mobile subscriber unit, a laptop, a non-mobile computing device (e.g., a desktop computer with wireless communication capability) or the like. In one or more aspects, a non-AP STA may act as an AP (e.g., a wireless hotspot).

In one aspect, an AP is a functional entity for providing access to a distribution system, by way of a wireless medium, for an associated STA. For example, an AP may provide access to the internet for one or more STAs that are wirelessly and communicatively connected to the AP. In FIG. **1**, wireless communications between non-AP STAs are made by way of an AP. However, when a direct link is established between non-AP STAs, the STAs can communicate directly with each other (without using an AP).

In one or more implementations, OFDMA-based 802.11 technologies are utilized, and for the sake of brevity, a STA refers to a non-AP HE STA, and an AP refers to a HE AP. In one or more aspects, a STA may act as an AP.

FIG. **2** illustrates a schematic diagram of an example of a wireless communication device. The wireless communication device **200** includes a baseband processor **210**, a radio frequency (RF) transceiver **220**, an antenna unit **230**, a memory **240**, an input interface unit **250**, an output interface unit **260**, and a bus **270**, or subsets and variations thereof. The wireless communication device **200** can be, or can be a part of, any of the wireless communication devices **111-115**.

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In the example, the baseband processor **210** performs baseband signal processing, and includes a medium access control (MAC) processor **211** and a PHY processor **215**. The memory **240** may store software (such as MAC software) including at least some functions of the MAC layer. The memory may further store an operating system and applications.

In the illustration, the MAC processor **211** includes a MAC software processing unit **212** and a MAC hardware processing unit **213**. The MAC software processing unit **212** executes the MAC software to implement some functions of the MAC layer, and the MAC hardware processing unit **213** may implement remaining functions of the MAC layer as hardware (MAC hardware). However, the MAC processor **211** may vary in functionality depending on implementation. The PHY processor **215** includes a transmitting (TX) signal processing unit **280** and a receiving (RX) signal processing unit **290**. The term TX may refer to transmitting, transmit, transmitted, transmitter or the like. The term RX may refer to receiving, receive, received, receiver or the like.

The PHY processor **215** interfaces to the MAC processor **211** through, among others, transmit vector (TXVECTOR) and receive vector (RXVECTOR) parameters. In one or more aspects, the MAC processor **211** generates and provides TXVECTOR parameters to the PHY processor **215** to supply per-packet transmit parameters. In one or more aspects, the PHY processor **215** generates and provides RXVECTOR parameters to the MAC processor **211** to inform the MAC processor **211** of the received packet parameters.

In some aspects, the wireless communication device **200** includes a read-only memory (ROM) (not shown) or registers (not shown) that store instructions that are needed by one or more of the MAC processor **211**, the PHY processor **215** and/or other components of the wireless communication device **200**.

In one or more implementations, the wireless communication device **200** includes a permanent storage device (not shown) configured as a read-and-write memory device. The permanent storage device may be a non-volatile memory unit that stores instructions even when the wireless communication device **200** is off. The ROM, registers and the permanent storage device may be part of the baseband processor **210** or be a part of the memory **240**. Each of the ROM, the permanent storage device, and the memory **240** may be an example of a memory or a computer-readable medium. A memory may be one or more memories.

The memory **240** may be a read-and-write memory, a read-only memory, a volatile memory, a non-volatile memory, or a combination of some or all of the foregoing. The memory **240** may store instructions that one or more of the MAC processor **211**, the PHY processor **215**, and/or another component may need at runtime.

The RF transceiver **220** includes an RF transmitter **221** and an RF receiver **222**. The input interface unit **250** receives information from a user, and the output interface unit **260** outputs information to the user. The antenna unit **230** includes one or more antennas. When multi-input multi-output (MIMO) or multi-user MIMO (MU-MIMO) is used, the antenna unit **230** may include more than one antenna.

The bus **270** collectively represents all system, peripheral, and chipset buses that communicatively connect the numerous internal components of the wireless communication device **200**. In one or more implementations, the bus **270** communicatively connects the baseband processor **210** with the memory **240**. From the memory **240**, the baseband processor **210** may retrieve instructions to execute and data to process in order to execute the processes of the subject disclosure. The baseband processor **210** can be a single processor, multiple processors, or a multi-core processor in different implementations. The baseband processor **210**, the memory **240**, the input interface unit **250**, and the output interface unit **260** may communicate with each other via the bus **270**.

The bus **270** also connects to the input interface unit **250** and the output interface unit **260**. The input interface unit **250** enables a user to communicate information and select commands to the wireless communication device **200**. Input devices that may be used with the input interface unit **250** may include any acoustic, speech, visual, touch, tactile and/or sensory input device, e.g., a keyboard, a pointing device, a microphone, or a touchscreen. The output interface unit **260** may enable, for example, the display or output of videos, images, audio, and data generated by the wireless communication device **200**. Output devices that may be used with the output interface unit **260** may include any visual, auditory, tactile, and/or sensory output device, e.g., printers and display devices or any other device for outputting information. One or more implementations may include devices that function as both input and output devices, such as a touchscreen.

One or more implementations can be realized in part or in whole using a computer-readable medium. In one aspect, a computer-readable medium includes one or more media. In one or more aspects, a computer-readable medium is a tangible computer-readable medium, a computer-readable storage medium, a non-transitory computer-readable medium, a machine-readable medium, a memory, or some combination of the foregoing (e.g., a tangible computer-readable storage medium, or a non-transitory machine-readable storage medium). In one aspect, a computer is a machine. In one aspect, a computer-implemented method is a machine-implemented method.

A computer-readable medium may include storage integrated into a processor and/or storage external to a processor. A computer-readable medium may be a volatile, non-volatile, solid state, optical, magnetic, and/or other suitable storage device, e.g., RAM, ROM, PROM, EPROM, a flash, registers, a hard disk, a removable memory, or a remote storage device.

In one aspect, a computer-readable medium comprises instructions stored therein. In one aspect, a computer-readable medium is encoded with instructions. In one aspect, instructions are executable by one or more processors (e.g., **210**, **211**, **212**, **213**, **215**, **280**, **290**) to perform one or more operations or a method. Instructions may include, for example, programs, routines, subroutines, data, data structures, objects, sequences, commands, operations, modules, applications, and/or functions. Those skilled in the art would recognize how to implement the instructions.

A processor (e.g., **210**, **211**, **212**, **213**, **215**, **280**, **290**) may be coupled to one or more memories (e.g., one or more external memories such as the memory **240**, one or more memories internal to the processor, one or more registers internal or external to the processor, or one or more remote memories outside of the device **200**), for example, via one or more wired and/or wireless connections. The coupling may be direct or indirect. In one aspect, a processor includes one or more processors. A processor, including a processing circuitry capable of executing instructions, may read, write, or access a computer-readable medium. A processor may be, for example, an application specific integrated circuit (ASIC), a digital signal processor (DSP), or a field programmable gate array (FPGA).

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In one aspect, a processor (e.g., **210**, **211**, **212**, **213**, **215**, **280**, **290**) is configured to cause one or more operations of the subject disclosure to occur. In one aspect, a processor is configured to cause an apparatus (e.g., a wireless communication device **200**) to perform operations or a method of the subject disclosure. In one or more implementations, a processor configuration involves having a processor coupled to one or more memories. A memory may be internal or external to the processor. Instructions may be in a form of software, hardware or a combination thereof. Software instructions (including data) may be stored in a memory. Hardware instructions may be part of the hardware circuitry components of a processor. When the instructions are executed or processed by one or more processors, (e.g., **210**, **211**, **212**, **213**, **215**, **280**, **290**), the one or more processors cause one or more operations of the subject disclosure to occur or cause an apparatus (e.g., a wireless communication device **200**) to perform operations or a method of the subject disclosure.

FIG. **3A** illustrates a schematic block diagram of an example of a transmitting signal processing unit **280** in a wireless communication device. The transmitting signal processing unit **280** of the PHY processor **215** includes an encoder **281**, an interleaver **282**, a mapper **283**, an inverse Fourier transformer (IFT) **284**, and a guard interval (GI) inserter **285**.

The encoder **281** encodes input data. For example, the encoder **281** may be a forward error correction (FEC) encoder. The FEC encoder may include a binary convolutional code (BCC) encoder followed by a puncturing device, or may include a low-density parity-check (LDPC) encoder. The interleaver **282** interleaves the bits of each stream output from the encoder **281** to change the order of bits. In one aspect, interleaving may be applied only when BCC encoding is employed. The mapper **283** maps the sequence of bits output from the interleaver **282** into constellation points.

When MIMO or MU-MIMO is employed, the transmitting signal processing unit **280** may use multiple instances of the interleaver **282** and multiple instances of the mapper **283** corresponding to the number of spatial streams (N_{SS}). In the example, the transmitting signal processing unit **280** may further include a stream parser for dividing outputs of the BCC encoders or the LDPC encoder into blocks that are sent to different interleavers **282** or mappers **283**. The transmitting signal processing unit **280** may further include a space-time block code (STBC) encoder for spreading the constellation points from the number of spatial streams into a number of space-time streams (N_{STS}) and a spatial mapper for mapping the space-time streams to transmit chains. The spatial mapper may use direct mapping, spatial expansion, or beamforming depending on implementation. When MU-MIMO is employed, one or more of the blocks before reaching the spatial mapper may be provided for each user.

The IFT **284** converts a block of the constellation points output from the mapper **283** or the spatial mapper into a time domain block (e.g., a symbol) by using an inverse discrete Fourier transform (IDFT) or an inverse fast Fourier transform (IFFT). If the STBC encoder and the spatial mapper are employed, the IFT **284** may be provided for each transmit chain.

When MIMO or MU-MIMO is employed, the transmitting signal processing unit **280** may insert cyclic shift diversities (CSDs) to prevent unintentional beamforming. The CSD insertion may occur before or after the inverse Fourier transform operation. The CSD may be specified per transmit chain or may be specified per space-time stream. Alternatively, the CSD may be applied as a part of the spatial mapper.

The GI inserter **285** prepends a GI to the symbol. The transmitting signal processing unit **280** may optionally perform windowing to smooth edges of each symbol after inserting the GI. The RF transmitter **221** converts the symbols into an RF signal and transmits the RF signal via the antenna unit **230**. When MIMO or MU-MIMO is employed, the GI inserter **285** and the RF transmitter **221** may be provided for each transmit chain.

FIG. **3B** illustrates a schematic block diagram of an example of a receiving signal processing unit **290** in a wireless communication device. The receiving signal processing unit **290** of the PHY processor **215** includes a GI remover **291**, a Fourier transformer (FT) **292**, a demapper **293**, a deinterleaver **294**, and a decoder **295**.

The RF receiver **222** receives an RF signal via the antenna unit **230** and converts the RF signal into one or more symbols. In some aspects, the GI remover **291** removes the GI from the symbol. When MIMO or MU-MIMO is employed, the RF receiver **222** and the GI remover **291** may be provided for each receive chain.

The FT **292** converts the symbol (e.g., the time domain block) into a block of the constellation points by using a discrete Fourier transform (DFT) or a fast Fourier transform (FFT) depending on implementation. In one or more implementations, the FT **292** is provided for each receive chain.

When MIMO or MU-MIMO is employed, the receiving signal processing unit **290** may be a spatial demapper for converting the Fourier transformed receiver chains to constellation points of the space-time streams, and a STBC decoder (not shown) for despreading the constellation points from the space-time streams into the spatial streams.

The demapper **293** demaps the constellation points output from the FT **292** or the STBC decoder to the bit streams. If the LDPC encoding is used, the demapper **293** may further perform LDPC tone demapping before the constellation demapping. The deinterleaver **294** deinterleaves the bits of each stream output from the demapper **293**. In one or more implementations, deinterleaving may be applied only when BCC encoding is used.

When MIMO or MU-MIMO is employed, the receiving signal processing unit **290** may use multiple instances on the demapper **293** and multiple instances of the deinterleaver **294** corresponding to the number of spatial streams. In the example, the receiving signal processing unit **290** may further include a stream deparser for combining the streams output from the deinterleavers **294**.

The decoder **295** decodes the streams output from the deinterleaver **294** and/or the stream deparser. For example, the decoder **295** may be an FEC decoder. The FEC decoder may include a BCC decoder or an LDPC decoder.

FIG. **4** illustrates an example of a high efficiency (HE) frame **400**. The HE frame **400** is a physical layer convergence procedure (PLCP) protocol data unit (or PPDU) format. An HE frame may be referred to as an OFDMA frame, a PPDU, an OFDMA PPDU, an MU PPDU, another similar term, or vice versa. An HE frame may be simply referred to as a frame for convenience.

An AP may transmit a frame for downlink (DL) using a frame format shown in this figure or a variation thereof. A STA may transmit a frame for uplink (UL) using a frame format shown in this figure or a variation thereof (e.g., without any or some portions of an HE header **414**). In one or more aspects, the frames shown in FIGS. **5** through **8** may utilize a frame format shown in FIG. **4** or a variation thereof.

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Referring to FIG. **4**, the HE frame **400** contains a header **410** and a payload **430**. The header **410** includes a legacy header **412** comprised of a legacy short training field (L-STF), a legacy long training field (L-LTF), and a legacy signal (L-SIG) field. These legacy fields contain symbols based on an early design of an IEEE 802.11 specification. Presence of these symbols would make any new design compatible with the legacy designs and products.

In one or more implementations, the legacy STF, LTF, and SIG symbols are modulated/carried with FFT size of 64 on a 20 MHz sub-channel and are duplicated every 20 MHz if the frame has a channel bandwidth wider than 20 MHz. Therefore, the legacy field (i.e., the STF, LTF, and SIG fields) occupies the entire channel bandwidth of the frame. The L-STF field may be utilized for packet detection, automatic gain control (AGC), and coarse frequency-offset correction. The L-LTF field may be utilized for channel estimation, fine frequency-offset correction, and symbol timing.

The header **410** may include an HE header **414** comprised of an HE-SIG-A field and an HE-SIG-B field. These fields contain symbols that carry control information that may be vital regarding each PLCP service data unit (PSDU) and regarding the radio frequency (RF), PHY, and MAC properties of a PPDU. Several sub-fields may be located either in the HE-SIG-A and/or HE-SIG-B fields. In one aspect, the HE-SIG-A field can be carried/modulated using an FFT size of 64 for 20 MHz channel bandwidth. The HE-SIG-B field can be carried/modulated using an FFT size of e.g., 64 or 256 depending on implementation. The HE-SIG-A and HE-SIG-B fields may occupy the entire channel bandwidth of the frame. In some aspects, the size of the HE-SIG-B field is variable. In other words, the number of symbols contained in the HE-SIG-B field can vary from frame to frame. For example, the number of symbols in the HE-SIG-B field may be one symbol, two symbols, zero symbols, among other possibilities. In this regard, a HE-SIG-B field is not always present in all frames. To facilitate decoding of the HE frame **400** by a receiver, the size (e.g., number of symbols) contained in the HE-SIG-B field may be indicated in the HE-SIG-A field.

For a 20 MHz channel, an FFT size of 64 is associated with a discrete Fourier transform (DFT) period of 3.2 μs and a subcarrier spacing of 312.5 kHz. For a 20 MHz channel, an FFT size of 256 is associated with a DFT period of 12.8 μs and a subcarrier spacing of 78.125 kHz. The DFT period may also be referred to as an inverse DFT period (IDFT) or an IDFT/DFT period. The DFT period may be denoted as T_{DFT}. The subcarrier spacing may be referred to as a subcarrier frequency spacing and may be denoted as Δ_F. The subcarrier spacing may be obtained by dividing the channel bandwidth by the FFT size. The DFT period is the reciprocal of the subcarrier spacing.

The HE header **414** may further include HE-STF and HE-LTF fields, which contain symbols used to perform necessary RF and PHY processing for each PSDU and/or for the whole PPDU. The HE-LTF symbols may be modulated/carried with FFT size of 256 per 20 MHz channel bandwidth and modulated over the entire bandwidth of the frame. Thus, the HE-LTF field may occupy the entire channel bandwidth of the frame. The HE-STF symbols may have a fixed pattern and a fixed duration. For example, the HE-STF symbols may have a predetermined repeating pattern. In one aspect, the HE-STF symbols do not require FFT processing.

In one example, the legacy STF, LTF, and SIG symbols and the HE-SIG-A and HE-SIG-B symbols are modulated/carried with FFT size of 64 on a 20 MHz channel (e.g., using a DFT period of 3.2 μs and a subcarrier spacing of 312.5 kHz), whereas the HE-LTF symbols are modulated/carried with FFT size of 256 on a 20 MHz channel (e.g., using a DFT period of 12.8 μs and a subcarrier spacing of 78.125 kHz). In such implementations, a first part **420** of the HE frame **400** may include the legacy STF, LTF and SIG symbols and the HE-SIG-A and HE-SIG-B symbols. A second part **422** of the HE frame **400** may include HE-LTF symbols. The HE-STF symbols may be a known predetermined pattern that does not require FFT processing. Thus, the HE-STF symbols may be considered separate from the first part **420** and the second part **422** of the HE frame **400**. In one aspect, the payload **430** (containing data) is modulated/carried with FFT size of 256 (e.g., using a DFT period of 12.8 μs and a subcarrier spacing of 78.125 kHz), and the payload **430** may be included in the second part **422** of the HE frame **400**.

In one or more aspects, the first part **420** of the HE frame **400** is associated with a first FFT size, and the second part **422** of the HE frame **400** is associated with a second FFT size that is greater (or larger) than the first FFT size. In one or more aspects, the first part **420** of the HE frame **400** is associated with a first subcarrier spacing (e.g., 312.5 kHz), and the second part **422** of the HE frame **400** is associated with a second subcarrier spacing (e.g., 78.125 kHz) that is less than the first subcarrier spacing. In one aspect, a subcarrier spacing is a spacing between tones (or between subcarriers). In one or more aspects, the boundary of a first part and a second part of an HE frame **400** can be placed at a location other than the location shown in FIG. **4**. For example, the second part may start at the beginning of the payload **430**. In one aspect, a first part of an HE frame **400** always includes at least the legacy header (i.e., the L-STF, L-LTF, and L-SIG symbols).

In one or more aspects, additional one or more of the HE-STF and/or HE-LTF fields may be included in the header **410**. For example, an additional HE-STF field and/or an additional HE-LTF field may be included between the HE-SIG-A field and the HE-SIG-B field. The additional HE-STF and HE-LTF fields may be, for example, modulated/carried with FFT size of 64 on a 20 MHz channel and may be included as part of the first part **420** of the HE frame **400**. In one or more implementations, a TX signal processing unit **280** (or an IFT **284**) illustrated in FIG. **3A** may carry out the modulation described in this paragraph as well as the modulations described in other paragraphs above. In one or more implementations, an RX signal processing unit **290** (or an FT **292**) may perform demodulation for a receiver.

The horizontal dimension in FIG. **4** represents the time dimension or number of OFDM symbols. Each of the fields (e.g., L-LTF, HE-SIG-B, etc.) of the HE frame **400** includes one or more guard intervals and one or more OFDM symbols. The guard interval may be utilized to facilitate compensation of multi-path effects, which may cause inter-symbol interference (ISI). In one or more implementations, a guard interval is a cyclic prefix (CP), and a guard interval duration is a CP length. A guard interval associated with the first part **420** of the HE frame may be predetermined to be, and set to, for example, 0.8 μs. In one aspect, a guard interval for each of a legacy OFDM symbol in the legacy header in the first part **420** is set to, for example, 0.8 μs. Each guard interval may be associated with a symbol and may be present between symbols (or between consecutive symbols). In some aspects, each OFDM symbol is preceded by a guard interval.

In one aspect, multiple guard intervals may be represented as one long guard interval, and such long guard interval may

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precede the OFDM symbols associated with the multiple guard intervals. For example, a guard interval of 1.6 μs (representing two guard intervals, each being 0.8 μs) may be prepended to two consecutive OFDM symbols associated with the two guard intervals.

In one or more implementations of a transmitter, a GI inserter **285** illustrated in FIG. **3**A may prepend a guard interval to an OFDM symbol. For a receiver, a GI remover **291** of FIG. **3**B may remove the prepended guard interval. As used herein, the term "OFDM symbol duration" or "symbol duration" may refer to a sum of a duration of a guard interval and a duration of an OFDM symbol associated with the guard interval, rather than the duration of the OFDM symbol itself, e.g., without the duration of the guard interval.

In some aspects, a guard interval duration utilized in the first part **420** of the HE frame **400** is predetermined for all UL and DL transmissions associated with OFDMA. In some aspects, information regarding the guard interval duration (e.g., a value of the guard interval duration) utilized for the second part **422** of the HE frame **400** may be stored in an HE-SIG-A field of the HE frame **400**. The inclusion of the guard interval duration may facilitate decoding of the HE frame **400** by a receiver of the HE frame **400** by allowing the receiver to determine boundaries between adjacent symbols in the second part **422** of the HE frame **420** based on the guard interval duration. For example, a receiver of the HE frame **400** may decode the first part **420** of the HE frame **400** based on the predetermined guard interval duration to obtain the information indicative of the guard interval duration utilized for the second part **422** of the HE frame **400**. With the information, the receiver may decode the second part **422** of the HE frame **400**.

FIG. **5** illustrates a schematic diagram of an example of an exchange of frames among wireless communication devices for OFDMA transmission. One or more aspects of aligning GI duration of all participating stations of OFDMA transmission are illustrated. The horizontal dimension in FIG. **5** represents the time dimension or number of OFDM symbols. The wireless communication devices include an AP, a participating station STA1, and a participating station STA2. Although FIG. **5** illustrates an exchange of frames between an AP and two stations participating in OFDMA transmission, the exchange of frames may be between the AP and one participating station (e.g., the non-OFDMA case) or between the AP and more than two participating stations.

In FIG. **5**, the AP sends a downlink frame **510** to the participating stations (e.g., STA1 and STA2) during a time period T1. The downlink frame **510** is utilized to initiate OFDMA transmission. For example, the downlink frame **510** may be a trigger frame. The downlink frame **510** may provide, for example, a transmission opportunity to the participating stations and may indicate resource allocation information for the participating stations pertaining to OFDMA transmission. For example, the resource allocation information may include a sub-band assigned to a respective one of the participating stations as well as scheduling information regarding when a respective one of the participating stations may transmit using its assigned sub-band. For instance, when there are four STAs, and the uplink channel bandwidth is, for example, 80 MHz, then the AP may assign a sub-band of the uplink channel bandwidth (e.g., a portion of 80 MHz) to each respective STA so that each STA has its assigned sub-band. The downlink frame **510** may also include other information, such as FFT/IFFT period information.

The downlink frame **510** includes a first part **520** and a second part **522**. In one or more implementations, the first part **520** and the second part **522** of the downlink frame **510** may be (or may include, or may be a part of) the first part **420** and the second part **422**, respectively, of the frame **400** described with reference to FIG. **4**. The downlink frame **510** may include an HE-STF field that is in between the first part **520** and the second part **522** of the downlink frame **510**. Each guard interval (GI) of the first part **520** of the downlink frame **510** may be set at a predetermined guard interval duration GI1. The guard interval duration GI1 may be predetermined for all DL and/or UL transmissions. For example, the guard interval duration GI1 may be set to 0.8 μs regardless of using a short guard interval for the second part **522**. The AP may utilize a guard interval duration GI2 for the rest of the downlink frame **510**. The rest of the downlink frame **510** may include, for example, the HE-STF field and the second part **522** of the downlink frame **510**.

For example, a guard interval **521***a* having the guard interval duration GI1 may be prepended to a symbol **521***b* of the first part **520** of the downlink frame **510**. A symbol duration may be the sum of the duration of the guard interval **521***a* and the duration of the symbol **521***b*. For brevity, additional guard intervals and their associated symbols present in the first part **520** are not shown.

Guard interval **523***a* and **524***a*, each having the guard interval duration GI2, may be prepended to their respective symbols **523***b* and **524***b* of the second part **522** of the downlink frame **510**. Additional guard intervals and symbols that are present in the second part **522** are not shown for brevity. Information on the guard interval duration GI2 (e.g., a value representing GI2) may be stored in the first part **520** of the downlink frame **510**, such as in an HE-SIG-A field, and may be utilized by a receiver of the downlink frame **510** to determine, e.g., for decoding purposes, that the second part **522** of the downlink frame **510** utilizes guard intervals of the guard interval duration GI2.

When the participating stations receive the downlink frame **510** transmitted by the AP, the participating stations may decode the downlink frame **510** and identify that the participating stations are supposed to transmit their respective frames to the AP after a specified time period (e.g., T2) after the participating stations received the frame **510**. From the perspective of the AP, the predetermined time period T2 may be from the end of the transmission of the frame **510** (e.g., the end of the time period T1). After the predetermined time period T2, the participating stations send their respective uplink frames **530** and **550** to the AP during a time period T3 in response to the downlink frame **510**. The time period T2 may be around 6 μs to around 60 μs for example. In some aspects, the time period T2 may be a short interface space (SIFS). In FIG. **5**, the uplink frames **530** and **550** have a time duration equal to the time period T3. In other words, in one aspect, every UL OFDMA participating STA has the same frame length. In some cases, one or both of the uplink frames **530** and **550** may be of a time duration less than or greater than the time period T3. The uplink frame **530** may include a different number of symbols from the uplink frame **550**. In one aspect, an uplink frame may include additional guard intervals and symbols beyond those shown in this figure (e.g., additional guard intervals and symbols after the symbol **564***b*).

When the participating stations transmit the uplink frames **530** and **550** as part of OFDMA transmission, the participating stations use the predetermined guard interval duration GI1 for the first parts **540** and **560** of their respective frames **530** and **550** and use the same guard interval duration GI2,

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which is used in the second part **522** of the downlink frame **510**, for the second parts **542** and **562** of their respective uplink frames **530** and **550**. The uplink frames **530** and **550** may include a respective HE-STF field that is in between the first parts **540** and **560** and the second parts **542** and **562** of the respective uplink frames frame **530** and **550**. In one aspect, the HE-STF field does not utilize any guard interval. As the guard interval duration GI2 is included in the downlink frame **510** for decoding purposes, no additional overhead is used in the downlink frame **510** to indicate the guard interval duration to be used by the participating stations in the second parts **542** and **562** of their respective uplink frames **530** and **550**.

In one or more implementations, the AP may set the guard interval duration based on a communication environment. The communication environment utilized by the AP to determine the guard interval duration GI2 may include multi-path delay profile of a received signal, different propagation delay to and from multiple different stations (e.g., the participating stations), accuracy of timing alignment capabilities of the participating stations, and so on. For example, the participating stations may reside at different distances from the AP and/or in different environments (e.g., altitudes, atmosphere, density of buildings, temperature, etc.) such that propagation delay is different among the participating stations. The received signal may be a signal received at the stations, such as when the stations receive a signal transmitted to the stations by the AP. The received signal may be a signal received at the AP, such as when the AP receives a signal transmitted to the AP by the stations. In some cases, the guard interval duration GI2 is the same as the guard interval duration GI1. In other cases, the guard interval duration GI2 is different from the guard interval duration GI1.

In some aspects, the AP sets the guard interval duration GI2 to better accommodate the different propagation delays associated with the different stations. The AP may set the guard interval duration to a longer duration allowed by the IEEE 802.11 protocol to better accommodate the different propagation delays. For example, the AP may set the guard interval duration GI2 to a longest guard interval duration allowed by the IEEE 802.11 protocol (e.g., 3.2 μs). The use of a longer guard interval may allow the participating stations to synchronize the symbol duration, and the frames sent from the participating stations can avoid inter-symbol interferences caused, for example, by the propagation delay differences among participating stations.

In one or more implementations, the guard interval duration GI1 utilized by the first part (e.g., **520**, **540**, and **560**) of the downlink frame **510** and the uplink frames **530** and **550** are predetermined (e.g., predetermined before the AP begins to create/prepare the downlink frame **510**) such that APs and STAs participating in UL and DL OFDMA transmission throughout a network (e.g., an IEEE 802.1 lax-complant network) utilize the guard interval duration GI1 for the first parts of their respective frames. A guard interval duration to be utilized for the guard interval duration GI2 may be adaptively determined by an AP. For example, the AP may adjust the guard interval duration GI2 based on changes in the communication environment. The definition of the guard interval durations to be used in the uplink frames (e.g., **530** and **550**) of the participating stations allow synchronization of OFDM symbol boundaries of the uplink frames, since the OFDM symbol durations contained in the uplink frames are the same for each participating station. Although the number of symbols contained in the uplink frames (e.g., the number of symbols in the frame **530** compared to the number of symbols in the frame **550**) may be different. the respective OFDM symbol durations remain the same for the uplink frames.

In one or more aspects, the respective symbol durations of the uplink frames are the same, and the respective symbol boundaries are aligned. For example, a symbol duration **541***c* is the same as a symbol duration of **561***c*. A symbol duration **543***c* is the same as a symbol duration **563***c*. A symbol duration **544***c* is the same as a symbol duration **564***c*. Furthermore, a symbol boundary **541***d* is aligned with a symbol boundary of **561***d*. A symbol boundary **543***d* is aligned with a symbol boundary **563***d*. A symbol boundary **544***d* is aligned with a symbol boundary **564***d*.

In one or more implementations, the first part (e.g., **540** or **560**) and the second part (e.g., **542** or **562**) of an uplink frame (e.g., **530** or **560**) may be (or may include, or may be a part of) the first part **420** and the second part **422**, respectively, of the frame **400** described with reference to FIG. **4**.

FIG. **6** illustrates a schematic diagram of an example of an exchange of frames among wireless communication devices for OFDMA transmission. The description from FIG. **5** generally applies to FIG. **6**, with examples of differences between FIG. **5** and FIG. **6** and other descriptions provided herein for purposes of clarity and simplicity.

In FIG. **6**, the AP sends a downlink frame **610** to the participating stations during a time period T1. The downlink frame **610** includes a first part **620** that utilizes a guard interval duration GI1 and a second part **622** that utilizes a guard interval duration GI2. The downlink frame **610** may include an HE-STF field that is in between the first part **620** and the second part **622** of the downlink frame **610**. The guard interval duration GI1 may be predetermined whereas the guard interval duration GI2 may be based on a communication environment. Information (e.g., a value) indicative of the guard interval duration GI2 may be stored in the first part **620** of the downlink frame **610**, such as in an HE-SIG-A field, and may be utilized by a receiver of the downlink frame **610** to determine that the second part **622** of the downlink frame **610** utilizes guard intervals of the guard interval duration GI2.

When the participating stations receive the downlink frame **610** transmitted by the AP, the participating stations may decode the downlink frame **610** and identify that the participating stations are instructed to transmit their respective frames to the AP after a T2 time period after receiving the downlink frame **610**. The participating stations use the predetermined guard interval duration GI1 for the first parts **640** and **660** of their respective uplink frames **630** and **650**. The participating stations use another predetermined guard interval duration GI0 for the rest of their respective uplink frames (e.g., the second parts **642** and **662**) when the participating stations transmit the respective uplink frames (e.g., **630** and **650**) as part of OFDMA communication. The guard interval duration GI0 may be predetermined for UL OFDMA transmission throughout a network (e.g., an IEEE 802.1 lax-compliant network). As the guard interval duration GI0 is predetermined for UL OFDMA transmission throughout the network, the guard interval duration GI0 need not be explicitly indicated (e.g., signaled) to the participating stations. Utilization of the predetermined guard interval duration GI0 may reduce overhead for the OFDMA transmission, such as overhead of the downlink frame **610**. The uplink frames **630** and **650** may include a respective HE-STF field that is in between the first parts **640** and **660** and the second parts **642** and **662** of the respective uplink frames frame **630** and **650**.

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In some aspects, to better accommodate the different propagation delays that may possibly be associated with the different stations, the guard interval duration GI0 may be set to a longer guard interval duration. For example, the guard interval duration GI0 may be predetermined to be set to the longest guard interval defined by the IEEE 802.11 protocol. The use of a longer guard interval may allow the participating stations to synchronize the symbol duration, and the frames sent from the participating stations can avoid inter-symbol interferences caused, for example, by the propagation delay differences among participating stations.

Utilizing of predetermined guard interval durations in the first part and second part of the uplink frames (e.g., **630** and **650**) of the participating stations facilitate synchronization of OFDM symbol boundaries of the uplink frames, since the respective OFDM symbol durations contained in the uplink frames are the same for the participating stations. Although the number of symbols contained in the uplink frames may be different, the respective OFDM symbol durations remain the same and aligned for the uplink frames.

FIG. **7** illustrates a schematic diagram of an example of an exchange of frames among wireless communication devices for OFDMA transmission. The description from FIG. **5** generally applies to FIG. **7**, with examples of differences between FIG. **5** and FIG. **7** and other descriptions provided herein for purposes of clarity and simplicity.

In FIG. **7**, during a time period T0 that occurs before the AP initiates OFDMA transmission from multiple participating stations, the AP sends a downlink frame **770** that includes information associated with OFDMA transmission, such as a guard interval duration GI3, to be used for UL OFDMA transmission. In one aspect, a payload of the downlink frame **770** includes information regarding GI3 (e.g., information or a value that can be used to identify GI3). In one aspect, the downlink frame **770** may be referred to as a management frame. The downlink frame **770** may be, may include, or may be a part of, a beacon frame that periodically broadcasts the guard interval duration GI3, among other information associated with the OFDMA transmission. The downlink frame **770** may be, may include, or may be a part of, a response frame sent to a station when the station requests to associate with a network associated with the AP and/or requests for capabilities/services of the network. The network may utilize different types of management frames (e.g., beacon frame, probe response frame, association response frame, etc.). For example, a beacon frame may be transmitted by the AP to participating stations on a periodic basis whereas a probe or association response frame may be sent in response to inquiries and/or requests from stations.

The downlink frame **770** includes a first part **780** and a second part **782**. The downlink frame **770** may include an HE-STF field that is in between the first part **780** and the second part **782** of the downlink frame **770**. A guard interval duration GI1 of the first part **780** of the downlink frame **770** is set at a predetermined duration, and a guard interval duration GI4 of the second part **782** of the downlink frame **770** can be set at another value (e.g., based on communication environment). In some cases, the guard interval duration GI4 is the same as the guard interval duration GI1. In other cases, the guard interval duration GI4 is different from the guard interval duration GI1. In one or more implementations, the downlink frame **770** is, includes, or is a part of, a probe response frame, an association response frame, or a beacon frame of the IEEE 802.11 protocol.

To initiate the OFDMA transmission, the AP sends a downlink frame **710** to the participating stations. The downlink frame **710** may be a trigger frame. The downlink frame **710** includes a first part **720** that utilizes a guard interval duration GI1 and a second part **722** that utilizes a guard interval duration GI2. The downlink frame **710** may include an HE-STF field that is in between the first part **720** and the second part **722** of the downlink frame **710**. The guard interval duration GI1 may be predetermined whereas the guard interval duration GI2 may be based on a communication environment. Information regarding the guard interval duration GI2 (e.g., a value indicative of GI2) may be stored in the first part **720** of the downlink frame **710**, such as in an HE-SIG-A field, and may be utilized by a receiver of the downlink frame **710** to determine, e.g., for decoding purposes, that the second part **722** of the downlink frame **710** utilizes guard intervals of the guard interval duration GI2.

When the participating stations receive the downlink frame **710** from the AP, the participating stations may decode the downlink frame **710** and identify that the participating stations are supposed to transmit their uplink frames **730** and **750** after a T2 time period after receiving the downlink frame **710**. The participating stations use the predetermined guard interval duration GI1 for the first parts **740** and **760** of their respective uplink frames **730** and **750**. The participating stations use the guard interval duration GI3 indicated by the downlink frame **770** for UL OFDMA transmission for the second part of their respective uplink frames **730** and **750** (e.g., the remaining parts **742** and **762**) when the participating stations transmit the uplink frames as part of OFDMA transmission. The uplink frames **730** and **750** may include a respective HE-STF field that is in between the first parts **740** and **760** and the second parts **742** and **762** of the respective uplink frames frame **730** and **750**.

The IEEE 802.11 protocol guard interval durations include, for example, 0.4 μs, 0.8 μs, 1.6 μs, and 3.2 μs. In some aspects, the AP sets the guard interval duration GI3 to better accommodate the different propagation delays associated with the different stations. In one example, GI3 is different from GI1 or GI4. In one example, GI3 is different from GI2. In another example, GI3 is the same as GI2. In another example, GI3 is the same as GI4. In one or more implementations, the guard interval duration GI3 is set to a duration that is longer than any of the guard interval duration GI1, GI2, or GI4. For example, since GI3 is utilized by different STAs simultaneously, GI3 may be set to the longest guard interval defined by the IEEE 802.11 protocol (e.g., 3.2 μs) to better accommodate the different propagation delays associated with the different STAs.

Utilization of predetermined GI1 in the first parts (e.g., **740** and **760**) of the uplink frames (e.g., **730** and **750**) of the participating stations and utilization of GI3 in the second parts (e.g., **742** and **762**) facilitate synchronization of OFDM symbol boundaries of the uplink frames, since the respective OFDM symbol durations contained in the uplink frames are the same for the participating stations. Although the number of symbols contained in the uplink frames may be different, the respective OFDM symbol durations remain the same and aligned for the uplink frames.

FIG. **8** illustrates a schematic diagram of an example of an exchange of frames among wireless communication devices for OFDMA transmission. The description from FIG. **5** generally applies to FIG. **8**, with examples of differences between FIG. **5** and FIG. **8** and other descriptions provided herein for purposes of clarity and simplicity.

In FIG. **8**, the AP sends a downlink frame **810** to the participating stations of the OFDMA transmission (e.g., STA1 and STA2) during a time period T1. The downlink

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frame **810** is utilized to initiate OFDMA transmission. The downlink frame **810** may be a trigger frame. The downlink frame **810** includes a first part **820** that utilizes a guard interval duration GI1 and a second part **822** that utilizes a guard interval duration GI2. The downlink frame **810** may include an HE-STF field that is in between the first part **820** and the second part **822** of the downlink frame **810**. The guard interval duration GI1 may be predetermined whereas the guard interval duration GI2 may be based on a communication environment. Information regarding the guard interval duration GI2 (e.g., a value representing GI2) may be stored in the first part **820** of the downlink frame **810**, such as in an HE-SIG-A field, and may be utilized by a receiver of the downlink frame **810** to determine, e.g., for decoding purposes, that the second part **822** of the downlink frame **810** utilizes guard intervals of the guard interval duration GI2. The downlink frame **810** may also include information on a guard interval duration GI3 (e.g., information or a value that can identify GI3) to be utilized by the participating stations. In one aspect, the information on the guard interval duration GI3 may be provided in a payload in the second part **822** of the downlink frame **810**.

When the participating stations receive the downlink frame **810** transmitted by the AP, the participating stations may decode the downlink frame **810** and identify that the participating stations are supposed to transmit their own respective uplink frame **830** and **850** after a T2 time period after receiving the downlink frame **810**. The participating stations may also identify the guard interval duration GI3 to be utilized in the second parts **842** and **862** of the respective uplink frames **830** and **850**. The participating stations use the predetermined guard interval duration GI1 for the first parts **840** and **860** of their respective uplink frames **830** and **850**. The participating stations use the guard interval duration GI3 indicated by the downlink frame **810** for UL OFDMA transmission for the second part of their respective uplink frames **830** and **850** (e.g., the remaining parts **842** and **862**) when the participating stations transmit the uplink frame as part of OFDMA transmission. The uplink frames **830** and **850** may include a respective HE-STF field that is in between the first parts **840** and **860** and the second parts **842** and **862** of the respective uplink frames frame **830** and **850**.

In some aspects, the AP sets the guard interval duration GI3 to better accommodate the different propagation delays associated with the different stations. In one example, GB is different from GI1 or GI2. In another example, GI3 is the same as GI2. In one or more implementations, the guard interval duration GI3 is set to a duration that is longer than any of the guard interval duration GI1 or GI2. For example, since GI3 is utilized by different STAs simultaneously, GI3 may be set to the longest guard interval defined by the IEEE 802.11 protocol (e.g., 3.2 μs) to better accommodate the different propagation delays associated with the different STAs.

Utilization of predetermined GI1 in the first parts (e.g., **840** and **860**) of the uplink frames (e.g., **830** and **850**) of the participating stations and utilization of GI3 in the second parts (e.g., **842** and **862**) facilitate synchronization of OFDM symbol boundaries of the uplink frames, since the respective OFDM symbol durations contained in the uplink frames are the same for the participating stations. Although the number of symbols contained in the uplink frames may be different, the respective OFDM symbol durations remain the same and aligned for the uplink frames.

In one or more aspects, methods and systems allow aligning of symbol durations of multiple participating stations for UL OFDMA transmission by setting guard interval durations to be utilized by the participating stations. The methods and systems may facilitate maintaining the same respective OFDM symbol durations and symbol synchronization (or alignment) across MU simultaneous transmission by the participating stations. Such aligning and synchronizing may facilitate decrease of receiver complexity and increase of overall network efficiency for simultaneous transmission as part of OFDMA transmission.

Like reference numerals may designate like elements. For example, same reference numerals GI1, GI2, GI3, T1, T2, and T3 are used in various figures for simplicity and convenience. These components with the same reference numerals have certain characteristics that are the same, but as different figures illustrate different examples, the same reference numeral does not indicate that a component with the same reference numeral has the exact same characteristics. While the same reference numerals are used for certain components, examples of differences with respect to a component are described throughout this disclosure.

FIGS. 9A through 9C illustrate flow charts of examples of methods for facilitating wireless communication. For explanatory and illustration purposes, the example processes **900**, **920** and **930** may be performed by the wireless communication devices **111-115** of FIG. **1** and their components such as a baseband processor **210**, a MAC processor **211**, a MAC software processing unit **212**, a MAC hardware processing unit **213**, a PHY processor **215**, a transmitting signal processing unit **280** and/or a receiving signal processing unit **290**; however, the example processes **900**, **920** and **930** are not limited to the wireless communication devices **111-115** of FIG. **1** or their components, and the example processes **900**, **920** and **930** may be performed by some of the devices shown in FIG. **1**, or other devices or components. Further for explanatory and illustration purposes, the blocks of the example processes **900**, **920** and **930** are described herein as occurring in serial or linearly. However, multiple blocks of the example processes **900**, **920** and **930** may occur in parallel. In addition, the blocks of the example processes **900**, **920** and **930** need not be performed in the order shown and/or one or more of the blocks/actions of the example processes **900**, **920** and **930** need not be performed.

Various examples of aspects of the disclosure are described below as clauses for convenience. These are provided as examples, and do not limit the subject technology. As an example, some of the clauses described below are illustrated in FIGS. **9A** through **9C**.

Clause A. An apparatus for facilitating wireless communication, the apparatus comprising: one or more memories; and one or more processors coupled to the one or more memories, the one or more processors configured to cause: determining a second cyclic prefix length based on a first frame received; generating a second frame that comprises a first set of symbols and a second set of symbols, the first set of symbols being associated with a first cyclic prefix length, the second set of symbols being associated with the cyclic prefix length; and providing the second frame for transmission.

Clause B. An apparatus for facilitating wireless communication, the apparatus comprising: one or more memories; and one or more processors coupled to the one or more memories, the one or more processors configured to cause: determining a cyclic prefix length for an uplink multi-user transmission based on a first frame received from an access point, wherein the first frame includes resource allocation information for the uplink multi-user transmission and the cyclic prefix length; generating a second frame using the

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cyclic prefix length for the uplink multi-user transmission; and transmitting the second frame using the resource allocation information.

Clause C. A computer-implemented method of facilitating wireless communication, the method comprising: generating a first frame that comprises a payload, the payload comprising information indicative of a cyclic prefix length for a plurality of stations; and providing the first frame for transmission directed to the plurality of stations.

In one or more aspects, additional clauses are described below.

A method comprising one or more methods or operations described herein.

An apparatus comprising one or more memories (e.g., **240**, one or more internal, external or remote memories, or one or more registers) and one or more processors (e.g., **210**) coupled to the one or more memories, the one or more processors configured to cause the apparatus to perform one or more methods or operations described herein.

An apparatus comprising means (e.g., **210**) adapted for performing one or more methods or operations described herein.

A computer-readable storage medium (e.g., **240**, one or more internal, external or remote memories, or one or more registers) comprising instructions stored therein, the instructions comprising code for performing one or more methods or operations described herein.

In one aspect, a method may be an operation, an instruction, or a function and vice versa. In one aspect, a clause may be amended to include some or all of the words (e.g., instructions, operations, functions, or components) recited in other one or more clauses, one or more sentences, one or more phrases, one or more paragraphs, and/or one or more claims.

To illustrate the interchangeability of hardware and software, items such as the various illustrative blocks, modules, components, methods, operations, instructions, and algorithms have been described generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application.

A reference to an element in the singular is not intended to mean one and only one unless specifically so stated, but rather one or more. For example, "a" module may refer to one or more modules. An element proceeded by "a," "an," "the," or "said" does not, without further constraints, preclude the existence of additional same elements.

Headings and subheadings, if any, are used for convenience only and do not limit the invention. The word exemplary is used to mean serving as an example or illustration. To the extent that the term include, have, or the like is used, such term is intended to be inclusive in a manner similar to the term comprise as comprise is interpreted when employed as a transitional word in a claim. Relational terms such as first and second and the like may be used to distinguish one entity or action from another without necessarily requiring or implying any actual such relationship or order between such entities or actions.

Phrases such as an aspect, the aspect, another aspect, some aspects, one or more aspects, an implementation, the implementation, another implementation, some implementations, one or more implementations, an embodiment, the embodiment, another embodiment, some embodiments, one or more embodiments, a configuration, the configuration, another configuration, some configurations, one or more configurations, the subject technology, the disclosure, the present disclosure, other variations thereof and alike are for convenience and do not imply that a disclosure relating to such phrase(s) is essential to the subject technology or that such disclosure applies to all configurations of the subject technology. A disclosure relating to such phrase(s) may apply to all configurations, or one or more configurations. A disclosure relating to such phrase(s) may provide one or more examples. A phrase such as an aspect or some aspects may refer to one or more aspects and vice versa, and this applies similarly to other foregoing phrases.

A phrase "at least one of" preceding a series of items, with the terms "and" or "or" to separate any of the items, modifies the list as a whole, rather than each member of the list. The phrase "at least one of" does not require selection of at least one item; rather, the phrase allows a meaning that includes at least one of any one of the items, and/or at least one of any combination of the items, and/or at least one of each of the items. By way of example, each of the phrases "at least one of A, B, and C" or "at least one of A, B, or C" refers to only A, only B, or only C; any combination of A, B, and C; and/or at least one of each of A, B, and C.

It is understood that the specific order or hierarchy of steps, operations, or processes disclosed is an illustration of exemplary approaches. Unless explicitly stated otherwise, it is understood that the specific order or hierarchy of steps, operations, or processes may be performed in different order. Some of the steps, operations, or processes may be performed simultaneously. The accompanying method claims, if any, present elements of the various steps, operations or processes in a sample order, and are not meant to be limited to the specific order or hierarchy presented. These may be performed in serial, linearly, in parallel or in different order. It should be understood that the described instructions, operations, and systems can generally be integrated together in a single software/hardware product or packaged into multiple software/hardware products.

The disclosure is provided to enable any person skilled in the art to practice the various aspects described herein. In some instances, well-known structures and components are shown in block diagram form in order to avoid obscuring the concepts of the subject technology. The disclosure provides various examples of the subject technology, and the subject technology is not limited to these examples. Various modifications to these aspects will be readily apparent to those skilled in the art, and the principles described herein may be applied to other aspects.

All structural and functional equivalents to the elements of the various aspects described throughout the disclosure that are known or later come to be known to those of ordinary skill in the art are expressly incorporated herein by reference and are intended to be encompassed by the claims. Moreover, nothing disclosed herein is intended to be dedicated to the public regardless of whether such disclosure is explicitly recited in the claims. No claim element is to be construed under the provisions of 35 U.S.C. §112, sixth paragraph, unless the element is expressly recited using a phrase means for or, in the case of a method claim, the element is recited using the phrase step for.

The title, background, brief description of the drawings, abstract, and drawings are hereby incorporated into the disclosure and are provided as illustrative examples of the disclosure, not as restrictive descriptions. It is submitted with the understanding that they will not be used to limit the scope or meaning of the claims. In addition, in the detailed description, it can be seen that the description provides illustrative examples and the various features are grouped

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together in various implementations for the purpose of streamlining the disclosure. The method of disclosure is not to be interpreted as reflecting an intention that the claimed subject matter requires more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive subject matter lies in less than all features of a single disclosed configuration or operation. The following claims are hereby incorporated into the detailed description, with each claim standing on its own as a separately claimed subject matter.

The claims are not intended to be limited to the aspects described herein, but are to be accorded the full scope consistent with the language claims and to encompass all legal equivalents. Notwithstanding, none of the claims are intended to embrace subject matter that fails to satisfy the requirements of the applicable patent law, nor should they be interpreted in such a way.

What is claimed is:

1. An apparatus for facilitating wireless communication, the apparatus comprising:

one or more memories; and

one or more processors coupled to the one or more memories, the one or more processors configured to cause:

receiving, in a trigger frame transmitted by an access point, an indication of a first guard interval length, wherein the trigger frame allocates one or more resources for an uplink (UL) multi-user (MU) transmission and solicits the UL MU transmission, wherein a value of the first guard interval length is to be used by each of a plurality of stations, including the apparatus, associated with the UL MU transmission,

generating an uplink frame for the UL MU transmission solicited by the trigger frame, wherein the uplink frame comprises a payload and a physical layer (PHY) header, and

transmitting the uplink frame using a resource allocated by the trigger frame to the apparatus,

wherein at least a portion of the payload of the uplink frame is associated with the first guard interval length.

2. The apparatus of claim 1, wherein the trigger frame comprises an implicit indication of when the uplink frame is to be transmitted as part of the UL MU transmission.

3. The apparatus of claim 1, wherein the one or more processors are further configured to cause transmitting the uplink frame at a predetermined time after receipt of a PHY protocol data unit (PPDU) that carries the trigger frame.

4. The apparatus of claim 1, wherein the UL MU transmission comprises an uplink Orthogonal-Frequency Division Multiple Access (OFDMA) transmission, and wherein the first guard interval length is for the uplink OFDMA transmission.

5. The apparatus of claim 1, wherein the PHY header is associated with a second guard interval length.

6. The apparatus of claim 5, wherein the payload is comprised of a first set of orthogonal frequency-division multiplexing (OFDM) symbols and each OFDM symbol in the first set of OFDM symbols includes a guard interval of the first guard interval length.

7. The apparatus of claim 6, wherein the PHY header is composed of a second set of OFDM symbols and a third set of OFDM symbols and each OFDM symbol in the second set of OFDM symbols includes a guard interval of the second guard interval length and each OFDM symbol in the third set of OFDM symbols includes a guard interval of the first guard interval length.

8. The apparatus of claim 7, wherein the second set of OFDM symbols comprises a legacy short training field, a legacy long training field, a legacy signal field, and a high efficiency signal A field, and wherein the third set of OFDM symbols comprises a high efficiency long training field.

9. A method for facilitating wireless communications between a wireless device and an access point, the method comprising:

receiving, by the wireless device in a downlink frame from the access point, an indication of a first cyclic prefix (CP) length, wherein the downlink frame is for allocating resources for an uplink (UL) multi-user (MU) transmission and for soliciting the UL MU transmission, wherein the first CP length is the same length to be used for all of a plurality of stations addressed by the downlink frame in the UL MU transmission;

generating, by the wireless device, an uplink frame for the UL MU transmission solicited by the downlink frame, wherein the uplink frame comprises a payload; and

transmitting the uplink frame using a resource allocated by the downlink frame,

wherein at least a portion of the payload of the uplink frame is associated with the first CP length.

10. The method of claim 9, wherein the uplink frame further comprises a legacy header, and wherein at least a portion of the legacy header is associated with a second CP length.

11. The method of claim 10, wherein the payload is comprised of a first set of orthogonal frequency-division multiplexing (OFDM) symbols and each OFDM symbol in the first set of OFDM symbols includes a CP of the first CP length, and

wherein the legacy header is composed of a second set of OFDM symbols and each OFDM symbol in the second set of OFDM symbols includes a CP of the second CP length.

12. The method of claim 9, wherein the UL MU transmission is an Orthogonal Frequency-Division Multiple Access (OFDMA) transmission.

13. The method of claim 9, wherein the uplink frame is transmitted at a predetermined time after a physical layer protocol data unit (PPDU) that carries the downlink frame.

14. The method of claim 9, wherein a payload of the downlink frame comprises the indication of the first CP length.

15. A computer-implemented method of facilitating wireless communication, the method comprising:

determining, by an access point, a first guard interval to be used by a set of stations participating in a multi-user (MU) uplink (UL) transmission;

creating, by the access point, a trigger frame, wherein the trigger frame includes information indicating the first guard interval for the UL MU transmission, wherein the trigger frame allocates resources for the UL MU transmission and solicits the UL MU transmission;

transmitting, by the access point, the trigger frame to the set of stations; and

processing an uplink frame comprising a plurality of frames from the set of stations based on the resources for the UL MU transmission, wherein each of the plurality of frames comprises a respective payload, and wherein at least a portion of the respective payload is associated with the first guard interval.

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16. The computer-implemented method of claim 15, wherein each of the plurality of frames comprises a respective non-legacy header, and wherein at least a portion of the respective non-legacy header is associated with the first guard interval.

17. The computer-implemented method of claim 16, wherein for each of the plurality of frames, a second portion of the respective non-legacy header is associated with a second guard interval.

18. The computer-implemented method of claim 15, wherein the trigger frame comprises an indication of when each of the plurality of frames is to be transmitted as part of the UL MU transmission.

19. The computer-implemented method of claim 15, wherein the UL MU transmission is an Orthogonal Frequency-Division Multiple Access (OFDMA) transmission.

* * * * *

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EXHIBIT 6

D 8146575

THE UNITED STATES OF AMERICA

TO ALL TO WHOM THESE PRESENTS SHALL COME:

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office

August 23, 2021

THIS IS TO CERTIFY THAT ANNEXED HERETO IS A TRUE COPY FROM THE RECORDS OF THIS OFFICE OF:

U.S. PATENT: *10,020,919*
ISSUE DATE: *July 10, 2018*

By Authority of the
Under Secretary of Commerce for Intellectual Property
and Director of the United States Patent and Trademark Office

SYLVIA HOLLEY
Certifying Officer

ATLAS-00018964

US010020919B2

(12) **United States Patent**
Lee et al.

(10) **Patent No.: US 10,020,919 B2**
(45) **Date of Patent: Jul. 10, 2018**

(54) **PROTECTION METHODS FOR WIRELESS TRANSMISSIONS**

(71) Applicant: **NEWRACOM, INC.**, Irvine, CA (US)

(72) Inventors: **Dae Won Lee**, Irvine, CA (US); **Young Hoon Kwon**, Irvine, CA (US); **Yujin Noh**, Irvine, CA (US); **Sungho Moon**, Irvine, CA (US); **Ahmad Reza Hedayat**, Irvine, CA (US)

(73) Assignee: **NEWRACOM, INC.**, Lake Forest, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **15/497,094**

(22) Filed: **Apr. 25, 2017**

(65) **Prior Publication Data**

US 2017/0230155 A1 Aug. 10, 2017

Related U.S. Application Data

(63) Continuation of application No. 15/291,947, filed on Oct. 12, 2016, now Pat. No. 9,667,394.
(Continued)

(51) **Int. Cl.**
H04L 5/00 (2006.01)
H04W 72/12 (2009.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H04L 5/0044*** (2013.01); ***H04W 72/121*** (2013.01); ***H04W 74/0816*** (2013.01);
(Continued)

(58) **Field of Classification Search**
None
See application file for complete search history.

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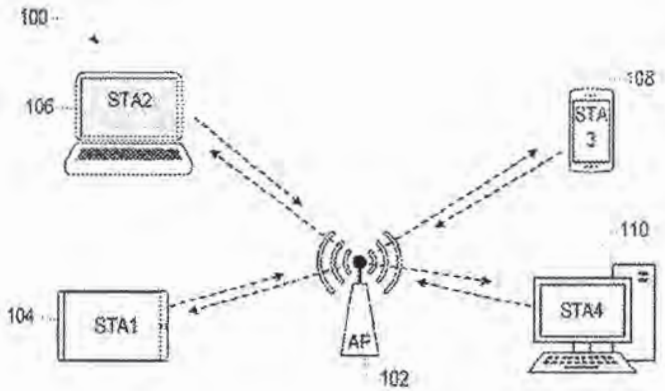
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Primary Examiner — Andrew Lai
Assistant Examiner — Jamaal Henson

(57) **ABSTRACT**

A wireless device receives a Multi-User Request-To-Send (MU-RTS) frame, descrambles first scrambled data in the MU-RTS frame using a first scrambling sequence, generates second scrambled data using a second scrambling sequence, and transmits a Clear-to-Send (CTS) frame including the second scrambled data in response to receiving the MU-RTS frame. The second scrambling sequence is an N-bit left cyclic shift of the first scrambling sequence. Another wireless device generates first scrambled data using a first scrambling sequence and transmits an MU-RTS frame including the first scrambled data. The wireless device receives a CTS frame transmitted in response to the MU-RTS frame, and descrambles second scrambled data in the CTS frame using a second scrambling sequence. The second scrambling sequence is an N-bit left cyclic shift of the first scrambling sequence. In either device, N may be 7, and lengths of the first and second scrambling sequences may be 127 bits.

20 Claims, 12 Drawing Sheets



Related U.S. Application Data

(60) Provisional application No. 62/333,192, filed on May 7, 2016, provisional application No. 62/333,077, filed on May 6, 2016, provisional application No. 62/331,380, filed on May 3, 2016, provisional application No. 62/240,419, filed on Oct. 12, 2015.

(51) **Int. Cl.**

H04W 74/08	(2009.01)
H04W 84/12	(2009.01)
H04W 88/08	(2009.01)

(52) **U.S. Cl.**
CPC *H04L 5/0007* (2013.01); *H04W 84/12* (2013.01); *H04W 88/08* (2013.01)

(56) **References Cited**

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FIG. 1

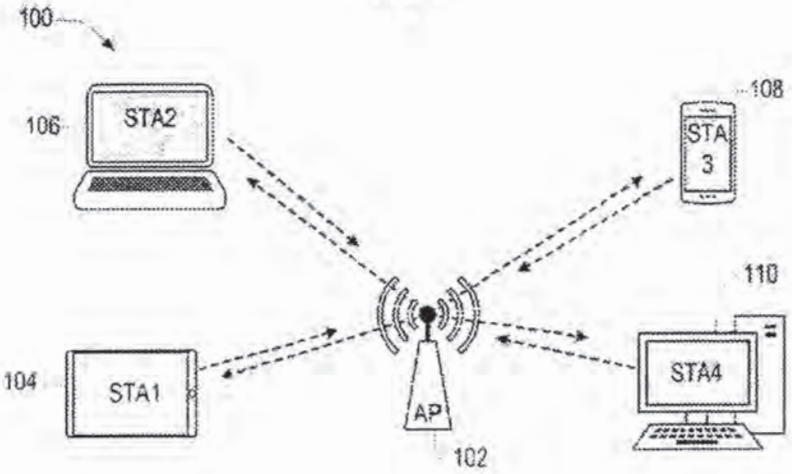
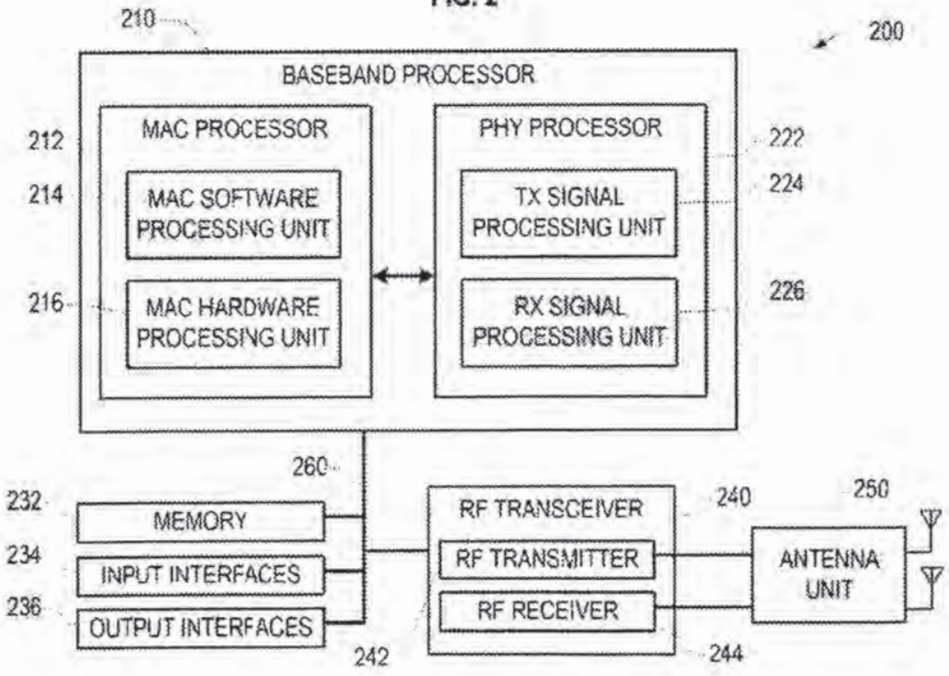


FIG. 2



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FIG. 3A

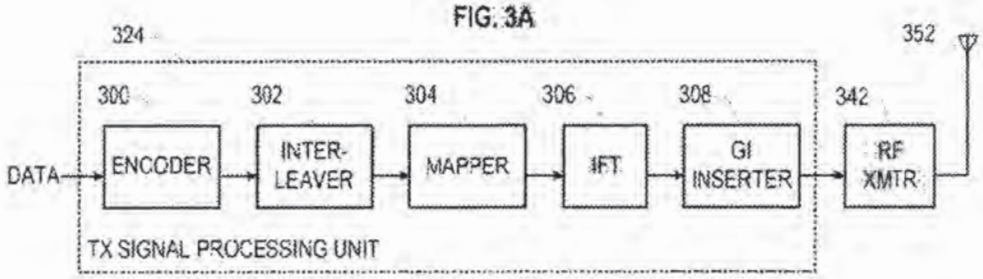


FIG. 3B

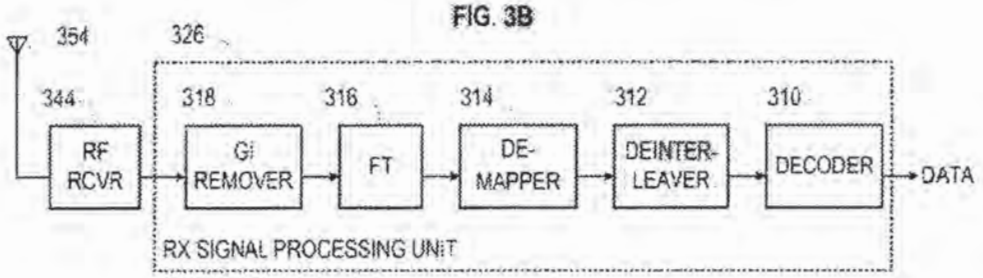
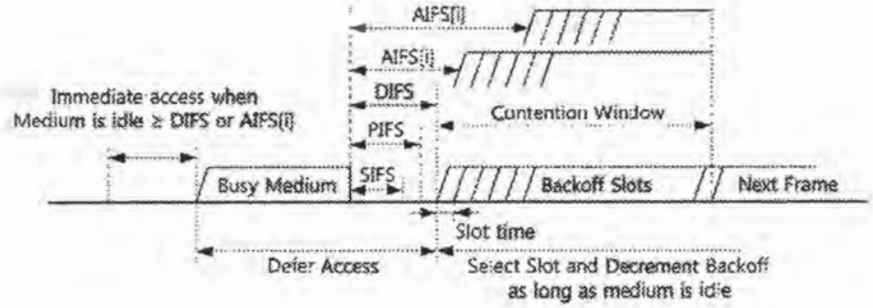
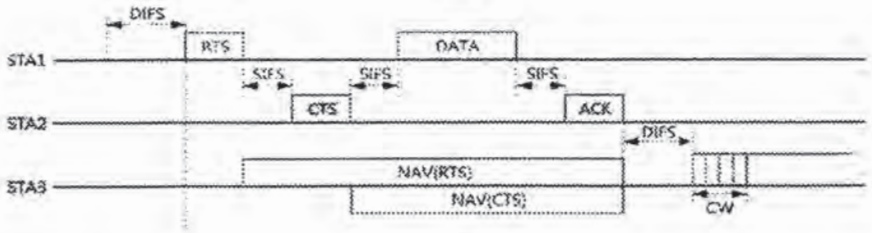


FIG. 4



FIG



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FIG. 6A

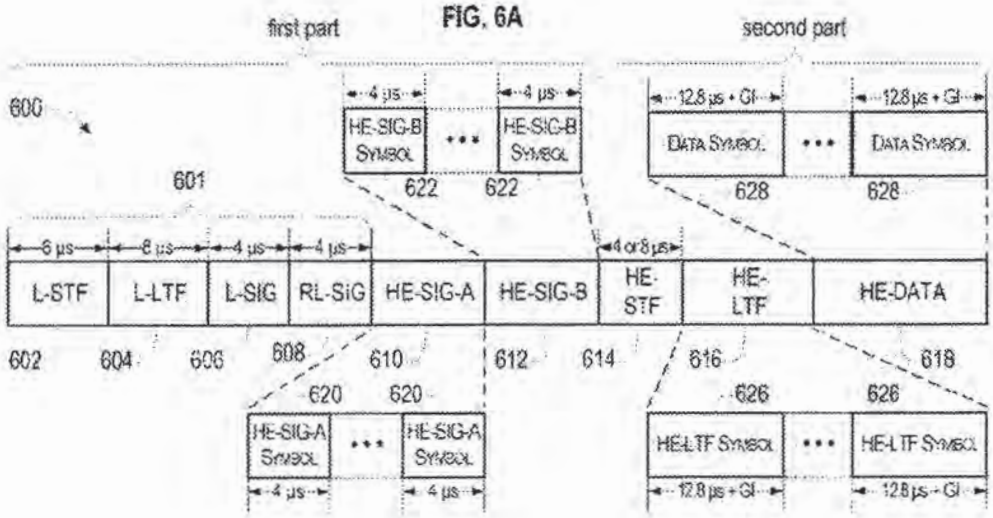


FIG. 6B

Table 1:

Element	definition	duration	DFT period	GI	Subcarrier spacing
Legacy (L)-STF	Non-HT Short Training field	8 µs	-	-	equiv. to 1,250 kHz
L-LTF	Non-HT Long Training field	8 µs	3.2 µs	1.6 µs	312.5 kHz
L-SIG	Non-HT Signal field	4 µs	3.2 µs	0.8 µs	312.5 kHz
RL-SIG	Repeated Non-HT SIGNAL field	4 µs	3.2 µs	0.8 µs	312.5 kHz
E-SIG-A	HE SIGNAL A field	N_{HESIGA} * 4 µs	3.2 µs	0.8 µs	312.5 kHz
HE-SIG-B	HE SIGNAL B field	N_{HESIGB} * 4 µs	3.2 µs	0.8 µs	312.5 kHz
HE-STF	HE Short Training field	4 or 8 µs	-	-	• non-trigger-based PPDU: (equiv. to) 1,250 kHz; • trigger-based PPDU: (equiv. to) 625 kHz
HE-LTF	HE Long Training field	N_{HELTF} * (DFT period + GI)µs	2xLTF: 6.4 µs 4xLTF: 12.8 µs	supports 0.8, 1.6, 3.2 µs	• 2xLTF: (equiv. to) 156.25 kHz; • 4xLTF: 78.125 kHz
HE-DATA	HE DATA field	N_{DATA} * (DFT period + GI)µs	12.8 µs	supports 0.8, 1.6, 3.2 µs	78.125 kHz

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FIG. 7

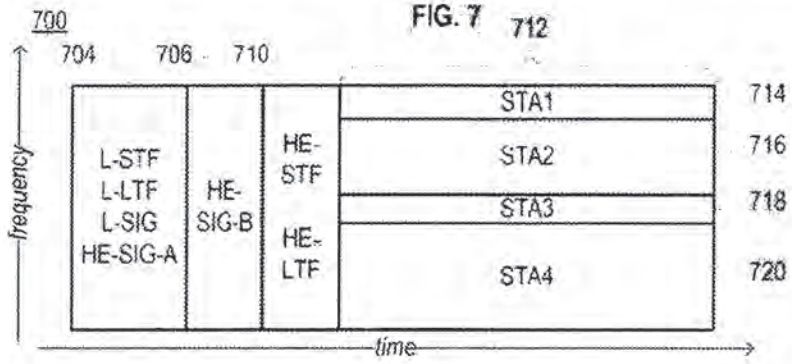


FIG. 8A

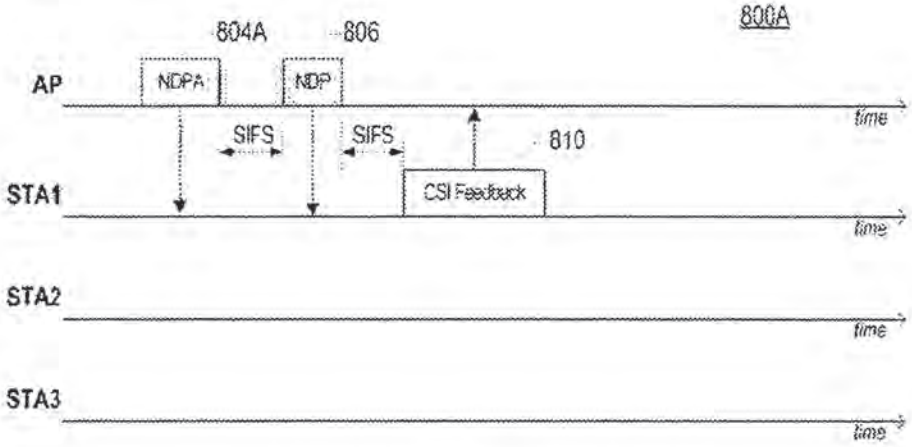
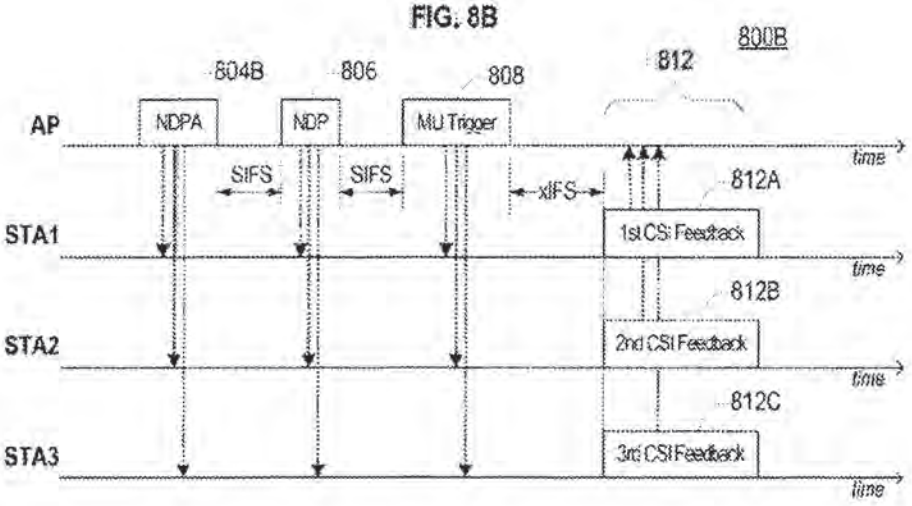


FIG. 8B



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FIG. 9A

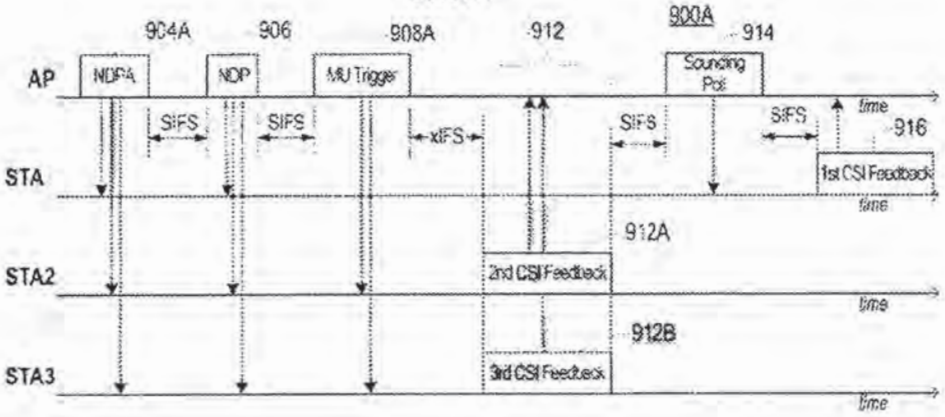
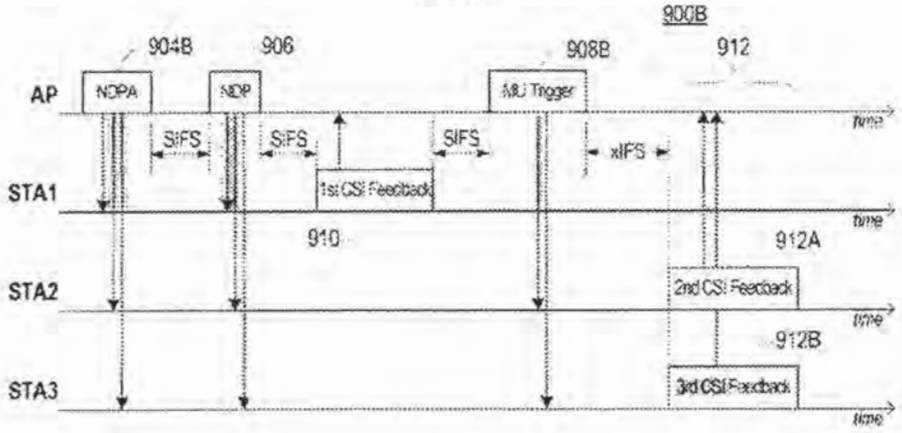


FIG. 9B



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FIG. 10

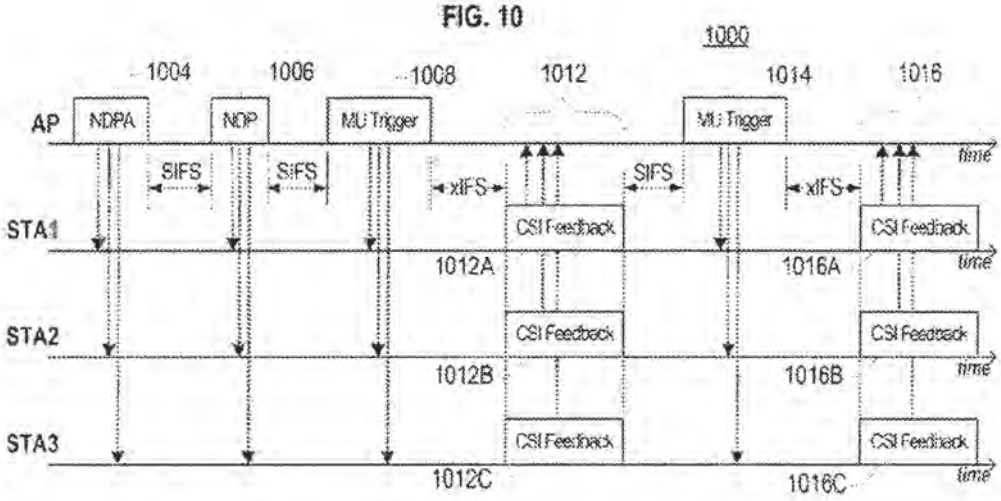
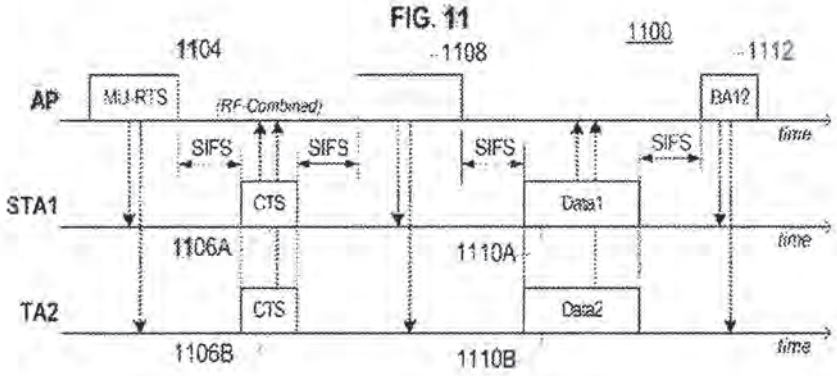


FIG. 11



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FIG. 12A

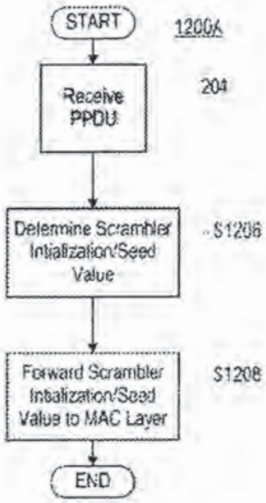


FIG. 12B

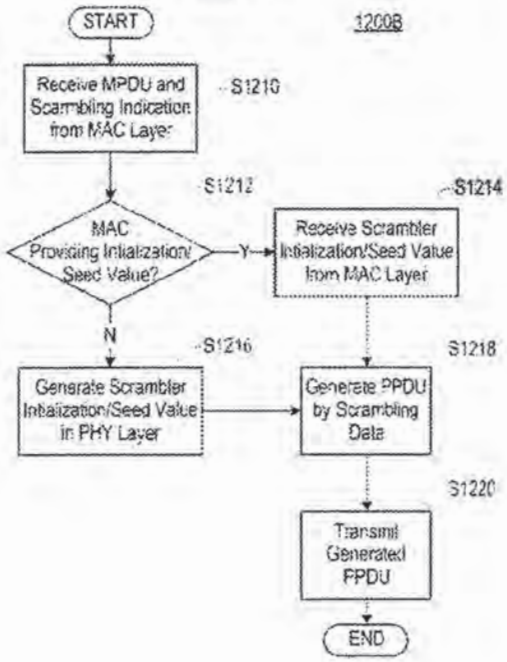


FIG. 13

Table 2

Parameter	Condition	Value	TXVECTOR	RXVECTOR
⋮	⋮	⋮	⋮	⋮
SCRAMBLER_ INITIALIZATION	FORMAT is NON_HT	In RXVECTOR, indicates the scrambler initialization value of the received PPDU. In TXVECTOR, if present, indicates the scrambler initialization value of the transmitted PPDU.	Y	Y
	Otherwise	Indicates the scrambler initialization value of the received PPDU.		Y (or MU)
⋮	⋮	⋮	⋮	⋮

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FIG. 14

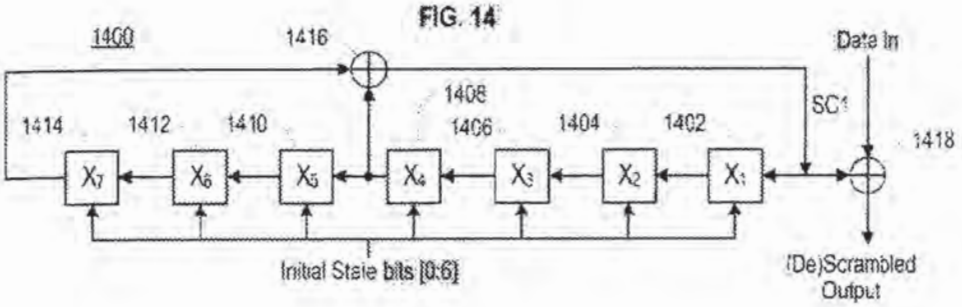


FIG. 15

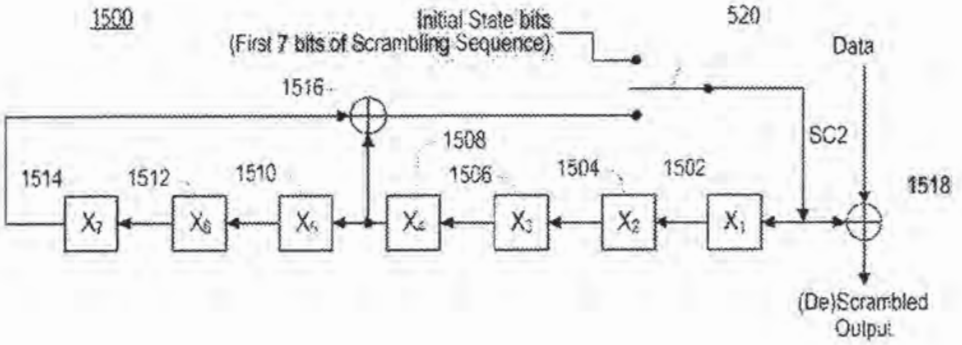
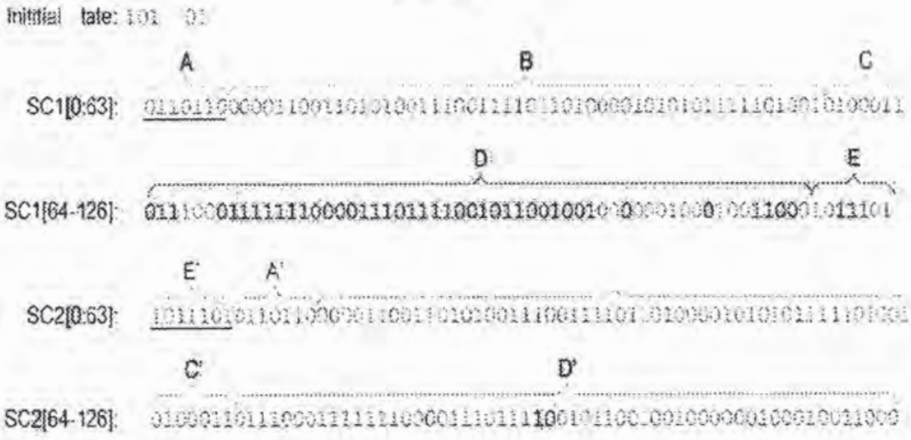


FIG. 16



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FIG. 17

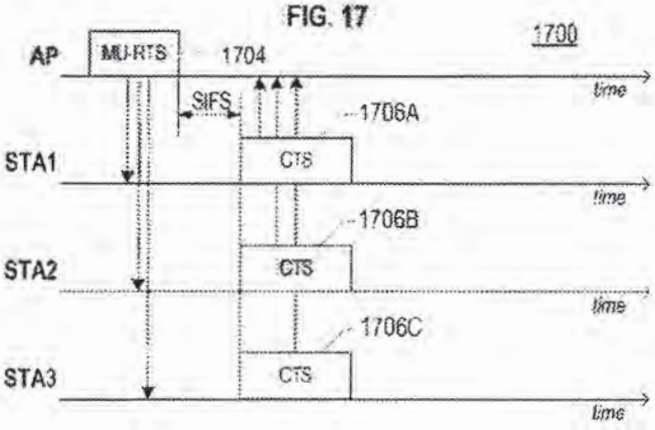


FIG 8A

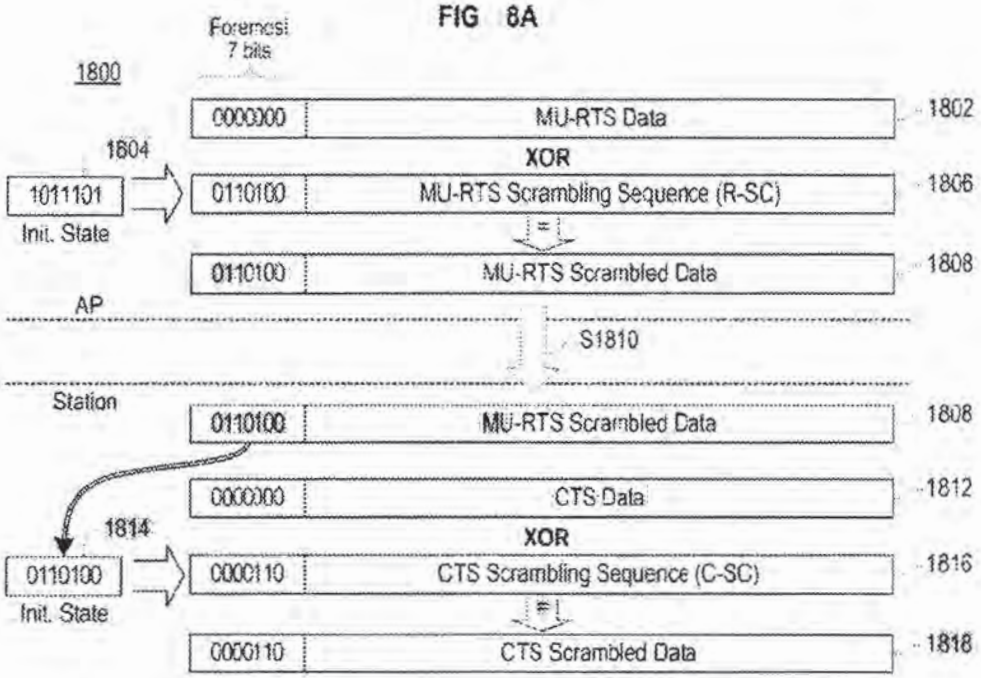


FIG. 18B

R-SC[0:63]: 0110111000011001101010011100111101010001010101111101000100011
R-SC[64-126]: 0111000111111100011101111001011001001000000100010011000101111

C-SC[0:63]: 0000110011010100111001111011010000101010111110100101000110111000
C-SC[64-126]: 1111111000111011110010110010010000001000100110001011101011010

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FIG. 19

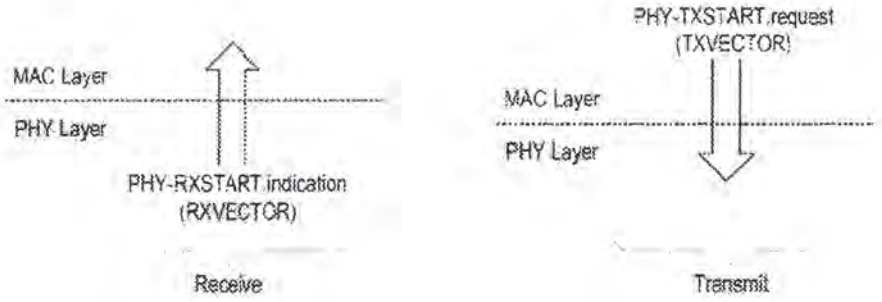


FIG. 20

Table 3

Parameter	Associated Primitive	Value
LENGTH	PHY-TXSTART.request (TXVECTOR)	1–4095
DATATRATE	PHY-TXSTART.request (TXVECTOR)	6, 9, 12, 18, 24, 36, 48, and 54 Mb/s for 20 MHz channel spacing (Support of 6, 12, and 24 Mb/s data rates is mandatory.) 3, 4.5, 6, 9, 12, 18, 24, and 27 Mb/s for 10 MHz channel spacing (Support of 3, 6, and 12 Mb/s data rates is mandatory.) 1.5, 2.25, 3, 4.5, 6, 9, 12, and 13.5 Mb/s for 5 MHz channel spacing (Support of 1.5, 3, and 6 Mb/s data rates is mandatory.)
SERVICE	PHY-TXSTART.request (TXVECTOR)	Null
TXPWR_LEVEL_INDEX	PHY-TXSTART.request (TXVECTOR)	1-8
TIME_OF_DEPARTURE_REQUESTED	PHY-TXSTART.request (TXVECTOR)	false, true. When true, the MAC entity requests that the PHY entity measures and reports time of departure parameters corresponding to the time when the first frame energy is sent by the transmitting port; when false, the MAC entity requests that the PHY entity neither measures nor reports time of departure parameters.
CH_BANDWIDTH_IN_NON_HT	PHY-TXSTART.request (TXVECTOR)	If present, CBW20, CBW40, CBW80, CBW160, or CBW80+80
DYN_BANDWIDTH_IN_NON_HT	PHY-TXSTART.request (TXVECTOR)	If present, Static or Dynamic
SCRAMBLER_INITIAL_STATE	PHY-TXSTART.request (TXVECTOR)	7 bit non-zero value

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FIG. 21

Table 4

Parameter	Associated Primitive	Value
LENGTH	PHYRXSTART. indication (RXVECTOR)	1–4095
RSSI	PHYRXSTART. indication (RXVECTOR)	0–RSSI maximum
DATATRATE	PHYRXSTART. request (RXVECTOR)	6, 9, 12, 18, 24, 36, 48, and 54 Mb/s for 20 MHz channel spacing (Support of 6, 12, and 24 Mb/s data rates is mandatory.) 3, 4.5, 6, 9, 12, 18, 24, and 27 Mb/s for 10 MHz channel spacing (Support of 3, 6, and 12 Mb/s data rates is mandatory.) 1.5, 2.25, 3, 4.5, 6, 9, 12, and 13.5 Mb/s for 5 MHz channel spacing (Support of 1.5, 3, and 6 Mb/s data rates is mandatory.)
SERVICE	PHYRXSTART. indication (RXVECTOR)	Null
RCPI (Parameter is present only when dot11RadioMeasurementActivated is true.)	PHYRXSTART. indication (RXVECTOR) PHY-RXEND.indication (RXVECTOR)	0-255
ANT_STATE (Parameter is present only when dot11RadioMeasurementActivated is true.)	PHYRXSTART. indication (RXVECTOR) PHY-RXEND.indication (RXVECTOR)	0-255
RX_START_OF_FRAM E_OFFSET	PHY-RXSTART. indication (RXVECTOR)	0 to $2^{32}-1$. An estimate of the offset (in 10 ns units) from the point in time at which the start of the preamble corresponding to the incoming frame arrived at the receive antenna connector to the point in time at which this primitive is issued to the MAC.
CH_BANDWIDTH_ IN_NON_HT	PHY-RXSTART.request (RXVECTOR)	If present, CBW20, CBW40, CBW80, CBW160, or CBW80+80
DYN_BANDWIDTH _IN_NON_HT	PHY-RXSTART.request (RXVECTOR)	If present, Static or Dynamic
SCRAMBLER_INITIALIZATION	PHY-RXSTART.request (RXVECTOR)	The scrambler initialization subfield of the SERVICE field prior to descrambling.

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Table 5

Parameter	Associated Primitive	Value
LENGTH	PH RXSTART. indication RXVECTOR)	1–4095
RSS	PHYRXSTART indicatio RXVECTOR)	0–RSSI maximum
DATATRATE	PHYRXSTART. request (RXVECTOR)	6, 9, 12, 18, 24, 36, 48, and 54 Mb/s for MHz channel spacing (Support of 6, 12, 24 Mb/s data rates is mandatory.) 3, 4 5, 6, 9, 12, 18, 24, and 27 Mb/s for 10 MHz channel spacing (Support of 3, 6, and 12 Mb/s data rates is mandatory.) 1.5, 2.25, 3, 4.5, 6, 9, 13.5 Mb/s for 5 MHz channel spacing (Support of 1.5, 3, and 6 Mb/s data rates is mandatory.)
SERVICE	PHYRXSTART. indication (RXVECTOR)	The scrambler initialization subfield of the SERVICE field prior to descrambling.
RCPI (Parameter is present only when dot11RadioMeasurementActivated is true.)	PHYRXSTART. indication (RXVECTOR) PHY-RXEND.indication (RXVECTOR)	0-255
ANT_STATE (Parameter is present only when dot11RadioMeasurementActivated is true.)	PHYRXSTART. indication (RXVECTOR) PHY-RXEND.indication (RXVECTOR)	0-2
RX_START_OF_ FRAME_OFFSET	HY-RXSTART indication (RXVECTOR)	0 to $2^{32}-1$. An estimate of the offset (in 10 ns units) from the point in time at which the start of the preamble corresponding to the incoming frame arrived at the receive antenna connector to the point in time at which this primitive is issued to the MAC.
CH_BANDW DTH_ NON	PHY-RXSTART.request (RXVECTOR)	If present, CBW20, CBW40, CBW80, CBW160, or CBW80+80
DYN_BANDWIDTH _IN_NON_HT	PHY-RXSTART uest (RXVECTO	If present, Static or Dynamic

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PROTECTION METHODS FOR WIRELESS TRANSMISSIONS

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation of U.S. patent application Ser. No. 15/291,947, filed Oct. 12, 2016, which claims the benefit of U.S. Provisional Patent Application No. 62/240,419, filed Oct. 12, 2015, U.S. Provisional Patent Application No. 62/331,380, filed May 3, 2016, U.S. Provisional Patent Application No. 62/333,077, filed May 6, 2016, and U.S. Provisional Patent Application 62/333,192, filed May 7, 2016, which are incorporated by reference herein in their entireties.

BACKGROUND

1. Technical Field

The technology described herein relates generally to wireless networking. More particularly, the technology relates to Multi-User Multiple-Input-Multiple-Output (MU-MIMO) and Orthogonal Frequency Division Multiple Access (OFDMA) communications in a wireless network.

2. Description of the Related Art

Wireless LAN (WLAN) devices are currently being deployed in diverse environments. Some of these environments have large numbers of access points (APs) and non-AP stations in geographically limited areas. In addition, WLAN devices are increasingly required to support a variety of applications such as video, cloud access, and offloading. In particular, video traffic is expected to be the dominant type of traffic in many high efficiency WLAN deployments. With the real-time requirements of some of these applications, WLAN users demand improved performance in delivering their applications, including improved power consumption for battery-operated devices.

A WLAN is being standardized by the IEEE (Institute of Electrical and Electronics Engineers) Part 11 under the name of "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications." A series of standards have been adopted as the WLAN evolved, including IEEE Std 802.11™-2012 (March 2012) (IEEE 802.11n). The IEEE Std 802.11 was subsequently amended by IEEE Std 802.11ae™-2012, IEEE Std 802.11aa™-2012, IEEE Std 802.11ad™-2012, and IEEE Std 802.11ac™-2013 (IEEE 802.11ac).

Recently, an amendment focused on providing a High Efficiency (HE) WLAN in high-density scenarios is being developed by the IEEE 802.11ax task group. The 802.11ax amendment focuses on improving metrics that reflect user experience, such as average per station throughput, the 5th percentile of per station throughput of a group of stations, and area throughput. Improvements may be made to support environments such as wireless corporate offices, outdoor hotspots, dense residential apartments, and stadiums.

An HE WLAN supports Down-Link (DL) and Up-Link (UL) Multi-User (MU) transmissions such as MU Orthogonal Frequency Division Multiple Access (MU OFDMA) transmission, Multi-User Multi-Input-Multi-Output (MU MIMO) transmissions, and MU transmissions that use both OFDMA and MU-MIMO. Collectively, transmissions using OFDMA, MU-MIMO, or both are referred to herein as MU transmissions.

MU communication as define herein are distinguished from other transmissions, such as broadcast transmissions, by the allocation in the MU communication of only a portion

of the channel (such as a sub-channel in an OFDMA communication, one or more spatial streams in an MU-MIMO communication, or one or more spatial streams of a sub-channel in a communication using both OFDMA and MU-MIMO) to a particular communication.

Sounding operations are used to identify channel conditions in a wireless network. Identifying the channel conditions permits better utilization of the channel by enabling one or more of higher bit rates, use of a greater number of spatial streams, and more effective utilization of transmission power. However, sounding operations may contribute to the total amount of overhead in a wireless network. Therefore it is advantageous for sounding processes, including sounding processes used for UL MU transmissions, to be efficient.

Protection mechanisms are used in wireless networks to prevent one station's transmissions from interfering with another station's transmissions. For example, a wireless network may use Clear-To-Send (CTS) and Ready-To-Send (RTS) packets to reserve a channel for a particular communication. When MU transmissions are being performed, including cascaded MU transmissions, such protection mechanisms should be efficient in order to increase the effective throughput of the wireless network.

A wireless network performing MU communications may Radio-Frequency (RF) combine all or portions of MU transmissions in the network. RF combining occurs when a plurality of stations simultaneous transmit respective transmissions into a channel, and the transmissions combine in the channel to form a single received transmission. The wireless network may apply scrambling sequences to information being transmitted in order to prevent the transmission of signal patterns which might result in an unwanted regularity in the transmitted signal. When a wireless network uses scrambling sequences, for two or more transmissions to be successfully RF-combined, all of the two or more transmissions must use a same scrambling sequence.

SUMMARY

In an embodiment, a method performed by a wireless device comprises receiving a Multi-User Request-To-Send (MU-RTS) frame including first scrambled data, descrambling the first scrambled data included in the MU-RTS frame using a first scrambling sequence, generating second scrambled data by scrambling data for a CTS frame using a second scrambling sequence, and transmitting the CTS frame in response to receiving the MU-RTS frame. The CTS frame includes the second scrambled data. For each i^{th} bit SS[i] of the second scrambling sequence, i=0 . . . M−1, SS[i] is equal to FS[(i+K) modulo L], where FS[j] is a j^{th} bit of the first scrambling sequence, K being a fixed integer greater than 1, M being an integer greater than 1, and L being equal to 2 to the K^{th} power minus 1.

In an embodiment, the MU-RTS frame further includes first data immediately followed by the first scrambled data, and the method further comprises generating the first scrambling sequence based on the first data.

In an embodiment, a size of the first data is equal to 7 bits.

In an embodiment, the CTS frame further includes second data immediately followed by the second scrambled data, and the second data is equal to foremost 7 bits of the first scrambling sequence.

In an embodiment, K is equal to 7.

In an embodiment, M is equal to a size of the second scrambled data.

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In an embodiment, the MU-RTS frame further includes first data immediately followed by the first scrambled data, and the method further comprises generating the second scrambling sequence based on the first data.

In an embodiment, generating the second scrambling sequence comprises generating the second scrambling sequence by using the first data as an initial state of a scrambler for scrambling the data for the CTS frame.

In an embodiment, the method further comprises providing, by a PHY layer of the wireless device, the first data to a MAC layer of the wireless device.

In an embodiment, generating the second scrambling sequence comprises i) determining, by the PHY layer of the wireless device, whether the PHY layer receives an initial state value from the MAC layer of the wireless device, and ii) generating, by the PHY layer of the wireless device, the second scrambling sequence by using the initial state value as the initial state of a scrambler, in response to determining that the PHY layer receives the initial state value from the MAC layer of the wireless device.

In an embodiment, generating the second scrambling sequence further comprises generating, by the PHY layer of the wireless device, the initial state value, in response to determining that the PHY layer does not receive the initial state value from the MAC layer of the wireless device.

In an embodiment, the method further comprises receiving, by the PHY layer of the wireless device, the initial state value from the MAC layer of the wireless device as a parameter of a TXVECTOR.

In an embodiment, the method further comprises providing, by a PHY layer of the wireless device, the first data to the MAC layer of the wireless device as a parameter of an RXVECTOR.

In an embodiment, the first data correspond to a value of a scrambler initialization field in a Service field of the received MU-RTS frame prior to descrambling.

In an embodiment, a method performed by a wireless device comprises generating first scrambled data by scrambling data for a Multi-User Request-To-Send (MU-RTS) frame using a first scrambling sequence, transmitting the MU-RTS frame, the MU-RTS frame including the first scrambled data, receiving a CTS frame transmitted in response to the MU-RTS frame, and descrambling second scrambled data included in the CTS frame using a second scrambling sequence. For each i^{th} bit SS[i] of the second scrambling sequence, i=0 . . . M−1, SS[i] is equal to FS[((i+K) modulo L)], where FS[j] is a j^{th} bit of the first scrambling sequence, K being a fixed integer greater than 1, M being an integer greater than 1, and L being equal to 2 to the K^{th} power minus 1.

In an embodiment, the MU-RTS frame further includes first data immediately followed by the first scrambled data.

In an embodiment, a size of the first data is equal to 7 bits.

In an embodiment, the method further comprises generating the second scrambling sequence based on the first data.

In an embodiment, the CTS frame further includes second data immediately followed by the second scrambled data, and the second data is equal to foremost 7 bits of the first scrambling sequence.

In an embodiment, K is equal to 7.

In an embodiment, a method performed by a wireless device comprises receiving a Null Data Packet Announcement (NDPA). The NDPA includes one or more station information fields. The method further comprises determining a number of the one or more station information fields in the NDPA, receiving a Null Data Packet (NDP), and when the number of one or more station information fields in the NDPA is one, transmitting first Channel State Information (CSI) feedback in response to receiving the NDP.

In an embodiment, the method further comprises when the number of one or more station information fields in the NDPA is greater than one, receiving a first trigger frame and transmitting the first CSI feedback in response to receiving the first trigger frame.

In an embodiment, transmitting the first CSI feedback in response to receiving the NDP comprises transmitting the first CSI feedback a first predetermined interframe space (IFS) after receiving the NDP.

In an embodiment, transmitting the first CSI feedback in response to receiving the first trigger frame comprises transmitting the first CSI feedback a second predetermined IFS after receiving the first trigger frame.

In an embodiment, transmitting the first CSI feedback in response to receiving the NDP comprises transmitting the first CSI feedback in a single user transmission in response to receiving the NDP.

In an embodiment, transmitting the first CSI feedback in response to receiving the first trigger frame comprises transmitting the first CSI feedback in a multi user transmission in response to receiving the first trigger frame.

In an embodiment, the first trigger frame comprises a resource assignment information.

In an embodiment, transmitting the first CSI feedback in a multi user transmission comprises participating the multi user transmission based on the resource assignment information to transmit the first CSI feedback in response to receiving the first trigger frame.

In an embodiment, the method further comprises when the number of one or more station information fields in the NDPA is greater than one, receiving a second trigger frame and transmitting second CSI feedback in response to receiving the second trigger frame.

In an embodiment, the method further comprises receiving a sounding poll frame, and transmitting the first CSI feedback in response to receiving the sounding poll frame.

In an embodiment, a method performed by a wireless device comprises transmitting a Null Data Packet Announcement (NDPA). The NDPA including one or more station information fields. The method further comprises transmitting a Null Data Packet (NDP), and when a number of one or more station information fields in the NDPA is one, receiving first Channel State Information (CSI) feedback in response to transmitting the NDP.

In an embodiment, the method further comprises when the number of one or more station information fields in the NDPA is greater than one, transmitting a first trigger frame and receiving the first CSI feedback in response to transmitting the first trigger frame.

In an embodiment, receiving the first CSI feedback in response to transmitting the NDP comprises receiving the first CSI feedback a first predetermined interframe space (IFS) after transmitting the NDP.

In an embodiment, receiving the first CSI feedback in response to transmitting the first trigger frame comprises receiving the first CSI feedback a second predetermined IFS after transmitting the first trigger frame.

In an embodiment, receiving the first CSI feedback in response to transmitting the NDP comprises receiving the first CSI feedback in a single user transmission in response to transmitting the NDP.

In an embodiment, receiving the first CSI feedback in response to transmitting the first trigger frame comprises receiving the first CSI feedback in a multi user transmission in response to transmitting the first trigger frame.

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In an embodiment, the first trigger frame comprises a resource assignment information.

In an embodiment, receiving the first CSI feedback in a multi user transmission comprises participating in the multi user transmission based on the resource assignment information to receive the first CSI feedback in response to transmitting the first trigger frame.

In an embodiment, the method further comprises when the number of one or more station information fields in the NDPA is greater than one transmitting a second trigger frame and receiving second CSI feedback in response to transmitting the second trigger frame.

In an embodiment, the method further comprises transmitting a sounding poll frame and receiving the first CSI feedback as a response to transmitting the sounding poll frame.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates a wireless network according to an embodiment.

FIG. **2** is a schematic diagram of a wireless device, according to an embodiment.

FIG. **3**A illustrates components of a wireless device configured to transmit data, according to an embodiment.

FIG. **3**B illustrates components of a wireless device configured to receive data, according to an embodiment.

FIG. **4** illustrates Inter-Frame Space (IFS) relationships.

FIG. **5** illustrates a Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) based frame transmission procedure.

FIG. **6**A illustrates an HE Physical Layer Convergence Protocol (PLCP) Protocol Data Units (PPDU), according to an embodiment.

FIG. **6**B shows a Table 1 disclosing additional properties of fields of the HE PPDU frame of FIG. **6**A, according to an embodiment.

FIG. **7** illustrates a DL MU OFDMA PPDU being transmitted to a set of stations, according to an embodiment.

FIG. **8**A illustrates a first process for obtaining Channel State Information (CSI) feedback using a first sounding procedure, according to an embodiment.

FIG. **8**B illustrates a second process for obtaining CSI feedback using the second sounding procedure, according to the embodiment.

FIG. **9**A illustrates a first process for obtaining CSI feedback using a first sounding procedure, according to another embodiment.

FIG. **9**B illustrates a second process for obtaining CSI feedback using a second sounding procedure, according to the other embodiment.

FIG. **10** illustrates a process for obtaining CSI feedback, according to an embodiment.

FIG. **11** illustrates a UL MU communication process including an MU-RTS frame, according to an embodiment.

FIG. **12**A illustrates a process for determining and saving a scrambler initialization (or seed value) from a received PPDU, according to an embodiment.

FIG. **12**B illustrates a process for using a scrambler initialization (or seed value) received from a MAC layer to scramble and transmit a PPDU, according to an embodiment.

FIG. **13** illustrates shows a Table 2 illustrating information in a TXVECTOR and an RXVECTOR, according to an embodiment.

FIG. **14** illustrates a circuit for performing the first scrambling operation, according to an embodiment.

FIG. **15** illustrates a circuit for performing the second scrambling operation, according to an embodiment.

FIG. **16** shows scrambling sequences generated by the first and second scrambling operations, according to an embodiment.

FIG. **17** illustrates a Multi-User Request-To-Send/Clear-To-Send (RTS/CTS) exchange process, according to an embodiment.

FIG. **18**A illustrates a process for scrambling data of a CTS frame, according to an embodiment.

FIG. **18**B shows illustrative 127-bit cycles of RTS and CTS scrambling sequences used in the process of FIG. **18**A, according to an embodiment.

FIG. **19** illustrates flows of information between a PHY layer and a MAC layer of a wireless device, according to an embodiment.

FIG. **20** shows a Table 3 of TXVECTOR parameters, according to an embodiment.

FIG. **21** shows a Table 4 of RXVECTOR parameters for non-High Throughput (non-HT) PPDU frames, according to an embodiment.

FIG. **22** shows a Table 5 of RXVECTOR parameters, according to another embodiment.

DETAILED DESCRIPTION

The technology described herein relates generally to wireless networking. More particularly, the technology relates Multi-User (MU) communications, including MU Multiple-Input-Multiple-Output (MU-MIMO) communications, Orthogonal Frequency Division Multiple Access (OFDMA) communications, and communications that use both MU-MIMO and OFDMA.

In the following detailed description, certain illustrative embodiments have been illustrated and described. As those skilled in the art would realize, these embodiments are capable of modification in various different ways without departing from the scope of the present disclosure. Accordingly, the drawings and description are to be regarded as illustrative in nature and not restrictive. Like reference numerals designate like elements in the specification.

FIG. **1** illustrates a wireless network according to an embodiment. The wireless network includes an infrastructure Basic Service Set (BSS) **100** of a Wireless Local Area Network (WLAN). In an 802.11 wireless LAN (WLAN), the BSS provides the basic organizational unit and typically includes an Access Point (AP) and one or more associated stations (STAs). In FIG. **1**, the BSS **100** includes an Access Point **102** (also referred to as the AP) wirelessly communicating with first, second, third, and fourth wireless devices (or stations) **104**, **106**, **108**, and **110** (also referred to as stations STA**1**, STA**2**, STA**3**, and STA**4**, respectively). The wireless devices may each include a medium access control layer (MAC) and a physical layer (PHY) according to an IEEE 802.11 standard.

Although FIG. **1** shows the BSS **100** including only the first to fourth stations STA**1** to STA**4**, embodiments are not limited thereto and may comprise BSSs including any number of stations.

The AP **102** is a station, that is, a STA, configured to control and coordinate functions of the BSS **100**. The AP **102** may transmit information to a single station selected from the plurality of stations STA**1** to STA**4** in the BSS **100** using a single frame, or may simultaneously transmit information to two or more of the stations STA**1** to STA**4** in the BSS **100** using either a single Orthogonal Frequency Division Multiplexing (OFDM) broadcast frame, a single OFDM

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Multi-User Multi-Input-Multi-Output (MU-MIMO) transmission, a single Orthogonal Frequency Division Multiple Access (OFDMA) frame, or a single MU-MIMO OFDMA frame.

The stations STA1 to STA4 may each transmit data to the AP **102** using a single frame, or transmit information to and receive information from each other using a single frame. Two or more of the stations STA1 to STA4 may simultaneously transmit data to the AP **102** using an Uplink (UL) OFDMA frame, an UL MU-MIMO frame, or an UL MU-MIMO OFDMA frame.

In another embodiment, the AP **102** may be absent and the stations STA1 to STA4 may be in an ad-hoc network.

Each of the stations STA1 to STA4 and the AP **102** includes a processor and a transceiver, and may further include a user interface and a display device.

The processor is configured to generate a frame to be transmitted through a wireless network, to process a frame received through the wireless network, and to execute protocols of the wireless network. The processor may perform some or all of its functions by executing computer programming instructions stored on a non-transitory computer-readable medium.

The transceiver represents a unit functionally connected to the processor, and designed to transmit and receive a frame through the wireless network. The transceiver may include a single component that performs the functions of transmitting and receiving, or two separate components each performing one of such functions.

The processor and transceiver of the stations STA1 to STA4 and the AP **102** may be respectively implemented using hardware components, software components, or both.

The AP **102** may be or may include a WLAN router, a stand-alone Access Point, a WLAN bridge, a Light-Weight Access Point (LWAP) managed by a WLAN controller, and the like. In addition, a device such as a personal computer, tablet computer, or cellular phone may configured able to operate as the AP **102**, such as when a cellular phone is configured to operate as a wireless "hot spot."

Each of the stations STA1 to STA4 may be or may include a desktop computer, a laptop computer, a tablet PC, a wireless phone, a mobile phone, a smart phone, an e-book reader, a Portable Multimedia Player (PMP), a portable game console, a navigation system, a digital camera, a Digital Multimedia Broadcasting (DMB) player, a digital audio recorder, a digital audio player, a digital picture recorder, a digital picture player, a digital video recorder, a digital video player, and the like.

The present disclosure may be applied to WLAN systems according to IEEE 802.11 standards but embodiments are not limited thereto.

In IEEE 802.11 standards, frames exchanged between stations (including access points) are classified into management frames, control frames, and data frames. A management frame may be a frame used for exchanging management information that is not forwarded to a higher layer of a communication protocol stack. A control frame may be a frame used for controlling access to a medium. A data frame may be a frame used for transmitting data to be forwarded to the higher layer of the communication protocol stack.

A type and subtype of a frame may be identified using a type field and a subtype field included in a control field of the frame, as prescribed in the applicable standard.

FIG. **2** illustrates a schematic block diagram of a wireless device **200** according to an embodiment. The wireless or WLAN device **200** may be included in the AP **102** or any of the stations STA1 to STA4 in FIG. **1**. The WLAN device **200** includes a baseband processor **210**, a radio frequency (RF) transceiver **240**, an antenna unit **250**, a storage device (e.g., memory) **232**, one or more input interfaces **234**, and one or more output interfaces **236**. The baseband processor **210**, the memory **232**, the input interfaces **234**, the output interfaces **236**, and the RF transceiver **240** may communicate with each other via a bus **260**.

The baseband processor **210** performs baseband signal processing, and includes a MAC processor **212** and a PHY processor **222**. The baseband processor **210** may utilize the memory **232**, which may include a non-transitory computer readable medium having software (e.g., computer programming instructions) and data stored therein.

In an embodiment, the MAC processor **212** includes a MAC software processing unit **214** and a MAC hardware processing unit **216**. The MAC software processing unit **214** may implement a first plurality of functions of the MAC layer by executing MAC software, which may be included in the software stored in the memory **232**. The MAC hardware processing unit **216** may implement a second plurality of functions of the MAC layer in special-purpose hardware. However, the MAC processor **212** is not limited thereto. For example, the MAC processor **212** may be configured to perform the first and second plurality of functions entirely in software or entirely in hardware according to an implementation.

The PHY processor **222** includes a transmitting signal processing unit (SPU) **224** and a receiving SPU **226**. The PHY processor **222** implements a plurality of functions of the PHY layer. These functions may be performed in software, hardware, or a combination thereof according to an implementation.

Functions performed by the transmitting SPU **224** may include one or more of Forward Error Correction (FEC) encoding, stream parsing into one or more spatial streams, diversity encoding of the spatial streams into a plurality of space-time streams, spatial mapping of the space-time streams to transmit chains, inverse Fourier Transform (iFT) computation, Cyclic Prefix (CP) insertion to create a Guard Interval (GI), and the like. Functions performed by the receiving SPU **226** may include inverses of the functions performed by the transmitting SPU **224**, such as GI removal, Fourier Transform computation, and the like.

The RF transceiver **240** includes an RF transmitter **242** and an RF receiver **244**. The RF transceiver **240** is configured to transmit first information received from the baseband processor **210** to the WLAN, and provide second information received from the WLAN to the baseband processor **210**.

The antenna unit **250** includes one or more antennas. When Multiple-Input Multiple-Output (MIMO) or Multi-User MIMO (MU-MIMO) is used, the antenna unit **250** may include a plurality of antennas. In an embodiment, the antennas in the antenna unit **250** may operate as a beamformed antenna array. In an embodiment, the antennas in the antenna unit **250** may be directional antennas, which may be fixed or steerable.

The input interfaces **234** receive information from a user, and the output interfaces **236** output information to the user. The input interfaces **234** may include one or more of a keyboard, keypad, mouse, touchscreen, microphone, and the like. The output interfaces **236** may include one or more of a display device, touch screen, speaker, and the like.

As described herein, many functions of the WLAN device **200** may be implemented in either hardware or software. Which functions are implemented in software and which

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functions are implemented in hardware will vary according to constraints imposed on a design. The constraints may include one or more of design cost, manufacturing cost, time to market, power consumption, available semiconductor technology, and so on.

As described herein, a wide variety of electronic devices, circuits, firmware, software, and combinations thereof may be used to implement the functions of the components of the WLAN device **200**. Furthermore, the WLAN device **200** may include other components, such as application processors, storage interfaces, clock generator circuits, power supply circuits, and the like, which have been omitted in the interest of brevity.

FIG. **3**A illustrates components of a wireless device configured to transmit data according to an embodiment, including a Transmitting (Tx) SPU (TxSP) **324**, an RF transmitter **342**, and an antenna **352**. In an embodiment, the TxSP **324**, the RF transmitter **342**, and the antenna **352** correspond to the transmitting SPU **224**, the RF transmitter **242**, and an antenna of the antenna unit **250** of FIG. **2**, respectively.

The TxSP **324** includes an encoder **300**, an interleaver **302**, a mapper **304**, an inverse Fourier transformer (IFT) **306**, and a guard interval (GI) inserter **308**.

The encoder **300** receives and encodes input data DATA. In an embodiment, the encoder **300** includes a forward error correction (FEC) encoder. The FEC encoder may include a binary convolutional code (BCC) encoder followed by a puncturing device. The FEC encoder may include a low-density parity-check (LDPC) encoder.

The TxSP **324** may further include a scrambler for scrambling the input data before the encoding is performed by the encoder **300** to reduce the probability of long sequences of 0s or 1s. When the encoder **300** performs the BCC encoding, the TxSP **324** may further include an encoder parser for demultiplexing the scrambled bits among a plurality of BCC encoders. If LDPC encoding is used in the encoder, the TxSP **324** may not use the encoder parser.

The interleaver **302** interleaves the bits of each stream output from the encoder **300** to change an order of bits therein. The interleaver **302** may apply the interleaving only when the encoder **300** performs the BCC encoding, and otherwise may output the stream output from the encoder **300** without changing the order of the bits therein.

The mapper **304** maps the sequence of bits output from the interleaver **302** to constellation points. If the encoder **300** performed LDPC encoding, the mapper **304** may also perform LDPC tone mapping in addition to the constellation mapping.

When the TxSP **324** performs a MIMO or MU-MIMO transmission, the TxSP **324** may include a plurality of interleavers **302** and a plurality of mappers **304** according to a number of spatial streams (NSS) of the transmission. The TxSP **324** may further include a stream parser for dividing the output of the encoder **300** into blocks and may respectively send the blocks to different interleavers **302** or mappers **304**. The TxSP **324** may further include a space-time block code (STBC) encoder for spreading the constellation points from the spatial streams into a number of space-time streams (NSTS) and a spatial mapper for mapping the space-time streams to transmit chains. The spatial mapper may use direct mapping, spatial expansion, or beamforming.

The IFT **306** converts a block of the constellation points output from the mapper **304** (or, when MIMO or MU-MIMO is performed, the spatial mapper) to a time domain block (i.e., a symbol) by using an inverse discrete Fourier transform (IDFT) or an inverse fast Fourier transform (IFFT). If the STBC encoder and the spatial mapper are used, the IFT **306** may be provided for each transmit chain.

When the TxSP **324** performs a MIMO or MU-MIMO transmission, the TxSP **324** may insert cyclic shift diversities (CSDs) to prevent unintentional beamforming. The TxSP **324** may perform the insertion of the CSD before or after the IFT **306**. The CSD may be specified per transmit chain or may be specified per space-time stream. Alternatively, the CSD may be applied as a part of the spatial mapper.

When the TxSP **324** performs a MIMO or MU-MIMO transmission, some blocks before the spatial mapper may be provided for each user.

The GI inserter **308** prepends a GI to each symbol produced by the IFT **306**. Each GI may include a Cyclic Prefix (CP) corresponding to a repeated portion of the end of the symbol that the GI precedes. The TxSP **324** may optionally perform windowing to smooth edges of each symbol after inserting the GI.

The RF transmitter **342** converts the symbols into an RF signal and transmits the RF signal via the antenna **352**. When the TxSP **324** performs a MIMO or MU-MIMO transmission, the GI inserter **308** and the RF transmitter **342** may be provided for each transmit chain.

FIG. **3**B illustrates components of a wireless device configured to receive data according to an embodiment, including a Receiver (Rx) SPU (RxSP) **326**, an RF receiver **344**, and an antenna **354**. In an embodiment, the RxSP **326**, RF receiver **344**, and antenna **354** may correspond to the receiving SPU **226**, the RF receiver **244**, and an antenna of the antenna unit **250** of FIG. **2**, respectively.

The RxSP **326** includes a GI remover **318**, a Fourier transformer (FT) **316**, a demapper **314**, a deinterleaver **312**, and a decoder **310**.

The RF receiver **344** receives an RF signal via the antenna **354** and converts the RF signal into symbols. The GI remover **318** removes the GI from each of the symbols. When the received transmission is a MIMO or MU-MIMO transmission, the RF receiver **344** and the GI remover **318** may be provided for each receive chain.

The FT **316** converts each symbol (that is, each time domain block) into a frequency domain block of constellation points by using a discrete Fourier transform (DFT) or a fast Fourier transform (FFT). The FT **316** may be provided for each receive chain.

When the received transmission is the MIMO or MU-MIMO transmission, the RxSP **326** may include a spatial demapper for converting the respective outputs of the FTs **316** of the receiver chains to constellation points of a plurality of space-time streams, and an STBC decoder for despreading the constellation points from the space-time streams into one or more spatial streams.

The demapper **314** demaps the constellation points output from the FT **316** or the STBC decoder to bit streams. If the received transmission was encoded using the LDPC encoding, the demapper **314** may further perform LDPC tone demapping before performing the constellation demapping.

The deinterleaver **312** deinterleaves the bits of each stream output from the demapper **314**. The deinterleaver **312** may perform the deinterleaving only when the received transmission was encoded using the BCC encoding, and otherwise may output the stream output by the demapper **314** without performing deinterleaving.

When the received transmission is the MIMO or MU-MIMO transmission, the RxSP **326** may use a plurality of demappers **314** and a plurality of deinterleavers **312** corresponding to the number of spatial streams of the transmis-

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sion. In this case, the RxSP **326** may further include a stream deparser for combining the streams output from the deinterleavers **312**.

The decoder **310** decodes the streams output from the deinterleaver **312** or the stream deparser. In an embodiment, the decoder **312** includes an FEC decoder. The FEC decoder may include a BCC decoder or an LDPC decoder.

The RxSP **326** may further include a descrambler for descrambling the decoded data. When the decoder **310** performs the BCC decoding, the RxSP **326** may further include an encoder deparser for multiplexing the data decoded by a plurality of BCC decoders. When the decoder **310** performs the LDPC decoding, the RxSP **326** may not use the encoder deparser.

Before making a transmission, wireless devices such as wireless device **200** will assess the availability of the wireless medium using Clear Channel Assessment (CCA). If the medium is occupied, CCA may determine that it is busy, while if the medium is available, CCA determines that it is idle.

FIG. **4** illustrates Inter-Frame Space (IFS) relationships. FIG. **4** illustrates a Short IFS (SIFS), a Point Coordination Function (PCF) IFS (PIFS), a Distributed Coordination Function (DCF) IFS (DIFS), and an Arbitration IFSs corresponding to an Access Category (AC) 'i' (AIFS[i]). FIG. **4** also illustrates a slot time.

A data frame is used for transmission of data forwarded to a higher layer. The WLAN device transmits the data frame after performing backoff if a DIFS has elapsed during which DIFS the medium has been idle.

A management frame is used for exchanging management information, which is not forwarded to the higher layer. Subtype frames of the management frame include a beacon frame, an association request/response frame, a probe request/response frame, and an authentication request/response frame.

A control frame is used for controlling access to the medium. Subtype frames of the control frame include a request to send (RTS) frame, a clear to send (CTS) frame, and an acknowledgement (ACK) frame.

When the control frame is not a response frame of another frame, the WLAN device transmits the control frame after performing backoff if a DIFS has elapsed during which DIFS the medium has been idle. When the control frame is the response frame of another frame, the WLAN device transmits the control frame after a SIFS has elapsed without performing backoff or checking whether the medium is idle.

A WLAN device that supports a Quality of Service (QoS) functionality (that is, a QoS station) may transmit the frame after performing backoff if an AIFS for an associated access category (AC), (AIFS[AC]), has elapsed. When transmitted by the QoS station, any of the data frame, the management frame, and the control frame which is not the response frame may use the AIFS[AC] of the AC of the transmitted frame.

A WLAN device may perform a backoff procedure when the WLAN device that is ready to transfer a frame finds the medium busy. In addition, a WLAN device operating according to the IEEE 802.11n and 802.11ac standards may perform the backoff procedure when the WLAN device infers that a transmission of a frame by the WLAN device has failed.

The backoff procedure includes determining a random backoff time composed of N backoff slots, each backoff slot having a duration equal to a slot time and N being an integer number greater than or equal to zero. The backoff time may be determined according to a length of a Contention Window (CW). In an embodiment, the backoff time may be determined according to an AC of the frame. All backoff slots occur following a DIFS or Extended IFS (EIFS) period during which the medium is determined to be idle for the duration of the period.

When the WLAN device detects no medium activity for the duration of a particular backoff slot, the backoff procedure shall decrement the backoff time by the slot time. When the WLAN determines that the medium is busy during a backoff slot, the backoff procedure is suspended until the medium is again determined to be idle for the duration of a DIFS or EIFS period. The WLAN device may perform transmission or retransmission of the frame when the backoff timer reaches zero.

The backoff procedure operates so that when multiple WLAN devices are deferring and execute the backoff procedure, each WLAN device may select a backoff time using a random function, and the WLAN device selecting the smallest backoff time may win the contention, reducing the probability of a collision.

FIG. **5** illustrates a Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) based frame transmission procedure for avoiding collision between frames in a channel according to an embodiment. FIG. **5** shows a first station STA**1** transmitting data, a second station STA**2** receiving the data, and a third station STA**3** that may be located in an area where a frame transmitted from the STA**1**, a frame transmitted from the second station STA**2**, or both can be received. The stations STA**1**, STA**2**, and STA**3** may be WLAN devices.

The STA**1** may determine whether the channel is busy by carrier sensing. The STA**1** may determine the channel occupation based on an energy level in the channel or an autocorrelation of signals in the channel, or may determine the channel occupation by using a network allocation vector (NAV) timer.

After determining that the channel is not used by other devices (that is, that the channel is IDLE) during a DIFS (and performing backoff if required), the STA**1** may transmit a Ready-To-Send (RTS) frame to the second station STA**2**. Upon receiving the RTS frame, after a SIFS the second station STA**2** may transmit a Clear-To-Send (CTS) frame as a response of the RTS frame. If Dual-CTS is enabled and the second station STA**2** is an AP, the AP may send two CTS frames in response to the RTS frame: a first CTS frame in the legacy non-HT format, and a second CTS frame in the HT format.

When the third station STA**3** receives the RTS frame, it may set a NAV timer of the third station STA**3** for a transmission duration of subsequently transmitted frames (for example, a duration of SIFS+CTS frame duration+SIFS+data frame duration+SIFS+ACK frame duration) using duration information included in the RTS frame. When the third station STA**3** receives the CTS frame, it may set the NAV timer of the third station STA**3** for a transmission duration of subsequently transmitted frames using duration information included in the CTS frame. Upon receiving a new frame before the NAV timer expires, the third station STA**3** may update the NAV timer of the third station STA**3** by using duration information included in the new frame. The third station STA**3** does not attempt to access the channel until the NAV timer expires.

When the STA**1** receives the CTS frame from the second station STA**2**, it may transmit a data frame to the second station STA**2** after SIFS elapses from a time when the CTS frame has been completely received. Upon successfully

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receiving the data frame, the second station STA2 may transmit an ACK frame as a response of the data frame after SIFS elapses.

When the NAV timer expires, the third station STA3 may determine whether the channel is busy using the carrier sensing. Upon determining that the channel is not used by other devices during a DIFS after the NAV timer has expired, the third station STA3 may attempt to access the channel after a contention window according to a backoff process elapses.

When Dual-CTS is enabled, a station that has obtained a transmission opportunity (TXOP) and that has no data to transmit may transmit a CF-End frame to cut short the TXOP. An AP receiving a CF-End frame having a Basic Service Set Identifier (BSSID) of the AP as a destination address may respond by transmitting two more CF-End frames: a first CF-End frame using Space Time Block Coding (STBC) and a second CF-End frame using non-STBC. A station receiving a CF-End frame resets its NAV timer to 0 at the end of the PPDU containing the CF-End frame.

FIG. **5** shows the second station STA1 transmitting an ACK frame to acknowledge the successful reception of a frame by the recipient. FIG. **6** illustrates an embodiment in which a station acknowledges successful receipt of a frame using a Block Acknowledgment (Block Ack, BlockAck, or BA) frame.

The Block Ack mechanism improves channel efficiency by aggregating several acknowledgments into one frame. There are two types of Block Ack mechanisms: Immediate and Delayed. The Immediate Block Ack mechanism is intended for use with high-bandwidth, low-latency traffic. The delayed Block Ack mechanism is intended for applications that tolerate moderate latency.

Here, a station with data to send which will be acknowledged using the Block Ack mechanism is referred to as the originator, and the receiver of that data as the recipient. An AP can be the recipient or the originator.

The Block Ack mechanism is initialized using a setup process that includes an exchange of ADDBA Request and ADDBA Response frames. The ADDBA Request and ADDBA Response frames include indications of whether Aggregate MAC Service Data Units (A-MSDUs) are permitted in the frames using the Black Ack mechanism, whether Immediate or Delayed Block Ack is to be used, and other information.

After initialization, blocks of data frames—in particular, Quality of Service (QoS) data frame according to IEEE Std 802.11-2012—may be transmitted from the originator to the recipient. A block may be started within a polled TXOP or by winning Enhanced Distributed Channel Access (EDCA) contention. The number of frames in the block is limited, and the amount of state that is to be kept by the recipient is bounded.

The MAC Protocol Data Units (MPDUs) within the block of frames are acknowledged by a BlockAck frame, which is requested by a BlockAckReq frame.

The Block Ack mechanism does not require the setting up of a Traffic Stream (TS); however, QoS stations using the TS facility may choose to signal their intention to use a Block Ack mechanism for the scheduler's consideration in assigning Transmission Opportunities (TXOPs).

Acknowledgments of frames belonging to the same Traffic Identifier (TID), but transmitted during multiple TXOPs, may also be combined into a single BlockAck frame. This mechanism allows the originator to have flexibility regarding the transmission of data MPDUs. The originator may split the block of frames across TXOPs, separate the data transfer and the Block Ack exchange, and interleave blocks of MPDUs carrying all or part of MAC Service Data Units (MSDUs) or Aggregate MSDUs (A-MSDUs) for different TIDs or receiver addresses.

The Block Ack mechanism is torn down using a DELBA frame including a DELBA Request. The DELBA frame is sent by either the originator or the recipient to terminate participation in the Block Ack mechanism.

The PHY entity for IEEE Std 802.11 is based on Orthogonal Frequency Division Multiplexing (OFDM) or Orthogonal Frequency Division Multiple Access (OFDMA). In either OFDM or OFDMA Physical (PHY) layers, a STA is capable of transmitting and receiving Physical Layer Convergence Protocol (PLCP) Protocol Data Units (PPDUs) that are compliant with the mandatory PHY specifications. A PHY specification defines a set of Modulation and Coding Schemes (MCS) and a maximum number of spatial streams. Some PHY entities define downlink (DL) and uplink (UL) Multi-User (MU) transmissions having a maximum number of space-time streams (STS) per user and employing up to a predetermined total number of STSs.

A PHY entity may define PPDUs that are individually addressed using an Association Identifier (AID) or Partial AID and may also define PPDUs that are group addressed based on Group ID (GID).

A PHY entity may provide support for 20 MHz, 40 MHz, 80 MHz, and 160 MHz contiguous channel widths and support for an 80+80 MHz non-contiguous channel width. Each channel includes a plurality of subcarriers, which may also be referred to as tones. Data subcarriers within the channels may be modulated using binary phase shift keying (BPSK), quadrature phase shift keying (QPSK), 16-quadrature amplitude modulation (16-QAM), 64-QAM, and 256-QAM. Forward error correction (FEC) coding (such as convolutional or Low Density Parity Check (LDPC) coding) may be used with coding rates of 1/2, 2/3, 3/4 and 5/6.

A PHY entity may define fields denoted as Legacy Signal (L-SIG), Signal A (SIG-A), and Signal B (SIG-B) within which some necessary information about PLCP Service Data Unit (PSDU) attributes are communicated. For example, a High Efficiency (HE) PHY entity may define an L-SIG field, an HE-SIG-A field, and an HE-SIG-B field. In an embodiment, the symbols in the L-SIG, SIG-A, and SIG-B fields are encoded with the most robust (and therefore least efficient) MCS of the PHY entity.

To prevent excessive consumption of WLAN resource by overhead, the L-SIG, HE-SIG-A, and HE-SIG-B fields have a limited number of bits and it is advantageous to encode them in the most compact form possible. In a receiving STA, the symbols of these fields are decoded first in order to obtain vital information about the PSDU attributes and some MAC attributes.

In the IEEE Std 802.11ac, SIG-A and SIG-B fields are called VHT SIG-A and VHT SIG-B fields. Hereinafter, IEEE Std 802.11ax SIG-A and SIG-B fields are respectively referred to as HE-SIG-A and HE-SIG-B fields.

FIG. **6A** illustrates an HE PPDU **600** according to an embodiment. A transmitting station generates the HE PPDU frame **600** and transmits it to one or more receiving stations. The receiving stations receive, detect, and process the HE PPDU frame **600**.

The HE PPDU frame **600** includes a Legacy Short Training Field (L-STF) field **602**, a Legacy (i.e., a Non-High Throughput (Non-HT)) Long Training Field (L-LTF) **604**, a Legacy Signal (L-SIG) field **606**, and a Repeated L-SIG field (RL-SIG) **608**, which together comprise a legacy preamble

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601. The L-STF **604** of a non-trigger-based PPDU has a periodicity of 0.8 μs is with 10 periods.

The HE PPDU frame **600** also includes an HE-SIG-A field **610**, an optional HE-SIG-B field **612**, an HE-STF **614**, an HE-LTF **616**, and an HE-Data field **618**.

The legacy preamble **601**, the HE-SIG-A field **610**, and the HE-SIG-B field **612** when present, comprise a first part of the HE PPDU frame **600**. In an embodiment, the first part of the HE PPDU frame **600** is decoded using a 64-element Discrete Fourier Transform (DFT), having a basic subcarrier spacing of 312.5 KHz.

The HE-SIG-A field **610** is duplicated on each 20 MHz segment after the legacy preamble to indicate common control information. The HE-SIG-A field **610** includes a plurality of OFDM HE-SIG-A symbols **620** each having a duration (including a Guard Interval (GI)) of 4 μs. A number of the HE-SIG-A symbols **620** in the HE-SIG-A field **610** is indicated by N_{HESIGA} and is either 2 or 4.

The HE-SIG-B field **612** is included in Down-Link (DL) Multi-User (MU) PPDUs. The HE-SIG-B field **612** includes a plurality of OFDM HE-SIG-B symbols **622** each having a duration including a Guard Interval (GI) of 4 μs. In embodiments, Single User (SU) PPDUs, Up-Link (UL) MU PPDUs, or both do not include the HE-SIG-B field **612**. A number of the HE-SIG-B symbols **622** in the HE-SIG-B field **612** is indicated by N_{HESIGB} and is variable.

When the HE PPDU **600** has a bandwidth of 40 MHz or more, the HE-SIG-B field **612** may be transmitted in first and second HE-SIG-B channels **1** and **2**. The HE-SIG-B field in the HE-SIG-B channel **1** is referred to as the RE-SIG-B1 field, and the HE-SIG-B field in the HE-SIG-B channel **2** is referred to as the HE-SIG-B2 field. The RE-SIG-B1 field and the HE-SIG-B2 field are communicated using different 20 MHz bandwidths of the HE PPDU **600**, and may contain different information. Within this document, the term "HE-SIG-B field" may refer to an HE-SIG-B field of a 20 MHz PPDU, or to either or both of an HE-SIG-B1 field or HE-SIG-B2 field of a 40 MHz or more PPDU.

An HE-STF **614** of a non-trigger-based PPDU has a periodicity of 0.8 μs with 5 periods. A non-trigger-based PPDU is a PPDU that is not sent in response to a trigger frame. An HE-STF **614** of a trigger-based PPDU has a periodicity of 1.6 μs with 5 periods. Trigger-based PPDUs include UL PPDUs sent in response to respective trigger frames.

The HE-LTF **616** includes one or more OFDM HE-LTF symbols **626** each having a duration of 12.8 μs plus a Guard Interval (GI). The HE PPDU frame **600** may support a 2×LTF mode and a 4×LTF mode. In the 2×LTF mode, an HE-LTF symbol **626** excluding a Guard Interval (GI) is equivalent to modulating every other tone in an OFDM symbol of 12.8 μs excluding the GI, and then removing the second half of the OFDM symbol in a time domain. A number of the HE-LTF symbols **626** in the HE-LTF field **616** is indicated by N_{HELTF}, and is equal to 1, 2, 4, 6, or 8.

The HE-Data field **618** includes one or more OFDM HE-Data symbols **628** each having a duration of 12.8 μs plus a Guard Interval (GI). A number of the HE-Data symbols **628** in the HE-Data field **618** is indicated by N_{DATA} and is variable.

FIG. **6B** shows a Table 1 indicating additional properties of the fields of the HE PPDU frame **600** of FIG. **6A**, according to an embodiment.

The descriptions below, for sake of completeness and brevity, refer to OFDMA-based 802.11 technology. Unless otherwise indicated, a station refers to a non-AP HE STA, and an AP refers to an HE AP.

FIG. **7** illustrates transmission of a DL MU OFDMA PPDU **700** to a set of stations, according to an embodiment. The set of stations includes first, second, third, and fourth stations STA**1**, STA**2**, STA**3**, and STA**4**. The concepts described herein with respect to DL OFDMA frame **700** also apply to UL OFDMA frames unless specifically stated otherwise. The bandwidth of the DL OFDMA frame **700** may be 20, 40, 80, 160, or 80+80 MHz.

In FIG. **7**, a horizontal dimension is a time dimension or number of OFDM symbols, and a vertical dimension is a frequency dimension, or a number of tones or subcarriers. For a given Fourier Transform (FT) size, the number of tones is a fixed value; however, depending on the subcarrier spacing, two OFDM symbols with, for example, respective FT sizes of 64 and 256 may require the same bandwidth to transmit.

Hereinafter, the term sub-band refers to a set of contiguous subcarriers (that is, a set of subcarriers for which no subcarrier not in the set is between any two subcarriers within the set) that as a whole are assigned for a payload whose expected destination is a single station, or a set of stations. A set of sub-bands or a set of subcarriers may also be referred to as a Resource Unit (RU).

In an embodiment, the set of contiguous subcarriers is a set of contiguous data subcarriers (that is, a set of data subcarriers for which no data subcarrier not in the set is between any two data subcarriers within the set).

A sub-band is represented in FIG. **7** as a horizontal partition of the DL OFDMA PPDU **700** where a set of contiguous tones for a contiguous set of OFDM symbols are designated for a given payload whose expected destination is a station or a set of stations. The bandwidth assigned to payloads of the stations STA**1** to STA**4** depend on the respective payload sizes, on a MCSs and numbers of spatial streams that the AP determines for the respective sub-band transmissions, and on the overall considerations that the AP needs to address in order to align the length or duration of various PSDU sub-bands.

The DL OFDMA PPDU **700** includes a first portion **704** including an L-STF, an L-LTF, and an L-SIG field based on IEEE Std 802.11n and 802.11ac. The symbols in these fields serve to make the DL OFDMA PPDU **700** compatible with legacy designs and products.

The L-STF, L-LTF, and L-SIG symbols of the first portion **704** are modulated using a Fourier Transform (FT) size of 64 on a 20 MHz channel and are duplicated within each 20 MHz channel of the DL OFDMA PPDU **700** when the DL OFDMA PPDU **700** has a bandwidth wider than 20 MHz.

The first portion **704** also includes an HE-SIG-A field. The symbols of the HE-SIG-A field may carry necessary information regarding each PSDU and regarding the RF, PHY, and MAC properties of the DL OFDMA PPDU **700**.

The DL OFDMA PPDU **700** includes an HE-SIG-B field **706**. The symbols of the HE-SIG-B field **706** may carry necessary information regarding each PSDU and regarding the RF, PHY, and MAC properties of the DL OFDMA PPDU **700**. In an embodiment, the HE-SIG-B field **706** may not always be present in all DL OFDM PPDUs and is not present in UL OFDMA PPDUs.

When the DL OFDMA PPDU **700** has a bandwidth of 40 MHz or more, the HE-SIG-B field **612** may be transmitted in first and second HE-SIG-B channels **1** and **2** respectively including an HE-SIG-B1 field and an HE-SIG-B2 field. The RE-SIG-B1 field and the HE-SIG-B2 field are communicated in first and second 20 MHz bandwidths of the DL

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OFDMA PPDU **700**, respectively, and may contain different information. The HE-SIG-B1 and HE-SIG-B2 fields are duplicated within each 40 MHz bandwidth of the DL OFDMA PPDU **700** when the DL OFDMA PPDU **700** has a bandwidth of 80 MHz or more.

In an embodiment, the HE-SIG-A field of the first portion **704** and HE-SIG-B field **706** are modulated using an FT size of 64. In another embodiment, the HE-SIG-A field of the first portion **704** and HE-SIG-B field **706** are modulated using an FT size of 256. In another embodiment, the HE-SIG-A field of the first portion **704** are modulated using an FT size of 64 and the HE-SIG-B field **706** are modulated using an FT size of 256.

The DL OFDMA PPDU **700** includes HE-STF and HE-LTF symbols in a second portion **710**. The HE-STF and HE-LTF symbols are used to perform necessary RF and PHY processing for each PSDU in the DL OFDMA PPDU **700**, for the whole DL OFDMA PPDU **700**, or both. Depending on whether the HE-STF and HE-LTF symbols in the second portion **710** are beamformed or not, there might be two or more sets of such symbols.

The DL OFDMA PPDU **700** includes a Multi-User (MU) payload region **712**. The MU payload region **712** includes first, second, third, and fourth unicast PSDUs **714**, **716**, **718**, and **720** intended for the first, second, third, and fourth stations STA1, STA2, STA3, and STA4, respectively. Each unicast PSDU **714**, **716**, **718**, and **720** contains a respective payload that is destined to the respective stations STA1, STA2, STA3, and STA4 plus necessary MAC padding and PHY padding. The unicast PSDU **714**, **716**, **718**, and **720** are sub-band PSDUs.

A bandwidth of the MU payload region **712** is divided into one or more Resource Units (RUs), and each of the PSDUs **714**, **716**, **718**, and **720** are allocated one or more of the RUs. In an embodiment, an RU is allocated to no more than one PSDU.

In an embodiment including MU-MIMO communications, an RU may be allocated to a plurality of PSDUs destined for respective stations, each of the plurality of PSDUs being communicated in a respective set of one or more spatial streams within the bandwidth of the RU.

The unicast PSDUs **714**, **716**, **718**, and **720** are destined to respective stations that are associated with the AP. The presence and length of unicast PSDUs **714**, **716**, **718**, and **720** in respective one or more sub-bands and the respective stations that are the recipients of the unicast PSDUs **714**, **716**, **718**, and **720** may be indicated by the HE-SIG-A field, the HE-SIG-B field, or both.

In an embodiment, the DL OFDMA PPDU **700** may include a full-band transmission region (not shown) for unicast or broadcast/multicast full-band PSDU(s). The full-band transmission region may be an optional region in a DL OFDMA PPDU **700** and may have a variable length. The full-band transmission region includes one or more sequential symbols that each covers the whole bandwidth of the DL OFDMA PPDU **700** and that occur before the start of a MU payload region **712**. The full-band transmission region may not be present in an UL OFDMA PPDU.

When the full-band transmission region is present in the DL OFDMA PPDU **700**, there may be a set of HE-STF and/or HE-LTF symbols that immediately precede the full-band PSDUs included in the full-band transmission region (not shown), where the set of HE-STF and/or HE-LTF symbols are not beamformed. The one or more full-band PSDUs in the full-band transmission region **708** could be carried with FT size=64 or FT size=256 according to a design choice to have the full-band PSDUs in the full-band transmission region **708** carried with FT size=64 as the HE-SIG-A field is or carried with FT size=256 as the MU payload region **712** is.

One or more of a Broadcast full-band PSDU, a Multicast full-band PSDU, and a unicast full-band PSDUs may be located in the full-band transmission region and destined to all, some, or one, respectively, of the stations that are associated with the AP. The presence and length of the full-band PSDUs may be indicated in the HE-SIG-A field, the HE-SIG-B field, or both.

Each PSDU in the DL OFDMA PPDU **700**, whether full-band or sub-band, contains a payload that is destined to a station, or to several stations, plus the necessary MAC padding and PHY padding.

Embodiments include signaling, either explicit or implicit, for indicating between various sounding feedback procedures.

A channel state information (CSI) feedback procedure, also known as sounding procedure, consist of a transmission, by the beamformer (such as an AP), of a non-data packet announcement (NDPA) transmission followed by non-data packet (NDP). In response to the NDPA transmission and the NDP, a beamformee (such as a station) transmits CSI feedback to the beamformer.

In an embodiment, in order to reduce overall sounding overhead, one or more beamformees may send the feedback packets at the same time in an Up-Link (UL) Multi-User (MU) transmission using OFDMA, MU-MIMO, or both. The uplink OFDMA and/or MU-MIMO transmissions, denoted as a UL MU transmission, are sent in response to a trigger frame. The trigger frame facilitates resource assignment among the participants in the UL MU transmission such that the transmissions that make up the UL MU transmission do not overlap in a frequency domain, do not overlap in a spatial domain, or both.

Embodiments include two procedures for providing CSI feedback in a wireless network according to an IEEE 802.11 standard. In a first procedures, a single user provides CSI feedback using a UL Single-User (SU) MIMO transmission. In a second procedures, a plurality of users provide CSI feedback simultaneously using an UL MU transmission that uses OFDMA, MU-MIMO, or both. Beamformees, that is, nodes providing CSI feedback, are configured to recognize which of the first and second procedures is being used. Embodiments include mechanisms for indicating which of the first and second procedures the beamformees should expect and conform to.

In an embodiment, either of a first sounding procedure illustrated in FIG. **8**A and a second sounding procedure illustrated in FIG. **8**B may be used. Which of the first sounding procedure and the second sounding procedure is used is indicated by a number of per-station information fields in the NDPA frame. The NDPA frame contains parameters for CSI feedback as well as list of STAs that are directed to participate in the CSI feedback process.

FIG. **8**A illustrates a first process **800**A for obtaining CSI feedback using the first sounding procedure, according to the embodiment. In the first process **800**A, an AP transmits an NPDA **804**A designating only a single station, a first station STA1. The AP then transmits an NDP **806**.

The first station STA1 receives the NPDA **804**A, determines that it indicates only a single station (itself), and based on the NPDA **804**A indicating only a single station (that is, based on the NDPA **804**A not indicating a plurality of stations) determines that the first sounding procedure for

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obtaining CSI feedback is being used. The first station STA1 then receives the NDP **806** and uses it to compute CSI feedback.

When the first station STA1 determines that the first sounding procedure for CSI feedback is being used, then in response to the NDP **806**, the first station STA1 transmits its CSI feedback after a SIFS has elapsed from the end of the NDP **806**. The first station STA1 transmits its CSI feedback in a Single User MIMO (SU-MIMO) UL transmission **810**.

FIG. **8**B illustrates a second process **800**B for obtaining CSI feedback using the second sounding procedure, according to the embodiment. In the second process **800**B, the AP transmits an NPDA **804**B designating first, second, and third stations STA1, STA2, and STA3, respectively. The AP then transmits the NDP **806**.

Each of the first, second, and third stations STA1, STA2, and STA3 receives the NPDA **804**B, determines that it indicates a plurality of stations including itself, and based on the NPDA **804**B indicating a plurality of stations, determines that the second sounding procedure for obtaining CSI feedback is being used.

The first, second, and third stations STA1, STA2, and STA3 then receive the NDP **806** and use it to compute first, second, and third CSI feedback, respectively.

An SIFS after the NDP, the AP transmits an MU Trigger frame **808**. The MU Trigger frame **808** indicates to the stations which resources (such as OFDMA Resource Units (RUs), MIMO spatial streams, or both) each of the stations STA1, STA2, and STA3 that providing the CSI feedback should use to provide the CSI feedback.

When the first, second, and third stations STA1, STA2, and STA3 have respectively determined that the second sounding procedure for CSI feedback is being used, in response to the MU Trigger **808**, the first, second, and third stations STA1, STA2, and STA3 transmit the first, second, and third CSI feedback, respectively, an Inter-Frame Space (xIFS) after the end of the frame including the MU Trigger **808** as part of an MU UL transmission **812**. The Inter-Frame Space may be any one of an SIFS, a PIFS, a DIFS, or an AIFS.

The MU UL transmission **812** includes first, second, and third transmissions **812**A, **812**B, and **812**C transmitted by the first, second, and third stations STA1, STA2, and STA3, respectively, and respectively including the first, second, and third CSI feedback.

In an embodiment, the UL MU transmission **812** is an OFDMA transmission and each of the first, second, and third transmissions **812**A, **812**B, and **812**C is transmitted in a different Resource Unit (RU). In an embodiment, the UL MU transmission **812** is an MU-MIMO transmission and each of the first, second, and third transmissions **812**A, **812**B, and **812**C is transmitted using a different spatial stream.

In an embodiment, MU Trigger frame **808** allocates resources to fewer than all of the stations indicated in the NDPA **804**B. When MU Trigger frame **808** allocates resources to fewer than all of the stations indicated in the NDPA **804**B, only stations directed to participate in the sounding process **800**B by the NDPA **804**B and having resources allocated to them by the MU Trigger frame **808** transmit CSI information in response to the MU Trigger frame **808**.

In an embodiment, a sounding poll frame is transmitted instead of the MU Trigger frame **808**. When the sounding poll frame is transmitted, only the station selected by the sounding poll frame transmits CSI feedback, and the selected station transmits the CSI feedback in a Single-User (SU) transmission.

In another embodiment, when more than one station is directed to participate in a sounding process, either of a first sounding procedure illustrated in FIG. **9**A and a second sounding procedure illustrated in FIG. **9**B may be used. Which of the first sounding procedure and the second sounding procedure is being used is indicated in an NDPA. The NDPA includes parameters for CSI feedback as well as list of stations that are directed to participate in the CSI feedback process.

FIG. **9**A illustrates a first process **900**A for obtaining CSI feedback using the first sounding procedure, according to the embodiment. In the first process **900**A, an AP transmits an NDPA **904**A that includes an indication that the AP will transmit an MU trigger frame **908**A immediately after an SIFS elapses after the end of an upcoming NDP **906**.

An SIFS after then end of the NDPA **904**A, the AP transmits the NDP **906**. An SIFS after then end of the NDP **906**, the AP transmits the MU trigger frame **908**A.

First, second, and third stations STA1, STA2, and STA3 respectively receive the NDPA **904**A, determine that they are to participate in the polling process, and determine that the MU trigger frame **908**A will be transmitted immediately after an SIFS elapses after the end of the NDP **906**.

The first, second, and third stations STA1, STA2, and STA3 respectively receive the NDP **906**, and use it to compute first, second, and third CSI feedback, respectively. Because the first, second and third stations STA1, STA2, and STA3 have respectively determined that the MU trigger frame **908**A will be transmitted immediately after an SIFS elapses after the end of the NDP **906**, the first, second, and third stations STA1, STA2, and STA3 do not perform a transmission in response to the NDP **906**.

The AP transmits the MU trigger frame **908**A immediately after an SIFS elapses after the end of the NDP **906**. The first, second, and third stations STA1, STA2, and STA3 respectively receive the MU trigger frame **908**A and respectively determine which resources (such as OFDMA Resource Units (RUs), MIMO spatial streams, or both) to use to provide the CSI feedback. In the example shown, the MU Trigger frame **908**A only allocates resources for CSI feedback to the second and third stations STA2 and STA3, and as a result only the second and third stations STA2 and STA3 transmit CSI information in response to the MU Trigger frame **908**A.

In response to the MU Trigger frame **908**A, the second and third stations STA2 and STA3 transmit the second and third CSI feedback, respectively, an Inter-Frame Space (xIFS) after the end of the frame including the MU Trigger frame **908**A as part of an MU UL transmission **912**.

The MU UL transmission **912** includes first and second transmissions **912**A and **912**B transmitted by the second and third stations STA2 and STA3, respectively. In an embodiment, the UL MU transmission **912** is an OFDMA transmission and each of the first and second transmissions **912**A and **912**B is transmitted in a different Resource Unit (RU). In an embodiment, the UL MU transmission **912** is an MU-MIMO transmission and each of the first and second transmissions **912**A and **912**B is transmitted using a different spatial stream.

An SIFS after the end of the MU UL transmission **912**, the AP transmits a sounding poll **914** to the first station STA1. In response to the sounding poll **914**, the first station STA1 transmits the first CSI feedback to the AP an SIFS after the

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end of the sounding poll **914**. In an embodiment, the first CSI feedback is sent in an UL SU-MIMO transmission.

In another embodiment, an NDPA and NDP may be sent to the first station STA1 instead of the sounding poll **914**.

FIG. **9**B illustrates a second process **900**B for obtaining CSI feedback using the second sounding procedure, according to the embodiment. In the second process **900**B, an AP transmits an NDPA **904**B that includes a list of per-station information field and an indication that the AP will not transmit an MU trigger frame immediately after an SIFS elapses after the end of an upcoming NDP **906**.

In an embodiment, the NDPA **904**B indicates that that the AP will not transmit the MU trigger frame immediately after the SIFS elapses after the end of the NDP **906** by not including the indication that the AP will transmit the MU trigger frame **908**A immediately after the SIFS elapses after the end of the NDP **906** that was included in the NDPA **904**A of FIG. **9**A.

An SIFS after the end of the NDPA **904**B, the AP transmits the NDP **906**. The first, second, and third stations STA1, STA2, and STA3 receive the NDP **906** and use it to compute first, second, and third CSI feedback, respectively.

When the NDPA **904**B contains the indication that the AP will not transmit the MU trigger frame immediately after the SIFS elapses after the end of the NDP **906**, the first station STA1 in the per-station information field list of the NDPA **904**B, in response to the NDP **906**, transmits CSI feedback immediately after a SIFS elapses after the NDP **906**.

The rest of the stations (stations STA2 and STA3) in the per-STA information list, because they are not the first station in that list, wait for either an MU trigger frame **908**B or a sounding poll frame. In response to the MU trigger frame **908**B the second and third stations STA2 and STA3 transmit the second and third CSI feedback, respectively, an Inter-Frame Space (xIFS) after the end of the frame including the MU Trigger frame **908**A. The second and third CSI feedback are transmitted as part of an MU UL transmission **912**.

The MU UL transmission **912** includes first and second transmissions **912**A and **912**B transmitted by the second and third stations STA2 and STA3 and including the second and third CSI feedback, respectively. In an embodiment, the UL MU transmission **912** is an OFDMA transmission. In an embodiment, the UL MU transmission **912** is an MU-MIMO transmission.

Because the sounding procedure and how the first station STA1 in the per-station information field list responds to an NDP **906** changes depending on which sounding procedure is chosen by the AP, the NDPA **904**B contains the indication on which procedure was chosen (or equivalently, whether the first station STA1 is to immediately transmit the CSI after the NDP **906** or wait for either an MU trigger or sounding poll frame).

In the embodiments of FIGS. **8**A and **8**B or the embodiments of FIGS. **9**A and **9**B, an AP may transmit a second MU trigger frame after the UL MU transmissions of CSI feedback, as shown in FIG. **10**. Transmitting a second MU trigger frame may be required when one or more stations were not able to send all the CSI feedback in a single uplink MU transmission.

In the process **1000** of FIG. **10**, an AP transmits a NDPA **1004** to first, second, and third stations STA1, STA2, and STA3. The NDPA **1004** includes an indication that a first MU Trigger frame **1008** will be transmitted after a next NDP **1006**.

The stations STA1, STA2, and STA3 respectively receive the NDPA **1004**, and determine, by decoding the NDPA **1004**, that they are to participate in the process **1000** and that the first MU Trigger frame **1008** will be transmitted after the NDP **1006**.

The AP transmits the NDP **1006** a SIFS after the end of the NDPA **1004**. The stations STA1, STA2, and STA3 receive the NDP **1006** and determine respective CSI information using the NDP **1006**.

The AP transmits the first MU Trigger frame **1008** a SIFS after the end of the NDP **1006**.

In response to the first MU Trigger frame **1008**, the stations STA1, STA2, and STA3 transmit respective first CSI feedback portions **1012**A, **1012**B, and **1012**C as part of a first UL MU transmission **1012**.

In an embodiment, the first MU Trigger frame **1008** allocates resources to fewer than all of the stations indicated in the NDPA **1004**. When first MU Trigger frame **1008** allocates resources to fewer than all of the stations indicated in the NDPA **1004**, only stations directed to participate in the sounding process **1000** by the NDPA **1004** and having resources allocated to them by the first MU Trigger frame **1008** transmit CSI information in response to the first MU Trigger frame **1008**.

The AP transmits the second MU Trigger frame **1014** a SIFS after the end of the first UL MU transmission **1012**.

In response to the second MU Trigger frame **1014**, the stations STA1, STA2, and STA3 transmit respective second CSI feedback portions **1016**A, **1016**B, and **1016**C as part of a second UL MU transmission **1016**.

In an embodiment, the second MU Trigger frame **1014** allocates resources to fewer than all of the stations indicated in the NDPA **1004**. When the second MU Trigger frame **1014** allocates resources to fewer than all of the stations indicated in the NDPA **1004**, only stations directed to participate in the sounding process **1000** by the NDPA **1004** and having resources allocated to them by the second MU Trigger frame **1014** transmit CSI information in response to the second MU Trigger frame **1014**.

Embodiments include processes that make efficient use of the medium by not always having a trigger frame or a poll frame following the NDP frame.

Embodiments include processes according to an IEEE 802.11 standard that includes multiple users' simultaneous transmission or reception scheduled within a BSS, wherein an RTS/CTS frame exchange protects multi-station communications efficiently, especially when multiple MU transmissions are performed in a cascaded manner.

When one or more RTS frames are transmitted simultaneously in a DL MU manner, and the one or more RTS frames solicit RF-combined CTS frames from multiple stations, all PPDUs comprising RTS frames shall use the same scrambling initialization (or seed), and all the RTS frames shall solicit CTS frames that use a same MCS. The one or more RTS frames can include a Multi-User RTS (MU-RTS) frame.

FIG. **11** illustrates a UL MU communication process **1100** including an MU-RTS frame **1104**, according to an embodiment. An AP sends an MU-RTS frame **1104** that solicits CTS frame transmissions from first and second stations STA1 and STA2, respectively. In response, the first and second stations STA1 and STA2 respectively transmit first and second CTS frames **1106**A and **1106**B.

The first and second CTS frames **1106**A and **1106**B are RF-combined in the channel medium. In order to be successfully RF-combined, the first and second CTS frames **1106**A and **1106**B include, within each 20 MHz bandwidth

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that is used by both, identical data scrambled using a same scrambling initialization (or seed) value and encoded using an identical MCS.

In an embodiment, when a CTS frame has a bandwidth of 40 MHZ or more, the identical data is replicated in each 20 MHz bandwidth used by the CTS frame. In an embodiment, a number of 20 MHz bandwidths used by the first CTS frame **1106**A is different from a number of 20 MHz bandwidths used by the second CTS frames **1106**B.

For example, in an illustrative embodiment, the first station STA**1** transmits the first CTS frame **1106**A using first and second 20 MHz bandwidths, and the second station STA**2** transmits the second CTS frame **1106**B using only the first 20 MHz bandwidths. The first station STA**1** transmits the first CTS frame **1106**A by transmitting a same data scrambled using a same scrambling initialization (or seed) value and encoded using an identical MCS in each the first and second 20 MHz bandwidths, and the second station STA**2** transmits the second CTS frame **1106**B by transmitting the same data scrambled using the same scrambling initialization (or seed) value and encoded using the identical MCS in the first 20 MHz bandwidth. The transmission of the first CTS frame **1106**A performed in the first 20 MHz bandwidth and the transmission of the second CTS frame **1106**B are RF-combined and received by the AP in the first 20 MHz bandwidth, and the transmission of the first CTS frame **1106**A performed in the second 20 MHz bandwidth is received by the AP without being RF-combined.

In response to receiving the RF-combined CTS frames **1106**A and **1106**B, the AP sends a Trigger frame **1108** that schedules UL MU transmissions from the first and second stations STA**1** and STA**2**.

In response to receiving the Trigger frame **1108**, the first and second stations STA**1** and STA**2** transmit first and second UL data frames **1110**A and **1110**B, respectively, according to the scheduling information in the Trigger frame **1108**. The first and second UL data frames **1110**A and **1110**B may be in different OFDMA RUs, in different MU-MIMO spatial streams, or both.

In response to receiving the first and second UL data frames **1110**A and **1110**B, the AP sends an acknowledgement frame **1112** to the first and second stations STA**1** and STA**2**.

In an embodiment, the use of the same scrambling initialization may be guaranteed by not allowing a station to send more than one MU-RTS frame in a PPDU. For example, the MU-RTS frame can be sent using any one of a Non-HT or non-HT-duplicate format, an HT format, a VHT format, an HE SU PPDU format, and an HE MU PPDU format.

In an embodiment wherein the MU-RTS frame is sent using the HE MU PPDU format, the PPDU consists of no more than one MU-RTS frame. In an embodiment wherein the MU-RTS frame is sent using the HE MU PPDU format, transmitting more than one MU-RTS frame in the PPDU is not allowed.

When an MU-RTS frame is sent using a PPDU format that allows an Aggregate MPDU (A-MPDU), the A-MPDU that includes the MU-RTS frame has only one A-MPDU subframe (excluding any null subframes).

In an embodiment, a wireless device transmits a CTS frame using a scrambler initialization (or seed value) determined from a received MU-RTS frame. In an embodiment, mechanisms enable a PHY layer to apply a same scrambler initialization (or seed value) to a CTS frame as a scrambler initialization (or seed value) of a successfully received MU-RTS frame.

FIG. **12**A illustrates a process **1200**A, performed by a PHY layer of a station, for determining and saving a scrambler initialization (or seed value) from a received PPDU, according to an embodiment.

At S**1204**, the PHY layer receives a PPDU. In an embodiment, the PPDU includes an MU-RTS frame that targets the station.

At S**1206**, the PHY layer determines a scrambler initialization (or seed value) from the received PPDU. Processes for determining the scrambler initialization (or seed value) from the received PPDU are described later in this disclosure.

At S**1208**, the PHY forwards the determined scrambler initialization (or seed value) to a MAC layer of the station. In an embodiment, the MAC layer stores the determined scrambler initialization (or seed value) for later use.

FIG. **12**B illustrates a process **1200**B, performed by a PHY later of a station, for using a scrambler initialization (or seed value) received from a MAC layer to scramble a PPDU to be transmitted, according to an embodiment.

In an embodiment, the scrambler initialization (or seed value) received from the MAC layer is a scrambler initialization (or seed value) previously forwarded to the MAC layer by the PHY layer using the process **1200**A of FIG. **12**A.

In an embodiment, the PPDU from which the scrambler initialization (or seed value) was determined by the process **1200**A of FIG. **12**A includes an MU-RTS frame, and the PPDU to be transmitted is a CTS frame transmitted in response to the MU-RTS frame.

At S**1210**, the PHY layer receives from the MAC layer an MPDU and an indication of whether generation of a PPDU from the MPDU is to use a scrambler initialization (or seed value) provided by the MAC layer.

At S**1212**, the PHY layer determines, using the indication, whether to generate the PPDU using the scrambler initialization (or seed value) provided by the MAC layer. When the PPDU is to be generated using the scrambler initialization (or seed value) provided by the MAC layer, the process **1200**B proceeds to S**1214**. Otherwise, at S**1212** the process **1200**B proceeds to S**1216**.

In an embodiment, the PPDU is to be generated using the scrambler initialization (or seed value) provided by the MAC layer when the indication has a first state, and using a scrambler initialization (or seed value) generated by the PHY layer when the indication has a state other than the first state (e.g., a second state).

In an embodiment, the MAC layer sets the indication to the first state when the PPDU is a CTS frame to be transmitted in response to an MU-RTS frame received by the process **1200**A.

In an embodiment, the MAC layer sets the indication to a state that is not the first state when a PPDU received in the process **1200**A is a data frame or management frame.

In an embodiment, the first state of the indication is to include a parameter related to the scrambler initialization/seed in a TXVECTOR set. In an embodiment, the state that is not the first state does not include the parameter.

In an embodiment, the MAC layer sets the indication to the first state only when the PPDU to be transmitted is using a non-HT format or a non-HT duplicate frame format.

At S**1214**, the PHY layer receives the scrambler initialization (or seed value) provided by the MAC layer. The process **1200**B then proceeds to S**1218**.

At S**1216**, the PHY layer generates the scrambler initialization (or seed value). In an embodiment, the scrambler

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initialization (or seed value) is a non-zero pseudo-random value generated by the PHY layer. The process **1200B** then proceeds to **S1218**.

At **S1218**, the PHY layer generates the PPDU to be transmitted by scrambling data in the MPDU using the scrambler initialization (or seed value) either provided by the MAC layer in **S1214** or generated by the PHY layer in **S1216**.

At **S1220**, the station transmits the generated PPDU.

FIG. **13** shows a Table 2 illustrating information in a TXVECTOR and an RXVECTOR used for the delivery of information on a scrambler initialization or seed value and whether a MAC-supplied scrambler initialization or seed value should be used.

In an embodiment, a MAC layer includes the TXVECTOR parameter SCRAMBER_INITIALIZATION when signaling the transmission of a CTS frame in response to a MU-RTS frame. In an embodiment, the included TXVECTOR parameter SCRAMBER_INITIALIZATION has a non-zero value.

Data information in a frame is scrambled prior to transmission and de-scrambled at reception. In order to avoid a fixed scrambling pattern, an initial state value of the scrambling sequence (based on maximum length sequence) is chosen. The initial state value determines the scrambling sequence.

The initial state value may at times be chosen using a random or pseudo-random number generator. For example, the initial state value may be a 7-bit non-zero pseudo-random number.

Frames in accordance with an IEEE 802.11 standard can be scrambled using one of first and second scrambling operations.

FIG. **14** illustrates a circuit **1400** for performing the first scrambling operation, according to an embodiment. In the IEEE 802.11 standard, the first scrambling operation is used for frames that do not contain dynamic bandwidth signaling.

The circuit **1400** includes first to seventh state bit latches **1402** to **1414**. When the circuit **1400** is in an initialization mode, the first to seventh state bit latches **1402** to **1414** are configured to receive seventh to first initial state bits[7:1], respectively, with the seventh state bit latches **1414** receiving the first initial state bit[1], with the sixth state bit latches **1412** receiving the second initial state bit[2], and so forth. When the circuit **1400** is in a scrambling mode, the second to seventh state bit latches **1404** to **1414** are configured to receive outputs of the first to sixth state bit latches **1402** to **1412**, respectively, and the first state bit latch **1402** is configured to receive a scrambling sequence (or scrambling code) SC1 output by a first XOR circuit **1416**.

The first XOR circuit **1416** receives the outputs of the fourth and seventh state bit latches **1408** and **1414** and generates an output equal to the exclusive-or of the outputs of the fourth and seventh state bit latches **1408** and **1414**. The output of the first XOR circuit **1416** is the scrambling sequence SC1.

A second XOR circuit **1418** receives the output of the first XOR circuit **1416** and a bit of a sequence of Data In bits, and generates an output equal to the exclusive-or of the output of the first XOR circuit **1416** and the bit of the sequence of Data In bits. When the circuit **1400** is used for transmission of a frame, the output of the second XOR circuit **1418** is a scrambled output. When the circuit **1400** is used for reception of the frame, the output of the second XOR circuit **1418** is a descrambled output.

Before scrambling (or descrambling) begins, the circuit **1400** is in the initialization mode, and the seventh to first initial state bits[7:1] of a selected initial state are loaded into the first to seventh state bit latches **1402** to **1414**, respectively.

When scrambling (or descrambling) is being performed, the circuit **1400** is in the scrambling mode, in which bits of the scrambling sequence SC1 produced by the first XOR circuit **1416** are bitwise exclusive-or'd with respective bits of the Data In sequence. Bits of the Data In sequence are provided one per clock cycle to the circuit **1400**. By clocking the first to seventh state bit latches **1402** to **1414** once for each bit of the Data In sequence, one new bit of the scrambling sequence SC1 is generated for and exclusive-or'd with each bit of the Data In sequence.

During each cycle of the clock, the second to seventh state bit latches **1404** to **1414** are set to respective values that the first to sixth state bit latches **1402** to **1412** had in the previous clock cycle, and the first state bit latch **1402** is set to a value the scrambling sequence SC1 had in the previous clock cycle.

FIG. **15** illustrates a circuit **1500** for performing the second scrambling operation, according to an embodiment. In the IEEE 802.11 standard, the second scrambling operation is used for frames that contain dynamic bandwidth signaling.

The circuit **1500** includes first to seventh state bit latches **1502** to **1514**. The second to seventh state bit latches **1504** to **1514** are configured to receive outputs of the first to sixth state bit latches **1502** to **1512**, respectively. The first state bit latch **1502** is configured to receive a bit of a scrambling sequence SC2.

A first XOR circuit **1516** receives the outputs of the fourth and seventh state bit latches **1508** and **1514** and generates an output equal to the exclusive-or of the outputs of the fourth and seventh state bit latches **1508** and **1514**. The output of the first XOR circuit **1516** is used to provide bits of the scrambling sequence SC2.

A second XOR circuit **1518** receives a bit of the scrambling sequence SC2 and a bit of a sequence of Data In bits, and generates an output equal to the exclusive-or of the bit of the scrambling sequence SC2 and the bit of the sequence of Data In bits. When the circuit **1500** is used for transmission of a frame, the output of the second XOR circuit **1518** is a scrambled output. When the circuit **1500** is used for reception of the frame, the output of the second XOR circuit **1518** is a descrambled output.

Bits of the Data In sequence are provided one per clock cycle to the circuit **1500**. During the first seven clock cycles, when the first to seventh bits of the Data In sequence are being provided, a switch **1520** provides first to seventh initial state bits as the first to seventh bits of the scrambling sequence SC2, respectively.

Over the course of the first seven clock cycles, the first to seventh initial state bits are exclusive-or'd with first to seventh bits of the Data In sequence to produce first to seventh bits of the scrambled or descrambled output, respectively. At the same time, the first to seventh initial state bits are shifted into the seventh to first state bit latches **1514** to **1502**, respectively.

After the seventh clock cycle, the switch **1520** provides the output of the first XOR circuit **1516** as the scrambling sequence SC2, and the circuit **1500** operates in the same manner as the circuit **1400** of FIG. **14** does when the circuit **1400** is in the scrambling mode.

For both the first scrambling procedure of FIG. **14** and the second scrambling procedure of FIG. **15**, after the seventh bit, each new bit of the scrambling sequence is determined by the previous seven bits of the scrambling sequence.

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When the initial state is a non-zero positive integer, each of the first and second scrambling operations produce scrambling sequences that repeat after 2^N−1 bits, where N is the number of the initial state bits. As a result, the respective scrambling sequences produced by the first and second scrambling operations each repeat every 127 bits (i.e., each has a 127-bit long cycle.)

Although FIGS. **14** and **15** are disclosed in terms of hardware implementations for performing the first and second scrambling operations, respectively, embodiments are not limited thereto. For example, in an embodiment, the scrambling sequence is generated using software to shift, mask, and exclusive-or bits in a first register and to exclusive-or the first register with bits from the Data In sequence that are stored in a second register. In another illustrative embodiment, 127-bit scrambling sequence cycles for each valid 7-bit initial state for the first scrambling operation, the second scrambling operation, or both, may be stored and read out of a computer-readable non-transient memory.

FIG. **16** illustrates differences and relationships between scrambling sequences generated by the first and second scrambling operations when using a same initial state. In the example of FIG. **16**, initial state bits [0:6] used are 1,0,1,1, 1,0, and 1, respectively.

FIG. **16** illustrates the first 127 bits of first and second scrambling sequences SC**1** and SC**2**. The first and second scrambling sequences SC**1** are cyclic with a period of 127 bits. That is, for all n≥127, an n^{th} bit of the scrambling sequences SC**1** is equal to an $(n-127)^{th}$ bit of the scrambling sequences SC**1**, and an n^{th} bit of the scrambling sequences SC**2** is equal to an $(n-127)^{th}$ bit of the scrambling sequences SC**2**. This can be expressed as:

$$SC[n]=SC[(n+k*127)] \quad \text{Equation 1}$$

where k is a integer greater than or equal to zero, SC is either of first scrambling sequence SC**1** or second scrambling sequence SC**2**, and SC[x] is an x^{th} bit of SC, wherein bits of the scrambling sequences are numbered starting with **0**.

SC**1**[0:63] lists the first to sixty-fourth bits of a first scrambling sequence generated by the first scrambling operation using the initial state bits [0:6]. SC**1**[64:126] lists the sixty-fifth to one-hundred-twenty-seventh bits of the first scrambling sequence.

SC**2**[0:63] lists the first to sixty-fourth bits of a second scrambling sequence generated by the second scrambling operation using the initial state bits[0:6]. SC**2**[64:126] lists the sixty-fifth to one-hundred-twenty-seventh bits of the second scrambling sequence.

The underlined bits of SC**1**[0:63] and SC**2**[0:63] indicate the first (i.e. the foremost) seven bits of the first and second scrambling sequences, respectively. As can be seen in SC**2** [0:63], the foremost seven bits of the second scrambling sequence are respectively equal to the first to seventh initial state bits (i.e. initial state bits[0:6]).

Also, the last seven bits of the 127-bit cycle of the first scrambling sequence SC**1**, indicated by E, are equal to the initial state. Because the initial state bits of the circuit **1400** used to generate the first scrambling sequence SC**1** are equal to the most recent seven bits of the first scrambling sequence SC**1**, the first scrambling sequence SC**1** repeats the 127-bit cycle.

Also for this reason, if the foremost seven bits of the first scrambling sequence SC**1** are used as the initial state of the circuit **1400**, a resulting scrambling sequence will be equal to the first scrambling sequence SC**1** cyclically rotated to the left by seven bits, so that the foremost seven bits of the first scrambling sequence SC**1** become the last seven bits of the 127-bit cycle of the resulting scrambling sequence.

Note that the second scrambling sequence SC**2** generated by the second scrambling operation using the initial state of 1011101 can also be generated by the first scrambling operation using the initial state of 0011000, that is, by using the last 7 bits of the 127-bit cycle of the second scrambling sequence SC**2** as the initial state for the first scrambling operation.

Also, note that SC**1**[0:6], indicated by A in FIG. **16**, is equal to SC**2**[7:13], indicated by A'. Similarly, SC**1**[7:56] (B) is equal to SC**2**[14:63] (B'), SC**1**[57:63] (C) is equal to SC**2**[64:70] (C'), SC**1**[64:119] (D) is equal to SC**2**[71:126] (D'), and SC**1**[120:126] (E) is equal to SC**2**[0:6] (E'). These relationships hold true for any non-zero seven-bit value of the Initial State, and can be expressed as:

$$SC1[n]=SC2[(n+7)\bmod 127] \quad \text{Equation 2}$$

where n is any integer equal to or greater than zero. As a result, for any given valid initial state, the 127-bit sequence for SC**1** produced using the first scrambling procedure is equal to the 127-bit sequence for SC**2** produced using the second scrambling procedure rotated 7 bits to the left. Conversely, for any given valid initial state, the 127-bit sequence for SC**2** produced using the second scrambling procedure is equal to the 127-bit sequence for SC**1** produced using the first scrambling procedure rotated 7 bits to the right.

In embodiments according to the IEEE 802.11 standard, a receiver node (e.g., a receiving station) receiving a scrambled data sequence can perform de-scrambling without knowing which of the first or second scrambling operation was used to scramble the data at the transmitter. The receiver node can also perform de-scrambling without knowing the initial state used by the transmitter to scramble the data. This is possible because the first 7 bits of the scrambling sequence are always bitwise exclusive-or'd with 0000000 (7 zeros) which are appended in the front of any data being scrambled. These seven zeros are denoted as the Scrambler Initialization subfield (bits B**0** to B**6**) of the PHY SERVICE field in the IEEE 802.11 ac standard.

As a result, the foremost seven bits of the scrambled data are always equal to the first 7 bits of the scrambling sequence. Given the first 7 bits of the scrambling sequence, it is possible for the receiver to correctly reconstruct the remainder of the scrambling sequence.

Note that the receiver is not able to correctly determine the initial state value of the scrambling sequence used by the transmitter when the receiver is not aware of which of the first or second scrambling operations was used at the transmitter.

For example, depending on whether the first or second scrambling operation was utilized at the transmitter, the receiver may not know whether the initial value used to generate the scrambling sequence SC**2** of FIG. **16** was 1011101 or 0011000.

FIG. **17** illustrates an MU RTS/CTS exchange process **1700**, according to an embodiment. In the process **1700**, a transmitter node (e.g. an AP) transmits a frame Multi-User Request To Send (MU-RTS) frame **1704**. The MU-RTS frame **1704** solicits Clear To Send (CTS) frames from each of the intended receivers (here, first, second, and third stations STA**1**, STA**2**, and STA**3**) of the MU-RTS frame **1704**.

Because the first, second, and third stations STA**1**, STA**2**, and STA**3** will transmit the respective first, second, and third CTS frames **1706**A, **1706**B, and **1706**C simultaneously in

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response to the MU-RTS frame **1704**, the respective contents of those portions of the CTS frames **1706**A, **1706**B, and **1706**C (including the scrambled data) that occupy a same bandwidth need to be identical to each other.

In an embodiment, the CTS frames **1706**A, **1706**B, and **1706**C occupy one or more 20 MHz bandwidths, wherein the respective one or more of 20 MHz bandwidths occupied may differ. Each of the CTS frames **1706**A, **1706**B, and **1706**C replicate a same content in each occupied 20 MHz bandwidth. As a result, when a particular 20 MHz bandwidth is occupied by two or more of the CTS frames **1706**A, **1706**B, and **1706**C, the transmissions of the CTS frames **1706**A, **1706**B, and **1706**C in that particular 20 MHz bandwidth are RF-combined properly.

All of the stations STA1, STA2, and STA3 sending a CTS frame in response to the MU-RTS frame must send a same data and must scramble that data using a same scrambling sequence, so that the CTS frames **1706**A, **1706**B, and **1706**C can be radio frequency (RF) combined in the channel medium. Furthermore, for the CTS frames **1706**A, **1706**B, and **1706**C to be successfully RF-combined, all the stations STA1, STA2, and STA3 transmitting in whole or in part in a particular bandwidth must send their respective CTS frames **1706**A, **1706**B, and **1706**C portions that are transmitted in that particular bandwidth using a same frame formatting, which frame formatting includes modulation, coding rate, encoding scheme, scrambling, and other attributes that effect a waveform of a transmission signal.

For example, in an embodiment, each of the stations STA1, STA2, and STA3 transmit in one or more respective 20 MHz bandwidths, wherein the respective one or more of 20 MHz bandwidths may differ. When two or more of the stations STA1, STA2, and STA3 simultaneously transmit all or part of respective CTS frames **1706**A, **1706**B, and **1706**C in a particular 20 MHz bandwidth, the two or more of the stations STA1, STA2, and STA3 transmitting in the particular 20 MHz bandwidth use a same frame formatting. In an embodiment, each of the stations STA1, STA2, and STA3 uses a same frame formatting in each respectively 20 MHz bandwidth that their respective transmission occupy.

A scrambling sequence for scrambling data in a transmitted frame has been traditionally determined by the transmitting node in a pseudo-random manner. This is done by (pseudo-)randomly choosing an initial state value of the scrambling sequence. However, in order for the CTS frames **1706**A, **1706**B, and **1706**C to be RF combined, identical initial state of a scrambler as well as a same scrambling operation mode (either the first or second scrambling operation of FIGS. **14** and **15**, respectively) must be used by all the stations STA1, STA2, and STA3 (that is, all the responding stations) transmitting the CTS frames **1706**A, **1706**B, and **1706**C in response to the MU-RTS frame **1704**.

One proposal is for the responding stations to respectively derive, from the MU-RTS frame, an initial state of a scrambler used to scramble data in the MU-RTS frame, and use the derived initial state to configure the initial state of the scrambling operation used to transmit the respective CTS frames. However, to do so, the responding nodes must identify the scrambling operation mode and the initial state value used to transmit the MU-RTS frame, which may be difficult, as explained above.

In an embodiment, each of the responding stations is mandated to use the foremost seven bits of the scrambled bit stream of a received MU-RTS frame, before it is descrambled, as the initial state for the scrambling operation used to transmit their CTS frame in response to the received MU-RTS frame. In an embodiment, the foremost seven bits of the scrambled bit stream, prior to descrambling, corresponds to a Scrambler Initialization value in a Service Field of an RXVECTOR of the received MU-RTS frame. This resolves the initial state estimation ambiguity of the proposal above by eliminating the need to determine the initial state used to scramble the data of the MU-RTS frame.

FIG. **18**A illustrates a process **1800** for scrambling data of a CTS frame, according to an embodiment. The CTS frame is a CTS frame to be transmitted in response to an MU-RTS frame.

In the example shown in FIG. **18**A, an AP generates a first scrambling sequence **1806** according to the first scrambling procedure **1400** of FIG. **14**. In the example, an initial state **1804** having a value of 1011101 is used, which generates the first scrambling sequence **1806** (the RTS Scrambling Sequence, or R-SC) having a foremost (that is, a first in the sequence) seven bits equal to 0110100. However, any valid (e.g. non-zero 7-bit) initial state may be used.

The first scrambling sequence **1806** is exclusive-or'd with MU-RTS Data **1802** to produce the MU-RTS scrambled data **1808**. Because a foremost seven bits of the MU-RTS Data **1802** has a value of 0000000, a foremost seven bits of the MU-RTS scrambled data **1808** is equal to the foremost seven bits of the first scrambling sequence **1806**.

At S**1810**, the MU-RTS frame including the MU-RTS scrambled data **1808** is transmitted by the AP to a station.

The station extracts the foremost seven bits of the MU-RTS scrambled data **1808** from the received MU-RTS frame and uses it as the initial state **1814** for generating the second scrambling sequence **1816**. Because the foremost seven bits of the MU-RTS scrambled data **1808** are equal to the foremost seven bits of the first scrambling sequence **1806**, the initial state **1814** used to generate the second scrambling sequence **1816** is equal to the foremost seven bits of the first scrambling sequence **1806**.

The station generates a second scrambling sequence **1816** (the CTS Scrambling Sequence, or C-SC) using the first scrambling procedure **1400** of FIG. **14** and the initial state **1814** having the value equal to the foremost seven bits of the first scrambling sequence **1806**. As a result, the 127-bit cycle of the second scrambling sequence **1816** is equal to the 127-bit cycle of the first scrambling sequence **1806** cyclically rotated 7 bits to the left. When M is defined as a size of CTS Data excluding foremost 7 bits of 0000000, the sequence C-SC is equal to eighth through (8+M−1)-th bits (R-SC[7] through R-SC[7+M−1]) of the sequence R-SC. That is,

$$\forall x=0 \ldots M1: CSC[x]=RSC[x+7] \quad \text{Equation 3}$$

where C-SC[i] is the i^{th} bit of the C-SC, M is the length of the C-SC and is seven or more less than a length of R-SC, R-SC[i] is the j^{th} bit of the R-SC, and the bits in C-SC and R-SC are numbered starting at 0. When M is greater than seven less than length of R-SC, the more general relationship of Equation 2 applies, wherein SC1 is the C-SC and SC2 is the R-SC.

In an embodiment, the CTS Data includes 9 bits of the Service field excluding a 7-bit Scrambler Initialization subfield, a 16-bit Frame Control field, a 16-bit Duration field, a 48-bit RA field, and a 32-bit FCS field, and therefore M is equal to 121 (i.e., equal to 9+16+16+48+32).

The station performs a bitwise exclusive-or of the second scrambling sequence **1816** with a CTS Data **1812** to generate a CTS scrambled data **1818**. The station then transmits the CTS frame including the CTS scrambled data **1818** as a response to the MU-RTS frame. The CTS frame further includes 7-bit data (shown as 0000110 in FIG. **18**A) which

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is used by the AP for generating the sequence C-SC. The 7-bit data is equal to the foremost 7 bits of the sequence R-SC.

FIG. **18**B shows the respective 127-bit cycles of the first scrambling sequence **1806** (R-SC) and the second scrambling sequence **1816** (C-SC) of the example of FIG. **18**A. The foremost seven bits of each scrambling sequence are underlined.

As can be seen in FIG. **18**B, the second scrambling sequence **1816** (C-SC) is equal to the first scrambling sequence **1806** (R-SC) cyclically rotated 7 bits to the left, so that bits **1-120** of the second scrambling sequence **1816** (C-SC) are respectively equal to bits **8-127** of the first scrambling sequence **1806** (R-SC), and bits **121-127** of the second scrambling sequence **1816** (C-SC) are respectively equal to bits **1-7** of the first scrambling sequence **1806** (R-SC).

When all of the stations responding to an MU-RTS frame use the process **1800** of FIG. **18**A to generate respective scrambling sequences for their respective responsive CTS frames, each of the CTS frames transmitted in response to the MU-RTS frame will use the same scrambling sequence.

In an embodiment, performing the RF-combined CTS transmission of FIG. **18**A requires the receiver of an MU-RTS frame (the station) to get information from a received frame in the PHY layer (e.g., the MU-RTS frame) and to use that information in a subsequent frame (such as a CTS frame transmitted in response to the MU-RTS frame). In an embodiment, this is performed using parameter passing, in an RXVECTOR, information derived from the received frame by the PHY layer and sent by the PHY Layer to the MAC layer, and receiving by the PHY layer, in a TXVECTOR, information from the MAC layer for configuring the frame to be transmitted.

FIG. **19** illustrates exchanges of information between a PHY layer and a MAC layer. The left side of FIG. **19** shows the PHY layer providing RXVECTOR parameters from a received MU-RTS frame to the MAC Layer, and the right side of FIG. **19** shows the MAC layer providing TXVECTOR parameters to the PHY layer for a CTS frame to be transmitted in response to the MU-RTS frame.

FIG. **20** shows a Table 3 of TXVECTOR parameters, according to an embodiment. The bottom row of Table 3 shows a "SCRAMBLER_INITIAL_STATE" TXVECTOR parameters that is received by the PHY layer from the MAC layer and used by the PHY layer as the initial state of a scrambling sequence of a frame to be transmitted (e.g., a CTS frame).

FIG. **21** shows a Table 4 of RXVECTOR parameters for Non-HT PPDU frames, according to an embodiment. A last entry "SCRAMBLER_INITIALIZATION" is retrieved from the first 7 bits of the scrambled data of the received frame associated with the RXVECTOR and provided by the PHY layer to the MAC layer.

Subsequently, the value provided by the PHY layer to the MAC layer using the SCRAMBLER_INITIALIZATION of the RXVECTOR may be provided by the MAC layer to the PHY layer in the a parameter of a TXVECTOR of a subsequent frame to be transmitted, and may be used by the PHY layer as the initial state of a scrambling sequence for an RF-combined frame (e.g. a CTS frame).

FIG. **22** shows a Table 5 of RXVECTOR parameters, according to another embodiment. In the embodiment of Table 4, the foremost seven bits of scrambled data of the received frame associated with the RXVECTOR are communicated to the MAC layer by the PHY layer in a first seven bits of an existing RXVECTOR SERVICE field.

Subsequently, the value provided by the PHY layer to the MAC layer using the first seven bits of the RXVECTOR SERVICE field may be provided by the MAC layer to the PHY layer in the SCRAMBLER_INITIAL_STATE parameter of a TXVECTOR of a subsequent frame to be transmitted, and may be used by the PHY layer as the initial state of a scrambling sequence for an RF-combined CTS frame.

The solutions provided herein have been described with reference to a wireless LAN system; however, it should be understood that these solutions are also applicable to other network environments, such as cellular telecommunication networks, wired networks, etc.

The above explanation and figures are applied to an HE station, an HE frame, an HE PPDU, an HE-SIG field and the like of the IEEE 802.11ax amendment, but they can also applied to a receiver, a frame, PPDU, a SIG field, and the like of another future amendment of IEEE 802.11.

Embodiments of the present disclosure include electronic devices configured to perform one or more of the operations described herein. However, embodiments are not limited thereto.

Embodiments of the present disclosure may further include systems configured to operate using the processes described herein. The systems may include basic service sets (BSSs) such as the BSSs **100** of FIG. **1**, but embodiments are not limited thereto.

Embodiments of the present disclosure may be implemented in the form of program instructions executable through various computer means, such as a processor or microcontroller, and recorded in a non-transitory computer-readable medium. The non-transitory computer-readable medium may include one or more of program instructions, data files, data structures, and the like. The program instructions may be adapted to execute the processes and to generate and decode the frames described herein when executed on a device such as the wireless devices shown in FIG. **1**.

In an embodiment, the non-transitory computer-readable medium may include a read only memory (ROM), a random access memory (RAM), or a flash memory. In an embodiment, the non-transitory computer-readable medium may include a magnetic, optical, or magneto-optical disc such as a hard disk drive, a floppy disc, a CD-ROM, and the like.

In some cases, an embodiment of the invention may be an apparatus (e.g., an AP station, a non-AP station, or another network or computing device) that includes one or more hardware and software logic structure for performing one or more of the operations described herein. For example, as described above, the apparatus may include a memory unit, which stores instructions that may be executed by a hardware processor installed in the apparatus. The apparatus may also include one or more other hardware or software elements, including a network interface, a display device, etc.

While this invention has been described in connection with what is presently considered to be practical embodiments, embodiments are not limited to the disclosed embodiments, but, on the contrary, may include various modifications and equivalent arrangements included within the spirit and scope of the appended claims. The order of operations described in a process is illustrative and some operations may be re-ordered. Further, two or more embodiments may be combined.

What is claimed is:

1. A method performed by a wireless device, the method comprising:

receiving a Null Data Packet Announcement (NDPA), the NDPA including one or more station information fields;

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determining exactly a number of the one or more station information fields in the NDPA;

receiving a Null Data Packet (NDP); and

in response to determining that the number of the one or more station information fields in the NDPA is one, transmitting first Channel State Information (CSI) feedback in response to receiving the NDP,

wherein the number of the one or more station information fields in the NDPA is the cardinality of the one or more station information fields in the NDPA.

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

when the number of the one or more station information fields in the NDPA is greater than one:

receiving a first trigger frame; and

transmitting the first CSI feedback in response to receiving the first trigger frame.

3. The method of claim **2**, wherein transmitting the first CSI feedback in response to receiving the NDP comprises:

transmitting the first CSI feedback a first predetermined interframe space (IFS) after receiving the NDP.

4. The method of claim **2**, wherein transmitting the first CSI feedback in response to receiving the NDP comprises:

transmitting the first CSI feedback in a single user transmission in response to receiving the NDP.

5. The method of claim **4**, wherein transmitting the first CSI feedback in response to receiving the first trigger frame comprises:

transmitting the first CSI feedback in a multi user transmission in response to receiving the first trigger frame.

6. The method of claim **5**, wherein the first trigger frame comprises resource assignment information.

7. The method of claim **6**, wherein transmitting the first CSI feedback in a multi user transmission comprises:

participating in the multi user transmission based on the resource assignment information to transmit the first CSI feedback in response to receiving the first trigger frame.

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

when the number of one or more station information fields in the NDPA is greater than one:

receiving a second trigger frame; and

transmitting second CSI feedback in response to receiving the second trigger frame.

9. The method of claim **3**, wherein transmitting the first CSI feedback in response to receiving the first trigger frame comprises:

transmitting the first CSI feedback a second predetermined IFS after receiving the first trigger frame.

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

receiving a sounding poll frame; and

transmitting the first CSI feedback in response to receiving the sounding poll frame.

11. A method performed by a wireless device, the method comprising:

transmitting a Null Data Packet Announcement (NDPA), the NDPA including one or more station information fields;

transmitting a Null Data Packet (NDP); and

when a number of the one or more station information fields in the NDPA is one, receiving first Channel State Information (CSI) feedback transmitted in response to the NDP having only one station information field,

wherein the number of the one or more station information fields in the NDPA is exactly the cardinality of the one or more station information fields in the NDPA.

12. The method of claim **11**, further comprising:

when the number of the one or more station information fields in the NDPA is greater than one:

transmitting a first trigger frame; and

receiving the first CSI feedback in response to transmitting the first trigger frame.

13. The method of claim **12**, wherein receiving the first CSI feedback in response to transmitting the NDP comprises:

receiving the first CSI feedback a first predetermined interframe space (IFS) after transmitting the NDP.

14. The method of claim **13**, wherein receiving the first CSI feedback in response to transmitting the first trigger frame comprises:

receiving the first CSI feedback a second predetermined IFS after transmitting the first trigger frame.

15. The method of claim **12**, wherein receiving the first CSI feedback in response to transmitting the NDP comprises:

receiving the first CSI feedback in a single user transmission in response to transmitting the NDP.

16. The method of claim **15**, wherein receiving the first CSI feedback in response to transmitting the first trigger frame comprises:

receiving the first CSI feedback in a multi user transmission in response to transmitting the first trigger frame.

17. The method of claim **16**, wherein the first trigger frame comprises resource assignment information.

18. The method of claim **17**, wherein receiving the first CSI feedback in a multi user transmission comprises:

participating in the multi user transmission based on the resource assignment information to receive the first CSI feedback in response to transmitting the first trigger frame.

19. The method of claim **12**, further comprising:

when the number of one or more station information fields in the NDPA is greater than one:

transmitting a second trigger frame; and

receiving second CSI feedback in response to transmitting the second trigger frame.

20. The method of claim **11**, further comprising:

transmitting a sounding poll frame; and

receiving the first CSI feedback in response to transmitting the sounding poll frame.

* * * * *

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EXHIBIT 7

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August 23, 2021

THIS IS TO CERTIFY THAT ANNEXED HERETO IS A TRUE COPY FROM THE RECORDS OF THIS OFFICE OF:

U.S. PATENT: *10,756,851*
ISSUE DATE: *August 25, 2020*

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Certifying Officer

ATLAS-00020345

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(12) **United States Patent**
Hedayat

(10) **Patent No.: US 10,756,851 B2**
(45) **Date of Patent: *Aug. 25, 2020**

(54) **MULTIPLEXING ACKNOWLEDGMENT MESSAGES IN RESPONSE TO DOWNLINK FRAMES**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

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(22) Filed: **Nov. 28, 2018**

(65) **Prior Publication Data**

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Related U.S. Application Data

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(Continued)

(51) **Int. Cl.**
H04L 1/16 (2006.01)
H04W 72/12 (2009.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H04L 1/1621*** (2013.01); ***H04B 7/0452*** (2013.01); ***H04L 5/0007*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC H04B 7/0452; H04L 5/00; H04L 1/1621; H04L 5/0055; H04L 5/0007;
(Continued)

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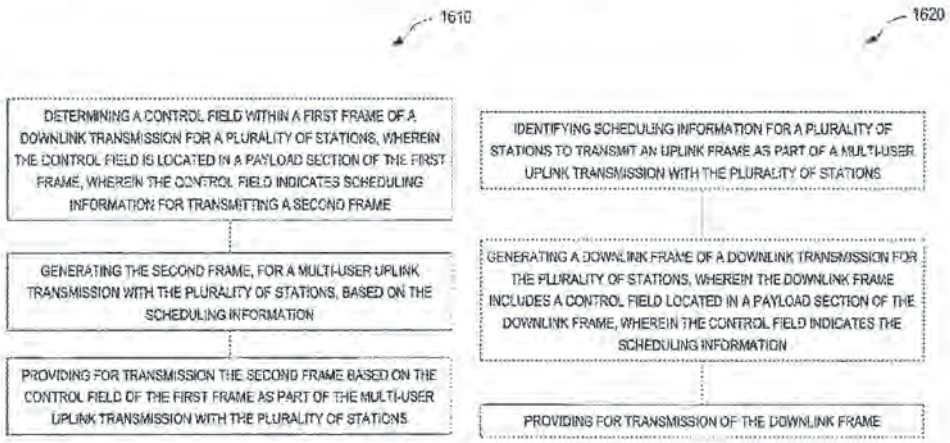
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Primary Examiner — Kyaw Z Soe
(74) *Attorney, Agent, or Firm* — Morgan, Lewis & Bockius LLP

(57) **ABSTRACT**

In an example of multi-user wireless communications, an access point may send a downlink frame to multiple stations. Some or all of the stations may generate and transmit their respective uplink frames. The uplink frames from the stations may be aggregated or multiplexed to form a final uplink frame that is received by the access point. The uplink frames may be block acknowledgment or acknowledgment (BA or ACK) frames. Uplink response scheduling may be located in a payload of the downlink frame, in which the uplink response scheduling indicates one or more resource units assigned to the multiple stations for transmitting the uplink frames. In some examples, the uplink response scheduling is in a control field of the payload, in a trigger frame as part of the payload. In some aspects, the downlink frame is part of a multicast transmission. Other methods, apparatus, and computer-readable media are also disclosed.

20 Claims, 18 Drawing Sheets



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Related U.S. Application Data

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H04W 84/12	(2009.01)
H04L 1/00	(2006.01)

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

CPC ***H04L 5/0023*** (2013.01); ***H04L 5/0055*** (2013.01); ***H04L 5/0091*** (2013.01); ***H04W 72/1289*** (2013.01); *H04L 5/0064* (2013.01); *H04L 5/0082* (2013.01); *H04L 2001/0093* (2013.01); *H04W 72/1268* (2013.01); *H04W 84/12* (2013.01)

(58) **Field of Classification Search**

CPC H04L 5/0023; H04L 5/0091; H04W 72/12; H04W 72/1289

See application file for complete search history.

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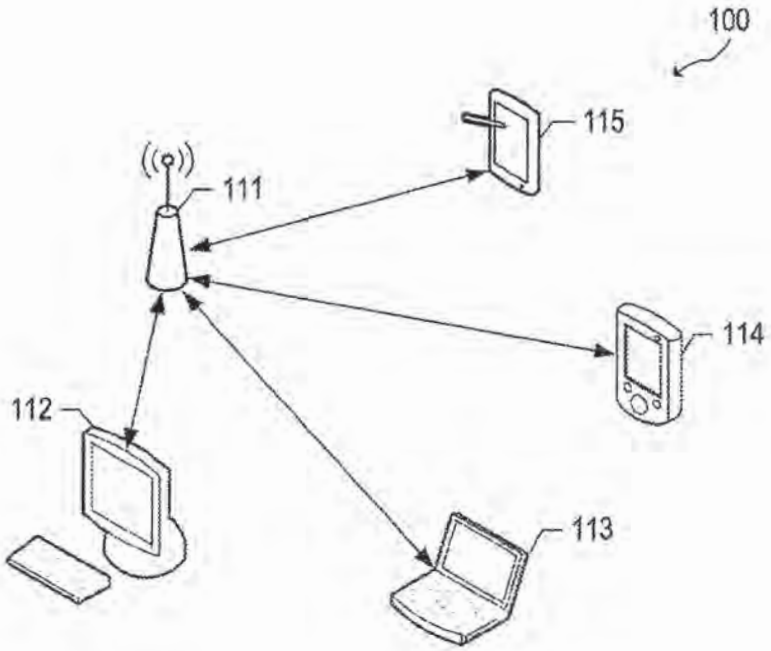


FIG. 1

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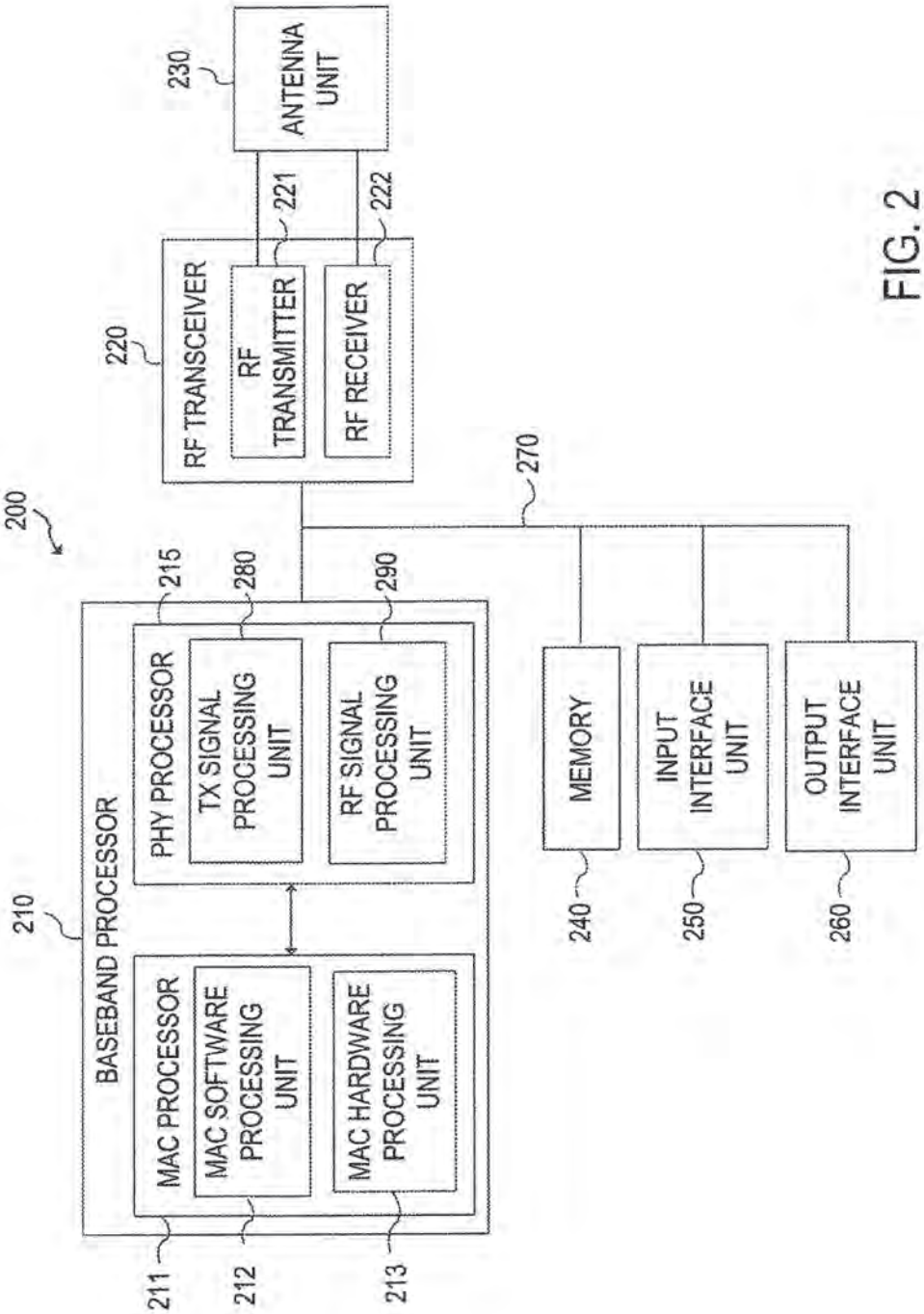


FIG. 2

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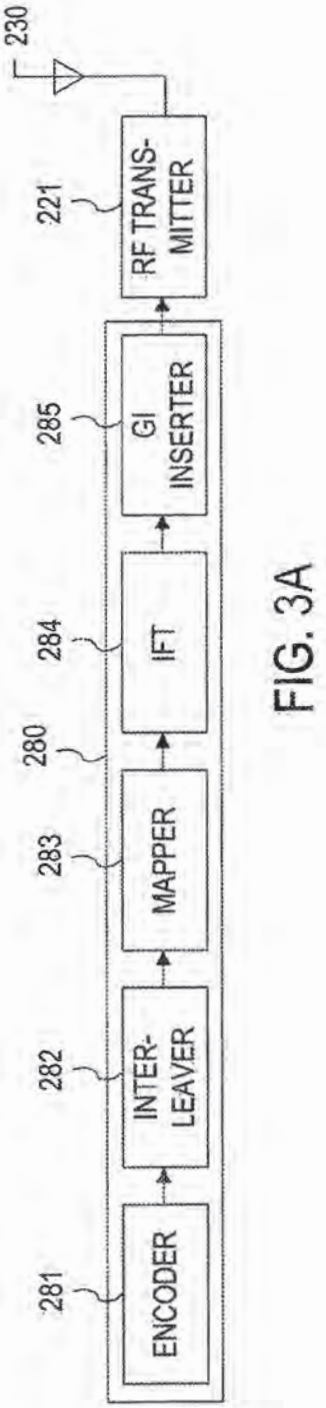


FIG. 3A

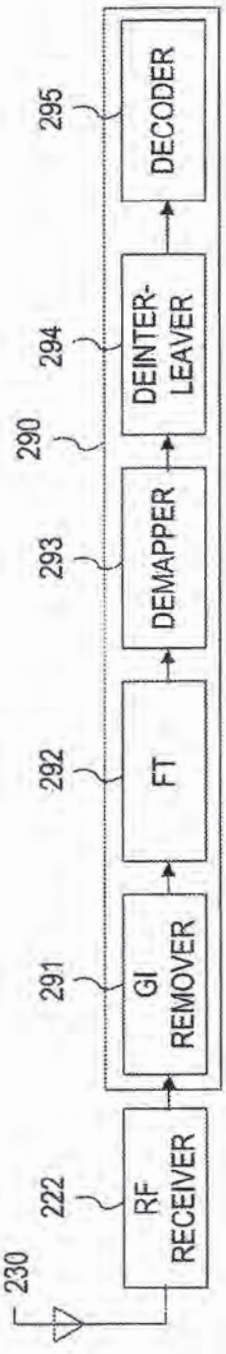


FIG. 3B

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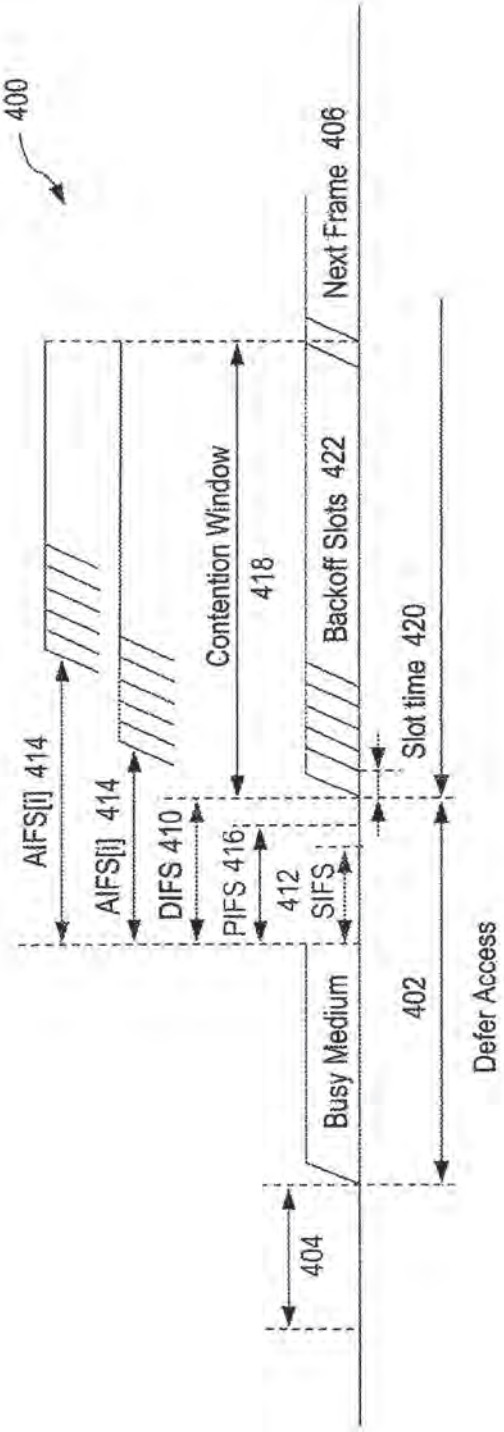


FIG. 4

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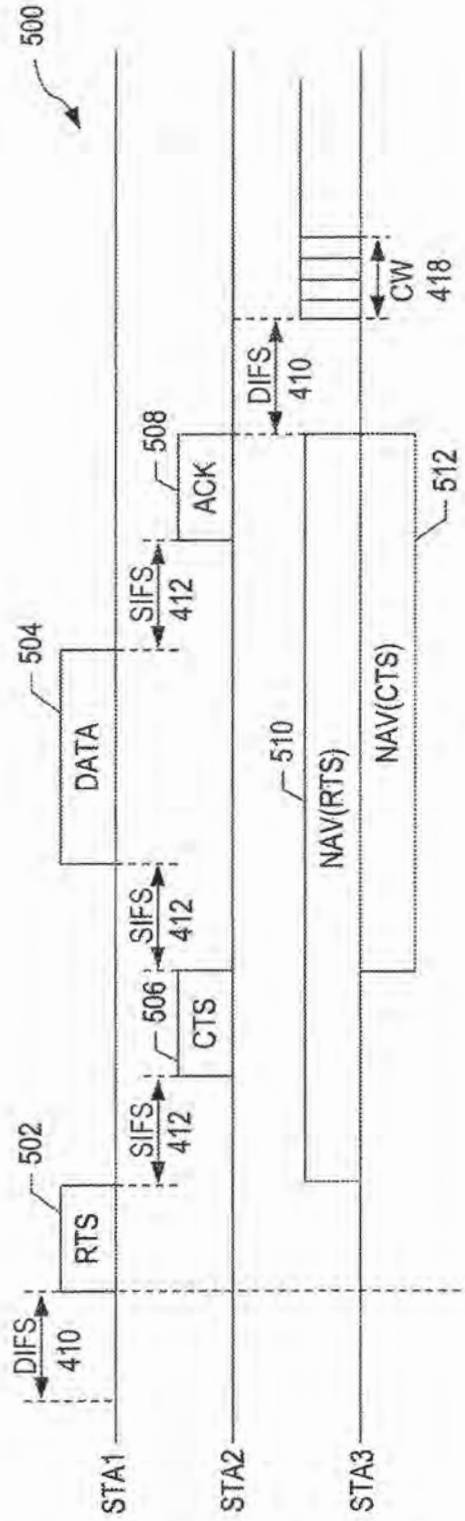


FIG. 5

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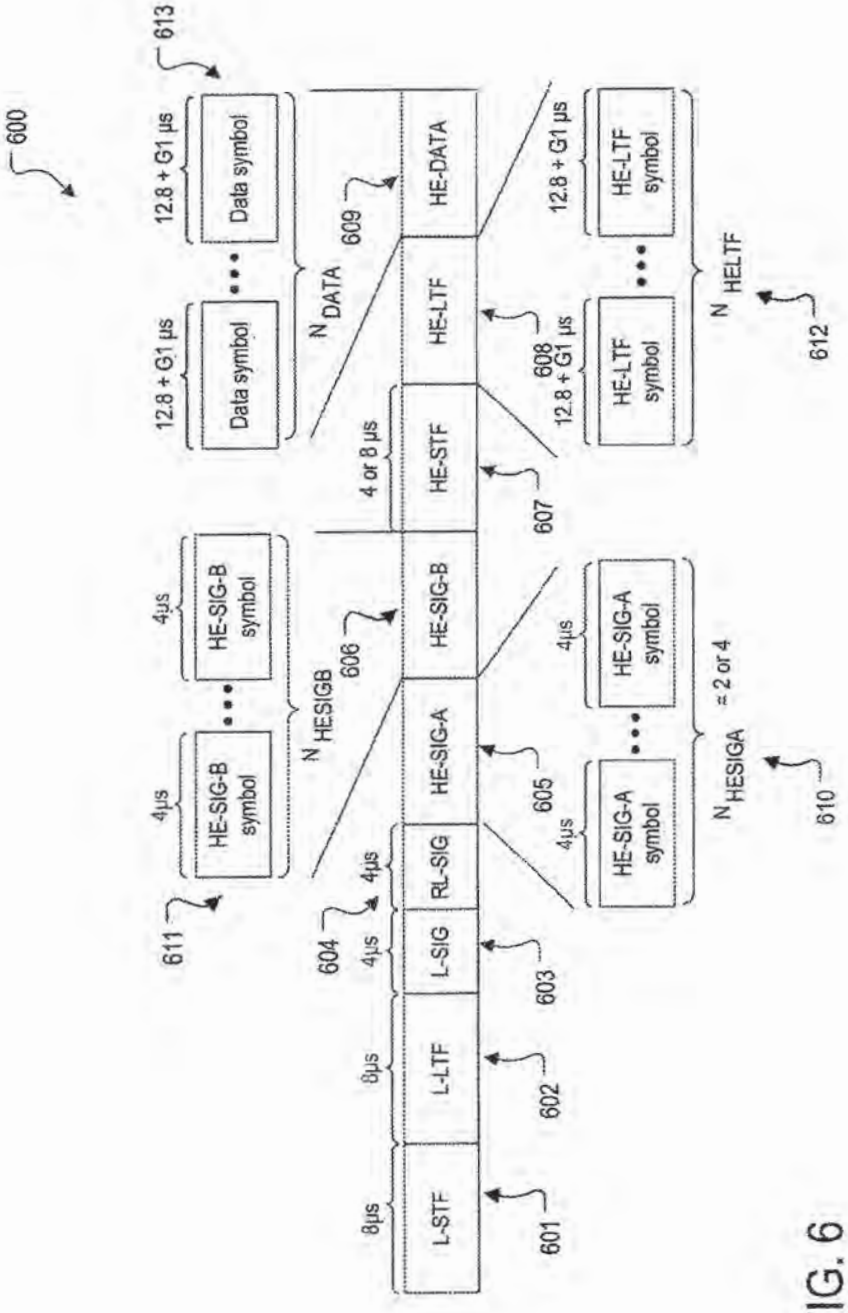


FIG. 6

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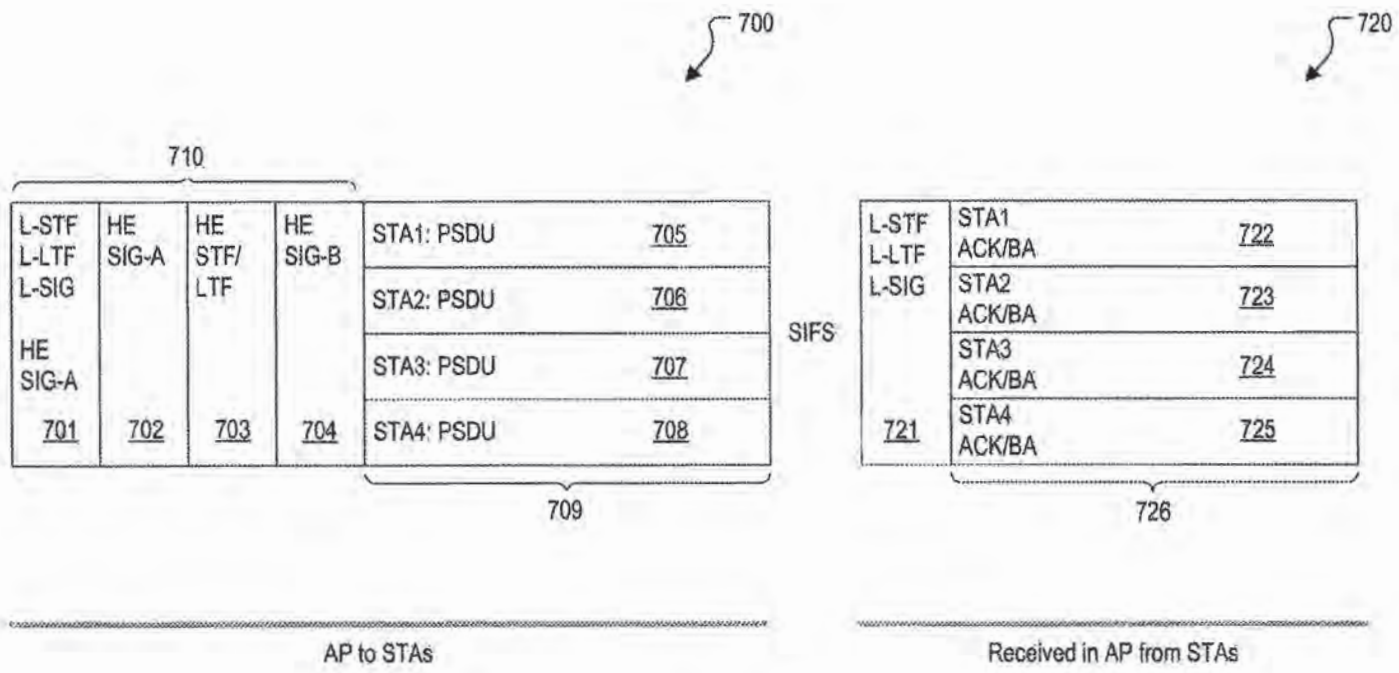


FIG. 7

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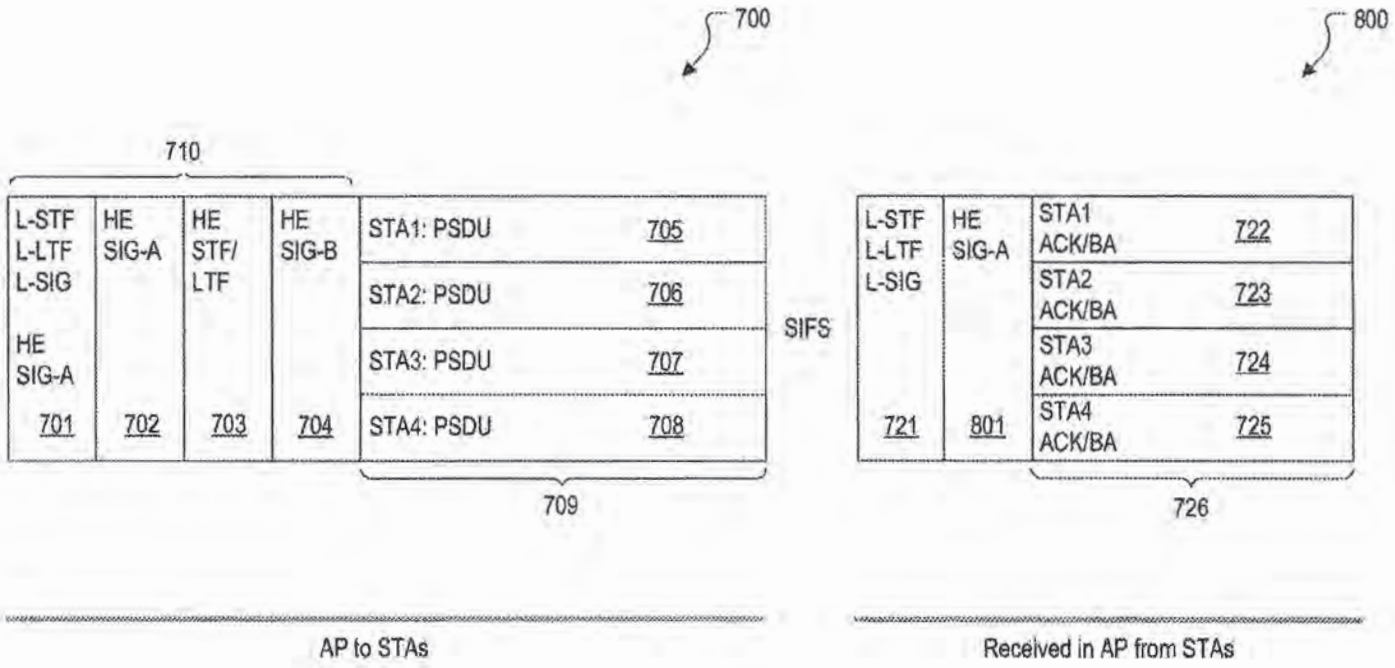


FIG. 8

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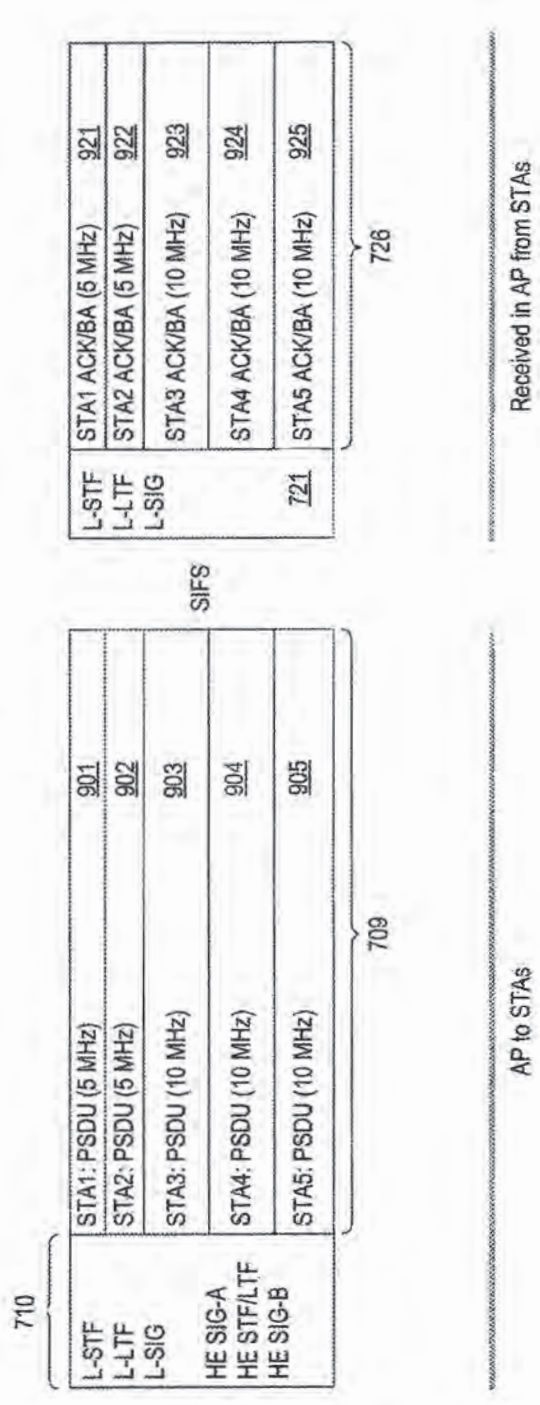


FIG. 9

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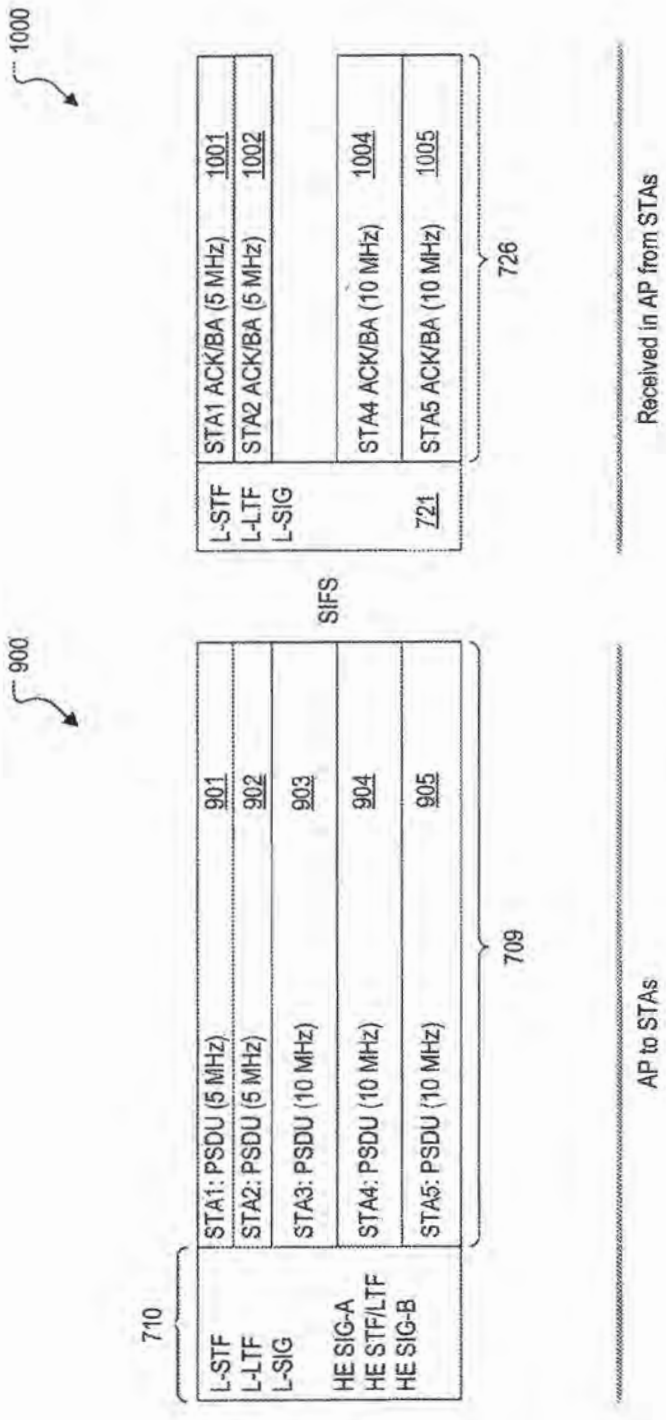


FIG. 10

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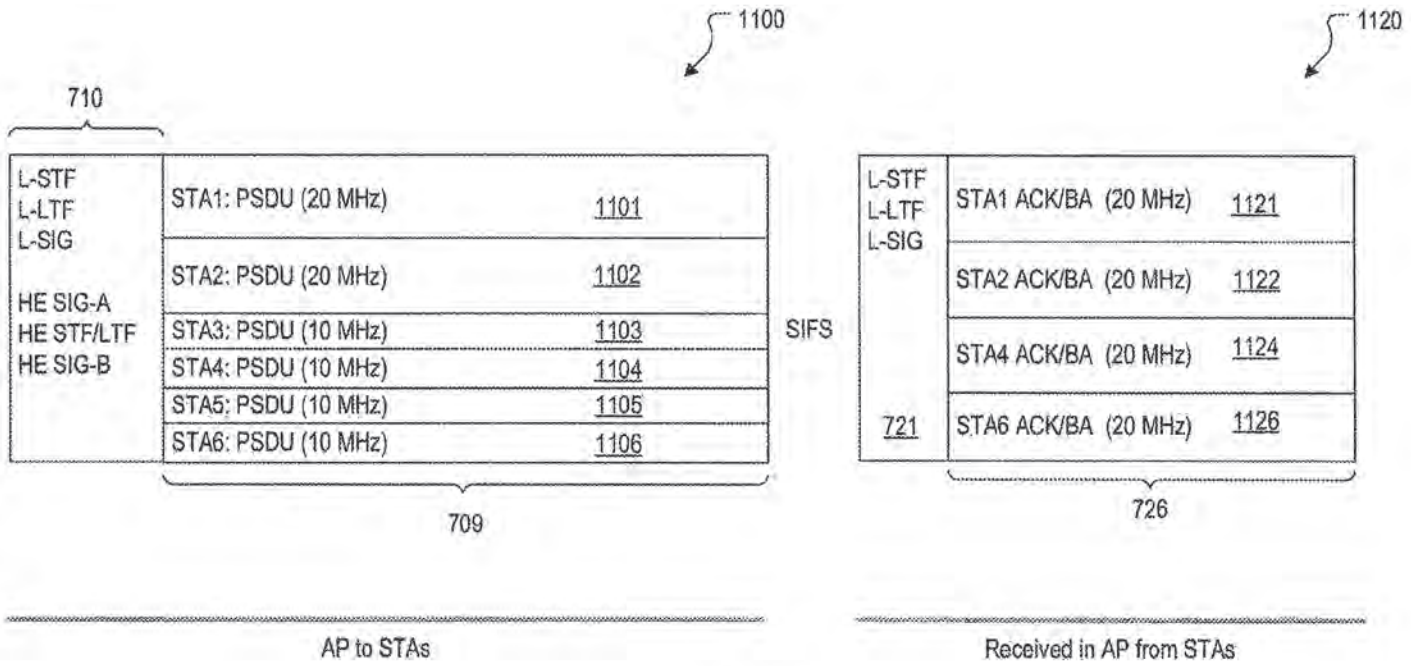


FIG. 11

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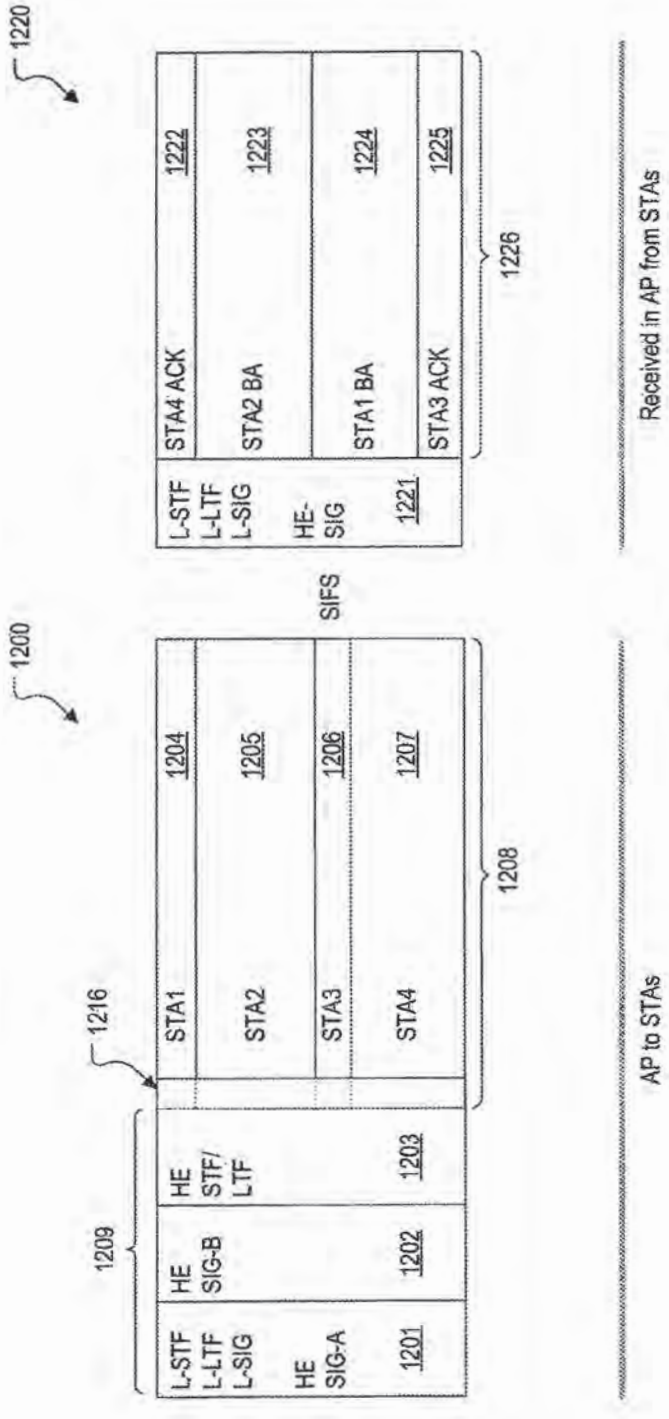


FIG. 12

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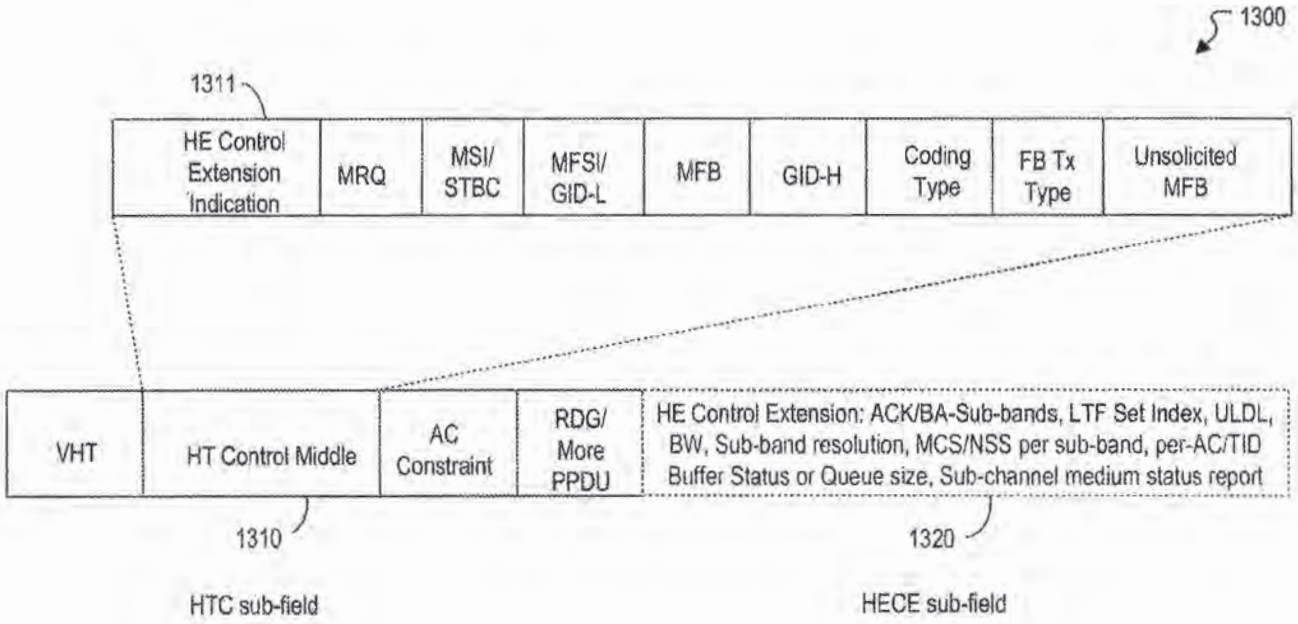


FIG. 13

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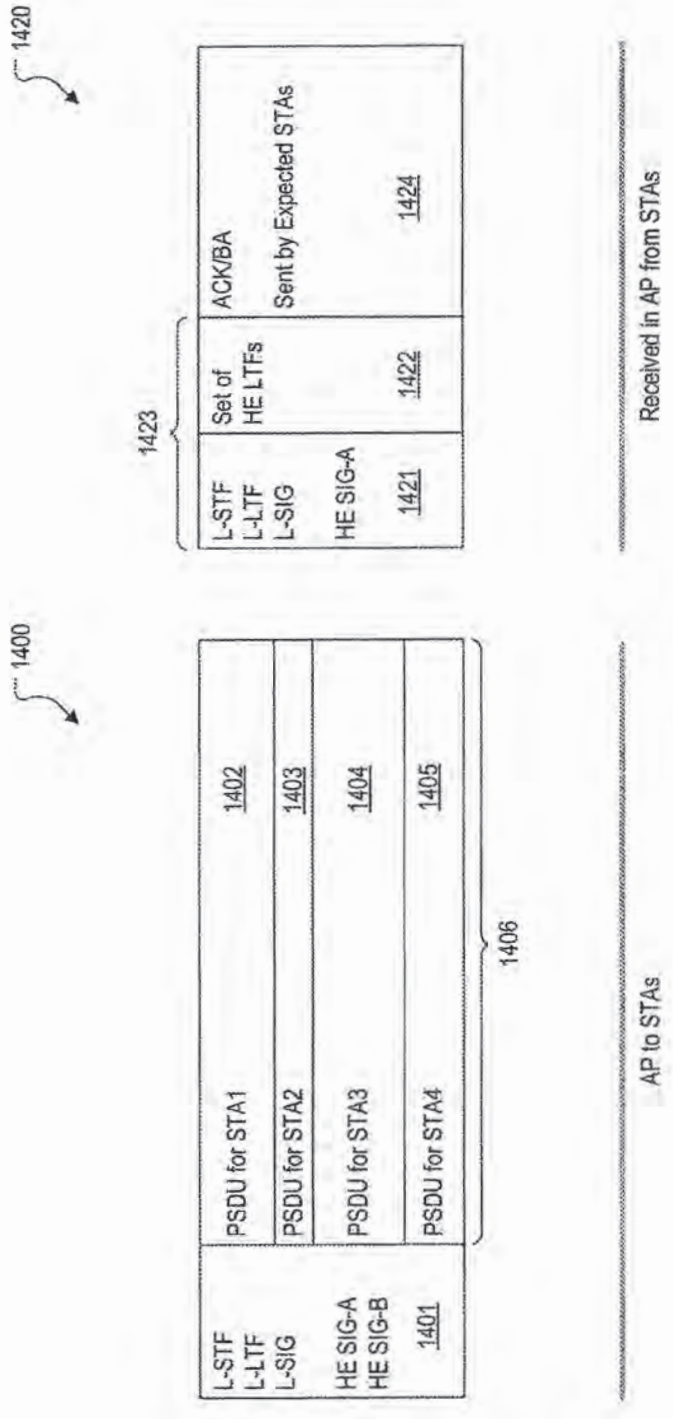


FIG. 14

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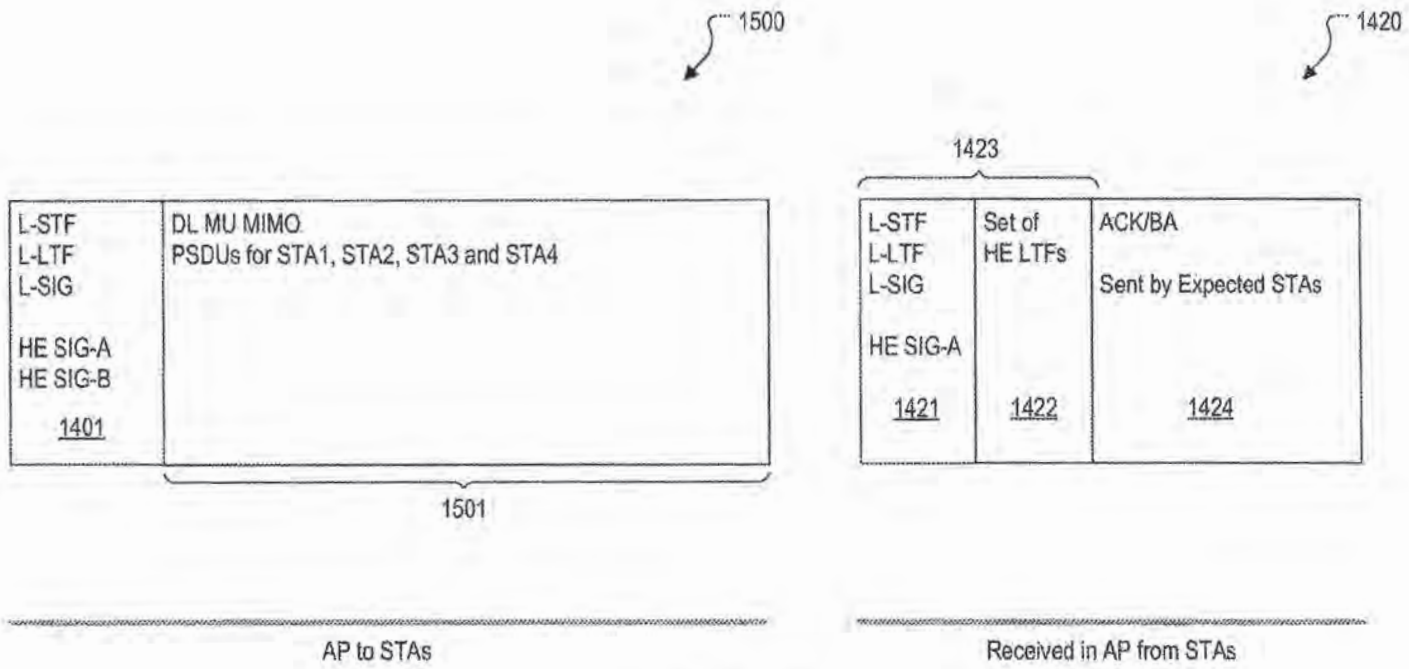


FIG. 15

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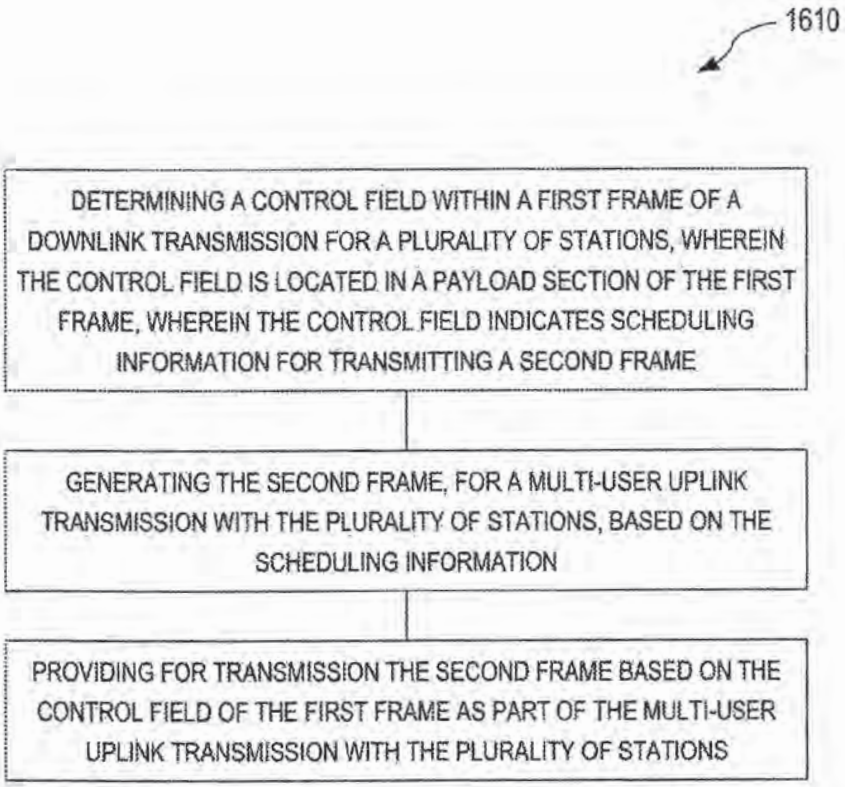


FIG. 16A

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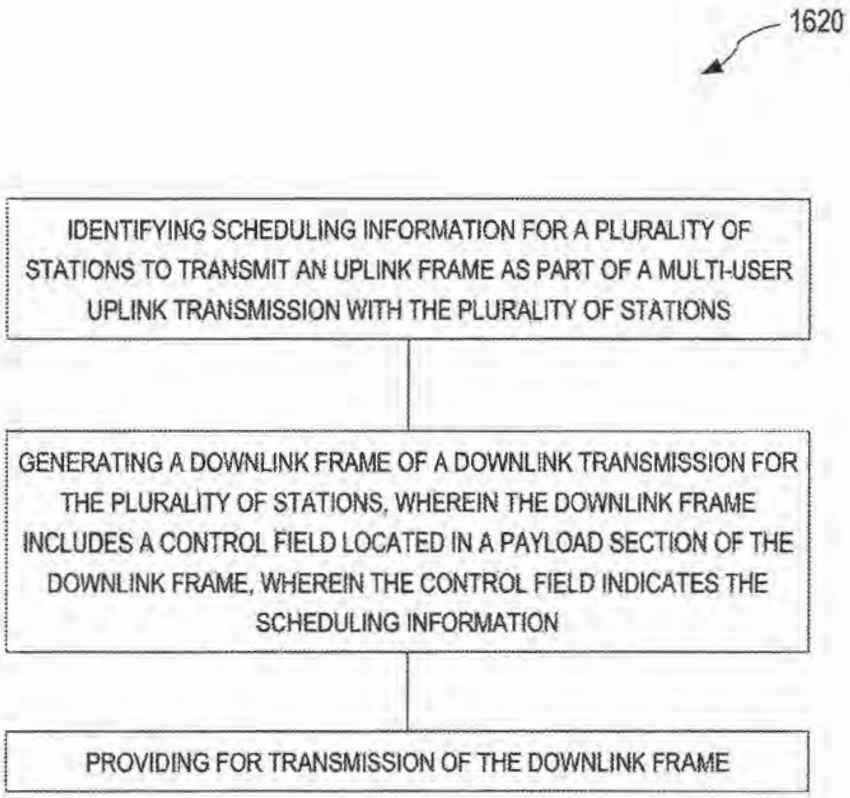


FIG. 16B

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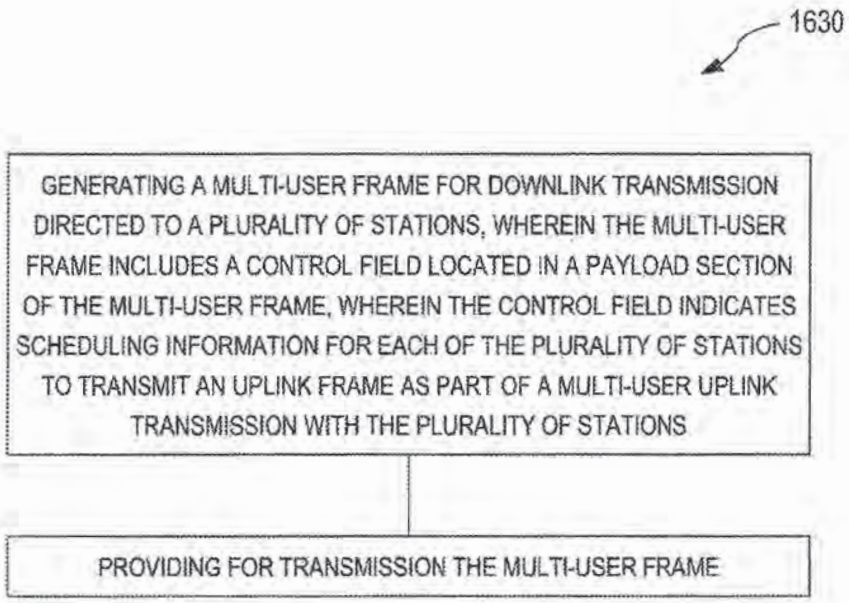


FIG. 16C

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MULTIPLEXING ACKNOWLEDGMENT MESSAGES IN RESPONSE TO DOWNLINK FRAMES

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of application Ser. No. 15/151,433, filed on May 10, 2016, now U.S. Pat. No. 10,181,930, which claims the benefit of U.S. Provisional Application No. 62/159,346, filed on May 10, 2015, U.S. Provisional Application No. 62/160,527, filed on May 12, 2015, U.S. Provisional Application No. 62/191,623, filed on Jul. 13, 2015, and U.S. Provisional Application No. 62/193,305, filed on Jul. 16, 2015, the entirety of each of which is incorporated herein by reference for all purposes.

TECHNICAL FIELD

The present description relates in general to wireless communication systems and methods, and more particularly to, for example, without limitation, multiplexing acknowledgment messages in response to downlink (DL) frames.

BACKGROUND

Wireless local area network (WLAN) devices are deployed in diverse environments. These environments are generally characterized by the existence of access points and non-access point stations. Increased interference from neighboring devices gives rise to performance degradation. Additionally, WLAN devices are increasingly required to support a variety of applications such as video, cloud access, and offloading. In particular, video traffic is expected to be the dominant type of traffic in many high efficiency WLAN deployments. With the real-time requirements of some of these applications, WLAN users demand improved performance in delivering their applications, including improved power consumption for battery-operated devices.

The description provided in the background section may not be assumed to be prior art merely because it is mentioned in or associated with the background section. The background section may include information that describes one or more aspects of the subject technology.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates a schematic diagram of an example of a wireless communication network.

FIG. **2** illustrates a schematic diagram of an example of a wireless communication device.

FIG. **3A** illustrates a schematic block diagram of an example of a transmitting signal processor in a wireless communication device.

FIG. **3B** illustrates a schematic block diagram of an example of a receiving signal processor in a wireless communication device.

FIG. **4** illustrates an example of a timing diagram of interframe space (IFS) relationships.

FIG. **5** illustrates an example of a timing diagram of a carrier sense multiple access/collision avoidance (CSMA/CA) based frame transmission procedure for avoiding collision between frames in a channel.

FIG. **6** illustrates a schematic diagram of an example of a format of a high efficiency (HE) physical layer convergence procedure (PLCP) protocol data unit (HE PPDU) frame.

FIGS. **7** through **11** illustrate schematic diagrams of examples of a downlink OFDMA frame and an uplink OFDMA frame with varying uplink multi-user (MU) acknowledgment assignments.

FIG. **12** illustrates a schematic diagram of an example of a downlink frame and an uplink frame, where the downlink frame has a trigger frame in a payload of the downlink frame.

FIG. **13** illustrates an example of a control field of a data frame.

FIG. **14** illustrates a schematic diagram of an example of a downlink OFDMA frame and an uplink MU frame from a set of stations.

FIG. **15** illustrates a schematic diagram of an example of a downlink MU frame and an uplink MU frame from a set of stations.

FIGS. **16A** through **16C** illustrate flow charts of examples of multi-user aggregation methods for data and control frame operation.

In one or more implementations, not all of the depicted components in each figure may be required, and one or more implementations may include additional components not shown in a figure. Variations in the arrangement and type of the components may be made without departing from the scope of the subject disclosure. Additional components, different components, or fewer components may be utilized within the scope of the subject disclosure.

DETAILED DESCRIPTION

The detailed description set forth below is intended as a description of various implementations and is not intended to represent the only implementations in which the subject technology may be practiced. As those skilled in the art can realize, the described implementations may be modified in various different ways, all without departing from the scope of the present disclosure. Accordingly, the drawings and description are to be regarded as illustrative in nature and not restrictive.

New multi-user (MU) transmissions, such as downlink (DL) orthogonal frequency division multiple access (OFDMA) and DL MU multiple-input/multiple-output (MIMO), provide new opportunities for next-generation WiFi technology. For example, OFDMA is a technique that can be used in WiFi technology in order to enhance the aggregation of multiple payloads that are destined to multiple stations (STAs) within the same frame. Due to this and other advantages, OFDMA technique is being considered for next generation WLAN technologies, including 802.11ax which is also referred to as high efficiency (HE) technology.

With OFDMA technique, there comes new opportunities and challenges that can be considered in the design of OFDMA signaling and procedures. Among the opportunities that are provided by OFDMA is the frequency selectivity gain, where AP can allocate resources to each STA where those allocated resources offer highest frequency-gain for that STA. Using acknowledgement procedures, the access point (AP) can obtain the information that is needed to harvest frequency selectivity gain for each STA in the subsequent DL or uplink (UL) OFDMA frames.

The present disclosure describes methods that can be used among multiple nodes (e.g., between a pair of 802.11 nodes) while they exchange frames in OFDMA or MU MIMO formats. In OFDMA or other MU transmissions, the transmitter node, commonly an AP in 802.11 use cases, may send an OFDMA frame to several other STAs (or clients). In response, some or all of the STAs may send acknowledg-

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ment frames in form of an Acknowledgment (ACK) frame or a Block Acknowledgment (BlockAck or BA) frame. One or more implementations of the present disclosure describe a new uplink frame with specific formats where multiple STAs (or clients) participate in forming the uplink frame by embedding or multiplexing the STAs' ACK or BA frames into the uplink frame. Hence, several ACK or BA frames may be embedded into a single MU ACK/BA frame, thereby enhancing the OFDMA operation or the MU operation using MU MIMO techniques. One or more implementations of setting the parameters for the MU ACK/BA frame are described herein.

FIG. **1** illustrates a schematic diagram of an example of a wireless communication network **100**. In the wireless communication network **100**, such as a wireless local area network (WLAN), a basic service set (BSS) includes a plurality of wireless communication devices (e.g., WLAN devices). In one aspect, a BSS refers to a set of STAs that can communicate in synchronization, rather than a concept indicating a particular area. In the example, the wireless communication network **100** includes wireless communication devices **111-115**, which may be referred to as stations (STAs).

Each of the wireless communication devices **111-115** may include a media access control (MAC) layer and a physical (PHY) layer according to an IEEE 802.11 standard. In the example, at least one wireless communication device (e.g., device **111**) is an access point (AP). An AP may be referred to as an AP STA, an AP device, or a central station. The other wireless communication devices (e.g., devices **112-115**) may be non-AP STAs. Alternatively, all of the wireless communication devices **111-115** may be non-AP STAs in an Ad-hoc networking environment.

An AP STA and a non-AP STA may be collectively called STAs. However, for simplicity of description, in some aspects, only a non-AP STA may be referred to as a STA. An AP may be, for example, a centralized controller, a base station (BS), a node-B, a base transceiver system (BTS), a site controller, a network adapter, a network interface card (NIC), a router, or the like. A non-AP STA (e.g., a client device operable by a user) may be, for example, a device with wireless communication capability, a terminal, a wireless transmit/receive unit (WTRU), a user equipment (UE), a mobile station (MS), a mobile terminal, a mobile subscriber unit, a laptop, a non-mobile computing device (e.g., a desktop computer with wireless communication capability) or the like. In one or more aspects, a non-AP STA may act as an AP (e.g., a wireless hotspot).

In one aspect, an AP is a functional entity for providing access to a distribution system, by way of a wireless medium, for an associated STA. For example, an AP may provide access to the internet for one or more STAs that are wirelessly and communicatively connected to the AP. In FIG. **1**, wireless communications between non-AP STAs are made by way of an AP. However, when a direct link is established between non-AP STAs, the STAs can communicate directly with each other (without using an AP).

In one or more implementations, OFDMA-based 802.11 technologies are utilized, and for the sake of brevity, a STA refers to a non-AP high efficiency (HE) STA, and an AP refers to an HE AP. In one or more aspects, a STA may act as an AP.

FIG. **2** illustrates a schematic diagram of an example of a wireless communication device. The wireless communication device **200** includes a baseband processor **210**, a radio frequency (RF) transceiver **220**, an antenna unit **230**, a memory **240**, an input interface unit **250**, an output interface unit **260**, and a bus **270**, or subsets and variations thereof. The wireless communication device **200** can be, or can be a part of, any of the wireless communication devices **111-115**.

In the example, the baseband processor **210** performs baseband signal processing, and includes a medium access control (MAC) processor **211** and a PHY processor **215**. The memory **240** may store software (such as MAC software) including at least some functions of the MAC layer. The memory may further store an operating system and applications.

In the illustration, the MAC processor **211** includes a MAC software processing unit **212** and a MAC hardware processing unit **213**. The MAC software processing unit **212** executes the MAC software to implement some functions of the MAC layer, and the MAC hardware processing unit **213** may implement remaining functions of the MAC layer as hardware (MAC hardware). However, the MAC processor **211** may vary in functionality depending on implementation. The PHY processor **215** includes a transmitting (TX) signal processing unit **280** and a receiving (RX) signal processing unit **290**. The term TX may refer to transmitting, transmit, transmitted, transmitter or the like. The term RX may refer to receiving, receive, received, receiver or the like.

The PHY processor **215** interfaces to the MAC processor **211** through, among others, transmit vector (TXVECTOR) and receive vector (RXVECTOR) parameters. In one or more aspects, the MAC processor **211** generates and provides TXVECTOR parameters to the PHY processor **215** to supply per-packet transmit parameters. In one or more aspects, the PHY processor **215** generates and provides RXVECTOR parameters to the MAC processor **211** to inform the MAC processor **211** of the received packet parameters.

In some aspects, the wireless communication device **200** includes a read-only memory (ROM) (not shown) or registers (not shown) that store instructions that are needed by one or more of the MAC processor **211**, the PHY processor **215** and/or other components of the wireless communication device **200**.

In one or more implementations, the wireless communication device **200** includes a permanent storage device (not shown) configured as a read-and-write memory device. The permanent storage device may be a non-volatile memory unit that stores instructions even when the wireless communication device **200** is off. The ROM, registers and the permanent storage device may be part of the baseband processor **210** or be a part of the memory **240**. Each of the ROM, the permanent storage device, and the memory **240** may be an example of a memory or a computer-readable medium. A memory may be one or more memories.

The memory **240** may be a read-and-write memory, a read-only memory, a volatile memory, a non-volatile memory, or a combination of some or all of the foregoing. The memory **240** may store instructions that one or more of the MAC processor **211**, the PHY processor **215**, and/or another component may need at runtime.

The RF transceiver **220** includes an RF transmitter **221** and an RF receiver **222**. The input interface unit **250** receives information from a user, and the output interface unit **260** outputs information to the user. The antenna unit **230** includes one or more antennas. When multi-input multi-output (MIMO) or multi-user MIMO (MU-MIMO) is used, the antenna unit **230** may include more than one antenna.

The bus **270** collectively represents all system, peripheral, and chipset buses that communicatively connect the numerous internal components of the wireless communication device **200**. In one or more implementations, the bus **270**

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communicatively connects the baseband processor **210** with the memory **240**. From the memory **240**, the baseband processor **210** may retrieve instructions to execute and data to process in order to execute the processes of the subject disclosure. The baseband processor **210** can be a single processor, multiple processors, or a multi-core processor in different implementations. The baseband processor **210**, the memory **240**, the input interface unit **250**, and the output interface unit **260** may communicate with each other via the bus **270**.

The bus **270** also connects to the input interface unit **250** and the output interface unit **260**. The input interface unit **250** enables a user to communicate information and select commands to the wireless communication device **200**. Input devices that may be used with the input interface unit **250** may include any acoustic, speech, visual, touch, tactile and/or sensory input device, e.g., a keyboard, a pointing device, a microphone, or a touchscreen. The output interface unit **260** may enable, for example, the display or output of videos, images, audio, and data generated by the wireless communication device **200**. Output devices that may be used with the output interface unit **260** may include any visual, auditory, tactile, and/or sensory output device, e.g., printers and display devices or any other device for outputting information. One or more implementations may include devices that function as both input and output devices, such as a touchscreen.

One or more implementations can be realized in part or in whole using a computer-readable medium. In one aspect, a computer-readable medium includes one or more media. In one or more aspects, a computer-readable medium is a tangible computer-readable medium, a computer-readable storage medium, a non-transitory computer-readable medium, a machine-readable medium, a memory, or some combination of the foregoing (e.g., a tangible computer-readable storage medium, or a non-transitory machine-readable storage medium). In one aspect, a computer is a machine. In one aspect, a computer-implemented method is a machine-implemented method.

A computer-readable medium may include storage integrated into a processor and/or storage external to a processor. A computer-readable medium may be a volatile, non-volatile, solid state, optical, magnetic, and/or other suitable storage device, e.g., RAM, ROM, PROM, EPROM, a flash, registers, a hard disk, a removable memory, or a remote storage device.

In one aspect, a computer-readable medium comprises instructions stored therein. In one aspect, a computer-readable medium is encoded with instructions. In one aspect, instructions are executable by one or more processors (e.g., **210**, **211**, **212**, **213**, **215**, **280**, **290**) to perform one or more operations or a method. Instructions may include, for example, programs, routines, subroutines, data, data structures, objects, sequences, commands, operations, modules, applications, and/or functions. Those skilled in the art can recognize how to implement the instructions.

A processor (e.g., **210**, **211**, **212**, **213**, **215**, **280**, **290**) may be coupled to one or more memories (e.g., one or more external memories such as the memory **240**, one or more memories internal to the processor, one or more registers internal or external to the processor, or one or more remote memories outside of the device **200**), for example, via one or more wired and/or wireless connections. The coupling may be direct or indirect. In one aspect, a processor includes one or more processors. A processor, including a processing circuitry capable of executing instructions, may read, write, or access a computer-readable medium. A processor may be, for example, an application specific integrated circuit (ASIC), a digital signal processor (DSP), or a field programmable gate array (FPGA).

In one aspect, a processor (e.g., **210**, **211**, **212**, **213**, **215**, **280**, **290**) is configured to cause one or more operations of the subject disclosure to occur. In one aspect, a processor is configured to cause an apparatus (e.g., a wireless communication device **200**) to perform operations or a method of the subject disclosure. In one or more implementations, a processor configuration involves having a processor coupled to one or more memories. A memory may be internal or external to the processor. Instructions may be in a form of software, hardware or a combination thereof. Software instructions (including data) may be stored in a memory. Hardware instructions may be part of the hardware circuitry components of a processor. When the instructions are executed or processed by one or more processors, (e.g., **210**, **211**, **212**, **213**, **215**, **280**, **290**), the one or more processors cause one or more operations of the subject disclosure to occur or cause an apparatus (e.g., a wireless communication device **200**) to perform operations or a method of the subject disclosure.

FIG. **3A** illustrates a schematic block diagram of an example of a transmitting signal processing unit **280** in a wireless communication device. The transmitting signal processing unit **280** of the PHY processor **215** includes an encoder **281**, an interleaver **282**, a mapper **283**, an inverse Fourier transformer (IFT) **284**, and a guard interval (GI) inserter **285**.

The encoder **281** encodes input data. For example, the encoder **281** may be a forward error correction (FEC) encoder. The FEC encoder may include a binary convolutional code (BCC) encoder followed by a puncturing device, or may include a low-density parity-check (LDPC) encoder. The interleaver **282** interleaves the bits of each stream output from the encoder **281** to change the order of bits. In one aspect, interleaving may be applied only when BCC encoding is employed. The mapper **283** maps the sequence of bits output from the interleaver **282** into constellation points.

When MIMO or MU-MIMO is employed, the transmitting signal processing unit **280** may use multiple instances of the interleaver **282** and multiple instances of the mapper **283** corresponding to the number of spatial streams (N_{SS}). In the example, the transmitting signal processing unit **280** may further include a stream parser for dividing outputs of the BCC encoders or the LDPC encoder into blocks that are sent to different interleavers **282** or mappers **283**. The transmitting signal processing unit **280** may further include a space-time block code (STBC) encoder for spreading the constellation points from the number of spatial streams into a number of space-time streams (N_{STS}) and a spatial mapper for mapping the space-time streams to transmit chains. The spatial mapper may use direct mapping, spatial expansion, or beamforming depending on implementation. When MU-MIMO is employed, one or more of the blocks before reaching the spatial mapper may be provided for each user.

The IFT **284** converts a block of the constellation points output from the mapper **283** or the spatial mapper into a time domain block (e.g., a symbol) by using an inverse discrete Fourier transform (IDFT) or an inverse fast Fourier transform (IFFT). If the STBC encoder and the spatial mapper are employed, the IFT **284** may be provided for each transmit chain.

When MIMO or MU-MIMO is employed, the transmitting signal processing unit **280** may insert cyclic shift diversities (CSDs) to prevent unintentional beamforming.

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The CSD insertion may occur before or after the inverse Fourier transform operation. The CSD may be specified per transmit chain or may be specified per space-time stream. Alternatively, the CSD may be applied as a part of the spatial mapper.

The GI inserter **285** prepends a GI to the symbol. The transmitting signal processing unit **280** may optionally perform windowing to smooth edges of each symbol after inserting the GI. The RF transmitter **221** converts the symbols into an RF signal and transmits the RF signal via the antenna unit **230**. When MIMO or MU-MIMO is employed, the GI inserter **285** and the RF transmitter **221** may be provided for each transmit chain.

FIG. **3**B illustrates a schematic block diagram of an example of a receiving signal processing unit **290** in a wireless communication device. The receiving signal processing unit **290** of the PHY processor **215** includes a GI remover **291**, a Fourier transformer (FT) **292**, a demapper **293**, a deinterleaver **294**, and a decoder **295**.

The RF receiver **222** receives an RF signal via the antenna unit **230** and converts the RF signal into one or more symbols. In some aspects, the GI remover **291** removes the GI from the symbol. When MIMO or MU-MIMO is employed, the RF receiver **222** and the GI remover **291** may be provided for each receive chain.

The FT **292** converts the symbol (e.g., the time domain block) into a block of the constellation points by using a discrete Fourier transform (DFT) or a fast Fourier transform (FFT) depending on implementation. In one or more implementations, the FT **292** is provided for each receive chain.

When MIMO or MU-MIMO is employed, the receiving signal processing unit **290** may further include a spatial demapper for converting the Fourier transformed receiver chains to constellation points of the space-time streams, and a STBC decoder (not shown) for despreading the constellation points from the space-time streams into the spatial streams.

The demapper **293** demaps the constellation points output from the FT **292** or the STBC decoder to the bit streams. If the LDPC encoding is used, the demapper **293** may further perform LDPC tone demapping before the constellation demapping. The deinterleaver **294** deinterleaves the bits of each stream output from the demapper **293**. In one or more implementations, deinterleaving may be applied only when BCC decoding is used.

When MIMO or MU-MIMO is employed, the receiving signal processing unit **290** may use multiple instances on the demapper **293** and multiple instances of the deinterleaver **294** corresponding to the number of spatial streams. In the example, the receiving signal processing unit **290** may further include a stream deparser for combining the streams output from the deinterleavers **294**.

The decoder **295** decodes the streams output from the deinterleaver **294** and/or the stream deparser. For example, the decoder **295** may be an FEC decoder. The FEC decoder may include a BCC decoder or an LDPC decoder.

FIG. **4** illustrates an example of a timing diagram of interframe space (IFS) relationships. In this example, a data frame, a control frame, or a management frame can be exchanged between the wireless communication devices **111**-**115** and/or other WLAN devices.

Referring to the timing diagram **400**, during the time interval **402**, access is deferred while the medium (e.g., a wireless communication channel) is busy until a type of IFS duration has elapsed. At time interval **404**, immediate access is granted when the medium is idle for a duration that is equal to or greater than a distributed coordination function IFS (DIFS) **410** duration or arbitration IFS (AIFS) **414** duration. In turn, a next frame **406** may be transmitted after a type of IFS duration and a contention window **418** have passed. During the time **408**, if a DIFS has elapsed since the medium has been idle, a designated slot time **420** is selected and one or more backoff slots **422** are decremented as long as the medium is idle.

The data frame is used for transmission of data forwarded to a higher layer. In one or more implementations, a WLAN device transmits the data frame after performing backoff if DIFS **410** has elapsed from a time when the medium has been idle.

The management frame is used for exchanging management information that is not forwarded to the higher layer. Subtype frames of the management frame include a beacon frame, an association request/response frame, a probe request/response frame, and an authentication request/response frame.

The control frame is used for controlling access to the medium. Subtype frames of the control frame include a request to send (RTS) frame, a clear to send (CTS) frame, and an ACK frame. In the case that the control frame is not a response frame of the other frame (e.g., a previous frame), the WLAN device transmits the control frame after performing backoff if the DIFS **410** has elapsed. In the case that the control frame is the response frame of the other frame, the WLAN device transmits the control frame without performing backoff if a short IFS (SIFS) **412** has elapsed. The type and subtype of frame may be identified by a type field and a subtype field in a frame control field of the frame.

On the other hand, a Quality of Service (QoS) STA may transmit the frame after performing backoff if AIFS **414** for access category (AC), e.g., AIFS[AC], has elapsed. In this case, the data frame, the management frame, or the control frame that is not the response frame may use the AIFS[AC].

In one or more implementations, a point coordination function (PCF) enabled AP STA transmits the frame after performing backoff if a PCF IFS (PIFS) **416** has elapsed. In this example, the PIFS **416** duration is less than the DIFS **410** but greater than the SIFS **412**. In some aspects, the PIFS **416** is determined by incrementing the SIFS **412** duration by a designated slot time **420**.

FIG. **5** illustrates an example of a timing diagram of a carrier sense multiple access/collision avoidance (CSMA/CA) based frame transmission procedure for avoiding collision between frames in a channel. In FIG. **5**, any one of the wireless communication devices **111**-**115** in FIG. **1** can be designated as one of STA1, STA2 or STA3. In this example, the wireless communication device **111** is designated as STA1, the wireless communication device **112** is designated as STA2, and the wireless communication device **113** is designated as STA3. While the timing of the wireless communication devices **114** and **115** is not shown in FIG. **5**, the timing of the devices **114** and **115** may be the same as that of STA2.

In this example, STA1 is a transmit WLAN device for transmitting data, STA2 is a receive WLAN device for receiving the data, and STA3 is a WLAN device that may be located at an area where a frame transmitted from the STA1 and/or a frame transmitted from the STA2 can be received by the STA3.

The STA1 may determine whether the channel (or medium) is busy by carrier sensing. The STA1 may determine the channel occupation based on an energy level on the channel or correlation of signals in the channel. In one or

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more implementations, the STA1 determines the channel occupation by using a network allocation vector (NAV) timer.

When determining that the channel is not used by other devices during the DIFS **410** (e.g., the channel is idle), the STA1 may transmit an RTS frame **502** to the STA2 after performing backoff. Upon receiving the RTS frame **502**, the STA2 may transmit a CTS frame **506** as a response of the CTS frame **506** after the SIFS **412**.

When the STA3 receives the RTS frame **502**, the STA3 may set a NAV timer for a transmission duration representing the propagation delay of subsequently transmitted frames by using duration information involved with the transmission of the RTS frame **502** (e.g., NAV(RTS) **510**). For example, the STA3 may set the transmission duration expressed as the summation of a first instance of the SIFS **412**, the CTS frame **506** duration, a second instance of the SIFS **412**, a data frame **504** duration, a third instance of the SIFS **412** and an ACK frame **508** duration.

Upon receiving a new frame (not shown) before the NAV timer expires, the STA3 may update the NAV timer by using duration information included in the new frame. The STA3 does not attempt to access the channel until the NAV timer expires.

When the STA1 receives the CTS frame **506** from the STA2, the STA1 may transmit the data frame **504** to the STA2 after the SIFS **412** elapses from a time when the CTS frame **506** has been completely received. Upon successfully receiving the data frame **504**, the STA2 may transmit the ACK frame **508** after the SIFS **412** elapses as an acknowledgment of receiving the data frame **504**.

When the NAV timer expires, the STA3 may determine whether the channel is busy by the carrier sensing. Upon determining that the channel is not used by the other WLAN devices (e.g., STA1, STA2) during the DIFS **410** after the NAV timer has expired, the STA3 may attempt the channel access after a contention window **418** has elapsed. In this example, the contention window **418** may be based on a random backoff.

Note that an ACK frame is sent to acknowledge the successful reception of a frame by a recipient (e.g., STA2). In one or more implementations, a recipient (e.g., STA2) sends a frame referred to as a block acknowledgment (Block Ack, BlockAck or BA) to acknowledge the successful reception of multiple consecutive frames at once. In this example, a Block Ack mechanism improves channel efficiency by aggregating several acknowledgments into one frame. There are two types of Block Ack mechanisms: immediate and delayed. Immediate Block Ack is suitable for high-bandwidth, low-latency traffic while the delayed Block Ack is suitable for applications that tolerate moderate latency. In FIG. **5**, the STA with data to send using the Block Ack mechanism is referred to as the originator, and the receiver of that data as the recipient.

The Block Ack mechanism is initialized by an exchange of add block acknowledgment (ADDBA) Request/Response frames. After initialization, blocks of quality-of-service (QoS) data frames may be transmitted from the originator (e.g., a STA such as an AP) to the recipient (e.g., a STA). A block may be initiated within a polled transmission opportunity (TXOP) or by winning an enhanced distributed channel access (EDCA) contention. The number of frames in the block may be limited, and the amount of state that is to be kept by the recipient may be bounded. The MPDUs within the block of frames are acknowledged by a BlockAck frame, which is requested by a BlockAckReq frame. The Block Ack mechanism does not require the setting up of a traffic stream (TS); however, QoS STAs using the TS facility may select to signal their intention to use the Block Ack mechanism for the scheduler's consideration in assigning TXOPs. Acknowledgments of frames belonging to the same traffic identifier (TID), but transmitted during multiple TXOPs, may also be combined into a single BlockAck frame. The Block Ack mechanism allows the originator to have flexibility regarding the transmission of data MPDUs. The originator may split the block of frames across TXOPs, separate the data transfer and the Block Ack exchange, and interleave blocks of MPDUs carrying all or part of MAC service data units (MSDUs) or aggregate MSDUs (A-MSDUs) for different TIDs or receiving station addresses (RAs).

FIG. **6** illustrates a schematic diagram of an example of a format of a high efficiency (HE) physical layer convergence procedure (PLCP) protocol data unit (HE PPDU) frame **600**. A transmitting STA generates the PPDU frame **600** and transmits the PPDU frame **600** to a receiving STA. The receiving STA receives, detects, and processes the PPDU frame **600**. The PPDU frame **600** includes an L-STF field **601**, an L-LTF field **602**, an L-SIG field **603**, an RL-SIG field **604**, an HE-SIG-A field **605**, an HE-SIG-B field **606**, an HE-STF field **607**, an HE-LTF field **608**, and an HE-DATA field **609**. The HE-SIG-A field **605** includes N_{HESIGA} symbols **610**, the HE-SIG-B field **606** includes N_{HESIGB} symbols **611**, the HE-LTF field **608** includes N_{HELTF} symbols **612**, and the HE-DATA field **609** includes N_{DATA} symbols **613**.

An HE frame may be referred to as an OFDMA frame, a PPDU, a PPDU format, an OFDMA PPDU, an MU PPDU, another similar term, or vice versa. An HE frame may be simply referred to as a frame for convenience. In one or more implementations, an AP may transmit a frame for downlink (DL) using a frame format shown in this figure or a variation thereof (e.g., without any or some portions of an HE header). A STA may transmit a frame for uplink (UL) using a frame format shown in this figure or a variation thereof (e.g., without any or some portions of an HE header).

Referring to FIG. **6**, the HE frame **600** contains a header and a data field. The header includes a legacy header comprised of a legacy short training field (L-STF), a legacy long training field (L-LTF), and a legacy signal (L-SIG) field. These legacy fields contain symbols based on an early design of an IEEE 802.11 specification. The L-STF, L-LTF, and L-SIG fields may be 8 μs, 8 μs, and 4 μs, respectively. Presence of these symbols can make any new design compatible with the legacy designs and products. The legacy header may be referred to as a legacy preamble. In one or more aspects, the term header may be referred to as a preamble.

In one or more implementations, the legacy STF, LTF, and SIG symbols are modulated/carried with FFT size of 64 on a 20 MHz sub-channel and are duplicated every 20 MHz if the frame has a channel bandwidth wider than 20 MHz (e.g., 40 MHz, 80 MHz, 160 MHz). Therefore, the legacy field (i.e., the STF, LTF, and SIG fields) occupies the entire channel bandwidth of the frame. The L-STF field may be utilized for packet detection, automatic gain control (AGC), and coarse frequency-offset (FO) correction. In one aspect, the L-STF field does not utilize frequency domain processing (e.g., FFT processing) but rather utilizes time domain processing. Thus, in one aspect, the L-STF field is not affected by the channel dispersion. The L-LTF field may be utilized for channel estimation, fine frequency-offset correction, and symbol timing. The L-SIG field includes one orthogonal frequency division multiplexing (OFDM) sym-

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bol. Thus, in one aspect, the term L-SIG field may be used interchangeably with L-SIG symbol. In one or more aspects, the L-SIG field may contain information indicative of a data rate and a length (e.g., in bytes) associated with the HE frame **600**, which may be utilized by a receiver of the HE frame **600** to calculate a time duration of a transmission of the HE frame **600**.

The header may also include an HE header comprised of an HE-SIG-A field and an HE-SIG-B field. The HE-SIG-A field may sometimes be referred to simply as a SIG-A field. These fields contain symbols that carry control information that may be vital regarding each PLCP service data unit (PSDU) and regarding the radio frequency (RF), PHY, and MAC properties of a PPDU. Several sub-fields may be located either in the HE-SIG-A and/or HE-SIG-B fields. In one aspect, the HE-SIG-A field can be carried/modulated using an FFT size of 64 on a 20 MHz basis. The HE-SIG-B field can be carried/modulated using an FFT size of e.g., 64 or 256 on a 20 MHz basis depending on implementation. The HE-SIG-A and HE-SIG-B fields may occupy the entire channel bandwidth of the frame. In some aspects, the size of the HE-SIG-A field and/or the HE-SIG-B field is variable. In other words, the number of symbols contained in the HE-SIG-A field and/or HE-SIG-B field can vary from frame to frame. An HE-SIG-B field is not always present in all frames. In some cases, single user (SU) packets and UL trigger-based packets do not contain the HE-SIG-B field. To facilitate decoding of the HE frame **600** by a receiver, the size of (e.g., number of symbols contained in) the HE-SIG-B field may be indicated in the HE-SIG-A field. In some aspects, the HE header also includes a repeated L-SIG (RL-SIG) field, whose content is the same as the L-SIG field.

For a 20 MHz channel, an FFT size of 64 is associated with a discrete Fourier transform (DFT) period of 3.2 μs and a subcarrier spacing of 312.5 kHz. For a 20 MHz channel, an FFT size of 256 is associated with a DFT period of 12.8 μs and a subcarrier spacing of 78.125 kHz. The DFT period may also be referred to as an inverse DFT period (IDFT) or an IDFT/DFT period. The DFT period may be denoted as T_{DFT}. The subcarrier spacing may be referred to as a subcarrier frequency spacing and may be denoted as ΔF. The subcarrier spacing may be obtained by dividing the channel bandwidth by the FFT size. The subcarrier spacing is the reciprocal of the DFT period.

The HE header may further include HE-STF and HE-LTF fields, which contain symbols used to perform necessary RF and PHY processing for each PSDU and/or for the whole PPDU. The HE-LTF symbols may be modulated/carried with an FFT size of 256 for 20 MHz bandwidth and modulated over the entire bandwidth of the frame. Thus, the HE-LTF field may occupy the entire channel bandwidth of the frame. In one aspect, an HE-LTF sequence may be utilized by a receiver to estimate MIMO channel between the transmitter and the receiver. Channel estimation may be utilized to decode data transmitted and compensate for channel properties (e.g., effects, distortions). For example, when a preamble is transmitted through a wireless channel, various distortions may occur, and a training sequence in the HE-LTF field is useful to reverse the distortion. This may be referred to as equalization. To accomplish this, the amount of channel distortion is measured. This may be referred to as channel estimation. In one aspect, channel estimation is performed using an HE-LTF sequence, and the channel estimation may be applied to other fields that follow the HE-LTF sequence.

The HE-STF symbols may have a fixed pattern and a fixed duration. For example, the HE-STF symbols may have a predetermined repeating pattern. In one aspect, the HE-STF symbols do not require FFT processing. The HE frame **600** may include the data field, represented as HE-DATA, that contains data symbols. The data field may also be referred to as a payload field, data, payload, PSDU, or Media Access Control (MAC) Protocol Data Units (MPDU) (e.g., MAC frame).

In one or more aspects, additional one or more HE-LTF fields may be included in the header. For example, an additional HE-LTF field may be located after a first HE-LTF field. The HE-LTF fields may be, for example, modulated/carried with FFT size of 64 on a 20 MHz channel and may be included as part of the first part of the HE frame **600**. In one or more implementations, a TX signal processing unit **280** (or an IFT **284**) illustrated in FIG. **3**A may carry out the modulation described in this paragraph as well as the modulations described in other paragraphs above. In one or more implementations, an RX signal processing unit **290** (or an FT **292**) may perform demodulation for a receiver.

FIGS. **7** through **12** show examples of downlink (DL) frames and uplink (UL) frames. In one aspect of the disclosure below, a downlink frame may refer to a DL OFDMA frame, a HE DL OFDMA frame, a DL OFDMA PPDU, a HE DL OFDMA PPDU, a DL PPDU, a DL MU frame, a DL MU MIMO frame, or vice versa. In one aspect, an uplink frame may refer to a UL OFDMA frame, a HE UL OFDMA frame, a UL OFDMA PPDU, a HE UL OFDMA PPDU, a UL PPDU, a UL MU frame, a UL MU MIMO frame, a MU ACK frame, a MU ACK PPDU, or vice versa. In one aspect, a PPDU refers to a HE PPDU or an OFDMA PPDU. In one aspect, a PPDU is a downlink frame (e.g., **700**) or an uplink frame (e.g., **720**). A frame may refer to a PPDU, a Media Access Control (MAC) Protocol Data Unit (MPDU) MPDU, or an A-MPDU.

In one or more aspects, a DL OFDMA frame (e.g., **700**) is sent to a set of STAs. After a predetermined time period (e.g., SIFS) after the receipt of the DL OFDMA frame, each STA of the same set of the STAs or each STA of a subset of the STAs replies with an individual ACK frame or BA frame in the form of a MU ACK frame (or a UL OFDMA PPDU **720**). In one aspect, a PHY processor **215** or a TX signal processing unit **280** generates the frames and their components shown in FIGS. 7 through **12**.

In FIGS. **7** through **12**, the horizontal dimension represents the time dimension or number of OFDM symbols, whereas the vertical dimension represents the frequency dimension, number of tones or number of sub-carriers. Note that for a given FFT size, the number of tones is given, however, depending on the sub-carrier spacing, two OFDM symbols with e.g., FFT=64 and FFT=256 can occupy the same bandwidth. In one or more implementations of the present disclosure, a sub-band refers to a set of contiguous tones or subcarriers that as a whole are assigned for a payload whose expected destination is a single STA, or a set of STAs. In one or more implementations, a sub-band is a horizontal partition of an OFDMA PPDU or frame where a set of contiguous tones for a contiguous set of OFDM symbols are designated for a given payload whose expected destination is a STA or a set of STAs.

Legacy STF/LTF/SIG (e.g., **701**) are several symbols based on an early design of an IEEE 802.11 specification. Presence of these symbols can make any new design compatible with the legacy designs and products. In one or more implementations, the legacy STF, LTF and SIG symbols are modulated/carried with FFT size of 64 on a 20 MHz sub-channel and are duplicated every 20 MHz if the DL OFDMA PPDU has a bandwidth wider than 20 MHz.

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In one or more aspects, the HE SIG-A and HE SIG-B are symbols that carry control information that may be vital regarding each PSDU and regarding the radio frequency (RF), PHY and MAC properties of the PPDU. In the present disclosure, several fields are located either in HE SIG-A and/or HE SIG-B. The HE SIG-A and HE SIG-B can be carried/modulated using FFT size of 64 or 256 depending on implementation. In some aspects, the HE SIG-B is not present in all UL OFDMA PPDUs.

The HE STF and HE LTF are symbols used to perform necessary RF and PHY processing for each PSDU and/or for the whole PPDU. Depending on whether the HE STF/LTF symbols are beamformed, there may be two sets of such symbols.

FIGS. **7** through **12** illustrate schematic diagrams of examples of downlink and uplink frames in an OFDMA exchange among WLAN devices. With reference to these figures, in one or more implementations, OFDMA-based 802.11 technology is utilized, and for the sake of brevity, a STA refers to a non-AP HE STA, and an AP refers to a HE AP. In one or more aspects, a STA may act as an AP.

In FIGS. **7** through **12**, a reference numeral **700** is used for a DL OFDMA PPDU, a reference numeral **709** is used for a payload section of a DL OFDMA PPDU, a reference numeral **720** is used for a UL OFDMA PPDU, and a reference numeral **726** is used for a payload section of a UL OFDMA PPDU, all for simplicity and convenience. These components with the same reference numerals have certain characteristics that are the same, but as different figures illustrate different examples, the same reference numeral does not indicate that a component with the same reference numeral has the exact same characteristics. While the same reference numerals are used for these components, examples of differences with respect to a component are described in connection with different figures.

In one aspect, a DL OFDMA PPDU **700** is followed by a UL OFDMA PPDU **720** after a predetermined time period (e.g., SIFS) has elapsed. In one aspect, a DL OFDMA PPDU (e.g., **700**) includes a header (e.g., **710**) and a payload (e.g., **709**). In one aspect, a UL OFDMA PPDU (e.g., **720**) includes a header (e.g., **721**) and a payload (e.g., **726**).

In one aspect, a header is referred to as a preamble header, a preamble, a header section, or vice versa. For the sake of brevity, a header may refer to a component of a header. Thus, in one aspect, a header may refer to one or more headers (e.g., a header **710** for headers **701**, **702**, **703** and **704**; a header **701** for legacy STF, LTF and SIG). In one aspect, a header is associated with a bandwidth of a PPDU. In one example, for a given bandwidth (e.g., 80 MHz) of a PPDU, a header is modulated on the entire bandwidth of the PPDU (e.g., entire 80 MHz). In another example, a header is modulated on a sub-channel (e.g., 20 MHz sub-channel) of the bandwidth (e.g., 80 MHz) and the modulated signal is duplicated on each of the remaining sub-channels (e.g., remaining three 20 MHz sub-channels) of the bandwidth.

In one aspect, a payload includes multiple payloads or PSDUs. The term PSDU refers to a PLCP service data unit. A PSDU for downlink (e.g., **705**) is associated with a sub-band of the bandwidth of its PPDU (e.g., **700**) and is modulated using the sub-band rather than the entire bandwidth of the PPDU. A PSDU for uplink (e.g., **722**) is associated with a sub-band of the bandwidth of its PPDU (e.g., **720**) and is modulated using the sub-band rather than the entire bandwidth of the PPDU. In one aspect, the modulation involves inverse Fourier transformation performed, for example, by an inverse Fourier transformer **284** in FIG. **3A**.

A MU ACK frame in the form of an UL OFDMA PPDU **720** includes ACK or BA frames from the STAs (e.g., STAs that receive and determine that an associated payload in the DL OFDMA PPDU **700** has an ACK policy field in a QoS control field set to 00 or "Normal Ack or Implicit Block Ack Request"). For example, STA**1** determines (e.g., detects, searches for, checks, acknowledges and/or verifies) the ACK policy field in the QoS control field included in a PSDU payload **705** of the DL OFDMA PPDU **700** received by STA**1**.

Referring to FIG. **7**, in an example of operation, an AP (e.g., wireless communication device **111**) transmits the DL OFDMA PPDU **700** in a HE PPDU format. In one aspect, the HE PPDU format is comprised of a legacy header, a HE header (e.g., a HE SIG-A **702**, a HE STF/LTF **703**, a HE SIG-B **704**) and a payload section **709** (e.g., PSDUs). In some aspects, the legacy header **701** consists of L-STF, L-LTF and L-SIG. In one aspect, L-STF, L-LTF and L-SIG symbols are modulated with an FFT size of 64 on a 20 MHz sub-channel and the modulated symbols are duplicated on every 20 MHz sub-channel if the DL OFDMA PPDU **700** has a bandwidth wider than 20 MHz.

In one or more implementations, a HE PLCP is composed of all or part of the HE SIG-A **702**, the HE STF/LTF **703** (which are HE STF and HE LTF) and the HE SIG-B **704**. The HE SIG-A **702** is modulated with an FFT size of 64 and duplicated on all of the 20 MHz sub-channels that the DL OFDMA PPDU **700** consists of, if the DL OFDMA PPDU **700** has a bandwidth wider than 20 MHz. The HE STF/LTF **703** and the HE SIG-B **704** are modulated with an FFT size of 256 and modulated over the entire bandwidth of the DL OFDMA PPDU **700**.

The payload section **709** includes payloads (e.g., PSDUs) assigned to multiple STAs, and is modulated using an FFT size of 256. In this regard, the payloads are associated with STA**1**, STA**2**, STA**3**, and STA**4**. For example, the PSDU payload **705** is associated with STA**1**, PSDU payload **706** is associated with STA**2**, PSDU payload **707** is associated with STA**3**, and PSDU payload **708** is associated with STA**4**. The AP transmits the payloads through sub-bands of possibly varying bandwidth, and possibly non-contiguous sub-bands for STAs. In one aspect, each set of sub-bands is associated with its respective PSDU. In one aspect, each set of sub-bands is associated with its respective STA. In one aspect, the number of assigned sets of sub-bands is the same as the number of STAs. In FIG. **7**, the sub-bands assigned to STA**1**, STA**2**, STA**3**, and STA**4** have equal bandwidth and the sub-bands are contiguous; however, the procedure described in the present disclosure does not require contiguous or equal bandwidth for sets of assigned sub-bands.

A DL OFDMA PPDU has a predetermined bandwidth, e.g., 20 MHz, 40 MHz, 80 MHz, 160 MHz, or 80+80 MHz (i.e., two 80 MHz). A sub-band is a portion of the bandwidth of a DL OFDMA PPDU. For example, when the bandwidth of a DL OFDMA PPDU is 20 MHz, and there are four STAs, each of the sub-bands associated with a respective one of the STAs is 5 MHz in bandwidth. When the bandwidth is 40 MHz, each of the four sub-bands associated with a respective one of the four STAs may be 10 MHz in bandwidth. When the bandwidth is 80 MHz, each of the four sub-bands associated with a respective one of the four STAs may be 20 MHz in bandwidth. These are merely examples, and the present disclosure is not limited to these examples. A bandwidth (e.g., 20 MHz, 40 MHz, 80 MHz, 160 MHz, or 80+80 MHz) of a DL OFDMA PPDU may be referred to as a DL bandwidth, a DL PPDU bandwidth, or an overall DL bandwidth. A bandwidth (e.g., 20 MHz, 40 MHz, 80 MHz,

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160 MHz, or 80+80 MHz) of a UL OFDMA PPDU may be referred to as a UL bandwidth, a UL PPDU bandwidth, or an overall UL bandwidth. An overall bandwidth or an entire bandwidth may refer to a DL bandwidth or a UL bandwidth.

Upon the completion of the sequence of (a) the receipt of the DL OFDMA PPDU **700** by the STAs and (b) the passing of the time period of the SIFS, each of the STAs that determines that its ACK policy field in the QoS control field of its PSDU (e.g., data frame) in the DL OFDMA PPDU **700** is set to 00 or "Normal Ack or Implicit Block Ack Request," transmits its ACK or BA frame simultaneously in the format of the UL OFDMA PPDU **720** (which may be referred to as a MU ACK frame). The UL OFDMA PPDU **720** is composed of a legacy PLCP **721** and a payload section **726**, which are transmitted by all of the STAs that participate in forming the MU ACK frame.

In this example, each STA transmits its uplink frame that includes a header (e.g., a legacy PLCP **721**) and its acknowledgment frame (e.g., one of **722**, **723**, **724** or **725** associated with the STA). The UL OFDMA PPDU **720** is an uplink frame that includes a header (e.g., a legacy PLCP **721**) and the acknowledgment frames (e.g., all of **722**, **723**, **724** or **725**) from all of the STAs that participate in forming the MU ACK frame.

For example, STA**1** generates and transmits a first uplink frame comprised of a legacy PLCP **721** and an acknowledgment frame **722** (e.g., an ACK or BA frame), STA**2** generates and transmits a second uplink frame comprised of a legacy PLCP **721** and an acknowledgment frame **723** (e.g., an ACK or BA frame), STA**3** generates and transmits a third uplink frame comprised of a legacy PLCP **721** and an acknowledgment frame **724** (e.g., an ACK or BA frame), and STA**4** generates and transmits a fourth uplink frame comprised of a legacy PLCP **721** and an acknowledgment frame **725** (e.g., an ACK or BA frame). All of the first, second, third and fourth uplink frames are RF combined or aggregated to form a final uplink frame, which is the UL OFDMA PPDU **720**, for the AP. As all of the STAs are synchronized and transmit their respective uplink frames (e.g., the first, second, third and fourth uplink frames) at the same time (e.g., upon the completion of a predetermined time period of SIFS), all of these frames are multiplexed simultaneously into the uplink frame **720**.

In one or more aspects, for an uplink frame, each STA (e.g., each of STA**1**, STA**2**, STA**3** and STA**4**) generates a legacy PLCP **721** utilizing the entire UL channel bandwidth. A legacy PLCP **721** of a STA is associated with the entire UL channel bandwidth (rather than a sub-band). A legacy PLCP **721** of a STA occupies the entire UL channel bandwidth. In one aspect, a STA modulates a legacy PLCP **721** utilizing the entire UL channel bandwidth. For example, if the UL channel bandwidth is 80 MHz, a STA modulates the legacy PLCP with FFT size of 64 on a 20 MHz sub-channel and duplicates the modulated legacy PLCP on the remaining three 20 MHz sub-channels so that the legacy PLCP occupies the entire 80 MHz bandwidth.

In one or more aspects, each STA generates an acknowledgment frame (e.g., **722**, **723**, **724**, or **725**) utilizing a sub-band assigned to the STA (rather than the entire UL channel bandwidth). An acknowledgment frame of a STA is associated with a sub-band (rather than the entire channel bandwidth). An acknowledgment frame of a STA occupies a sub-band assigned to the STA. A sub-band is a portion of a UL channel bandwidth, and a STA modulates an acknowledgment frame utilizing a sub-band.

In one aspect, a baseband processor (e.g., a baseband processor **210** in FIG. **2**, or more specifically, e.g., a MAC processor **211**) of a STA can generate and provide an acknowledgment frame. In one aspect, a baseband processor (e.g., a baseband processor **210** in FIG. **2**, or more specifically, e.g., a PHY processor **215** or a TX signal processing unit **280**) of a STA can generate and facilitate transmission of an uplink frame directed to an AP.

In one aspect, the UL OFDMA PPDU **720** has a bandwidth that is the same as the bandwidth of the preceding DL OFDMA PPDU **700**. The legacy PLCP **721** (of each of the first, second, third and fourth uplink frames) is associated with the bandwidth of the UL OFDMA PPDU **720**. Likewise, the legacy PLCP **721** of the UL OFDMA PPDU **720** is associated with the bandwidth of the UL OFDMA PPDU **720**.

Each of the acknowledgment frames of the STAs is associated with its respective sub-band, where a sub-band is a portion of the bandwidth of the UL OFDMA PPDU **720**.

In some aspects, the legacy PLCP **721** (of each of the first, second, third and fourth uplink frames and the UL OFDMA PPDU **720**) consists of the STF, the LTF and the SIG symbols, which are modulated with an FFT size of 64 on a 20 MHz sub-channel, and the modulated signal is duplicated every 20 MHz sub-channel if the UL OFDMA PPDU **720** has a bandwidth wider than 20 MHz. A legacy PLCP **721** thus utilizes the entire bandwidth (e.g., by duplication as described above).

In one aspect, the payload section **726** has multiple payloads (e.g., PSDUs) for all of the STAs that participate in forming the MU ACK frame, and is modulated using an FFT size of 256. In this regard, a payload is associated with its respective one of STA**1**, STA**2**, STA**3**, and STA**4**. In FIG. **7**, the STA**1**, the STA**2**, the STA**3** and the STA**4** participate in forming the UL OFDMA PPDU **720**. For example, the ACK/BA payload **722** is associated with STA**1**, ACK/BA payload **723** is associated with STA**2**, ACK/BA payload **724** is associated with STA**3**, and ACK/BA payload **725** is associated with STA**4**.

FIG. **8** shows a similar exchange as in FIG. **7** except that a UL OFDMA PPDU **800** has additional signaling between the legacy PLCP **721** and the payload section **726**. In this regard, examples of differences are described in FIG. **8** for purposes of simplicity.

In this configuration, the UL OFDMA PPDU **800** is comprised of not only the legacy PLCP **721** and the payload section **726** but also a partial HE PLCP. In one or more implementations, the partial HE PLCP consists of a HE SIG-A field **801**, which is modulated using an FFT size of 64 and duplicated on all of the 20 MHz sub-channels that the UL OFDMA PPDU **720** consists of. The HE SIG-A field **801** may be present either with multiple symbols or only with a first symbol referred to as a HE SIG-A**1**.

In one aspect, the content of a HE SIG-A field **801** of a UL OFDMA PPDU **800** from an intended STA is already known by the recipient (e.g., AP). In one aspect, the HE SIG-A is useful for unintended STAs to obtain some vital information about the frame and defer properly, and such information can be provided in HE SIG-A or the first symbol of the HE SIG-A. Examples of the above-mentioned vital information are: (a) the duration of the uplink (MU UL) frame and in this the duration of MU ACK frame and (b) an indication whether there can be a (downlink) response frame to the uplink (MU UL) frame. Unintended STA(s) may be one or more STAs that are not intended (or required by the AP) to participate in forming a MU ACK frame; however, they may monitor the wireless medium in order to send their frame. Given the possibility of such unintended STAs, and given that HE SIG-A is encoded robustly so that it can be often

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decoded successfully; the above-mentioned vital information gives some information about the status of the medium to the unintended STAs.

In this example, the bandwidth of the DL OFDMA PPDU **700** and the bandwidth of the subsequent UL OFDMA PPDU **800** are the same. For example, the bandwidth may be 20 MHz where each of the sub-bands assigned to each STA has 5 MHz of bandwidth, or the bandwidth may be 80 MHz where each of the sub-bands has 20 MHz of bandwidth.

FIG. **9** illustrates a schematic diagram of an example of a downlink frame and an uplink frame for an OFDMA exchange among WLAN devices. In this case, the DL OFDMA PPDU **900** includes a header section **710** comprised of the legacy PLCP **701**, the HE SIG-A **702**, the HE STF/LTF **703** and the HE SIG-B **704**. The payload section **709** contains multiple PSDU payloads where PSDU **901** is associated with STA1, PSDU **902** is associated with STA2, PSDU **903** is associated with STA3, PSDU **904** is associated with STA4 and PSDU **905** is associated with STA5. The UL OFDMA PPDU **920** includes the legacy PLCP **721** and the payload section **726**. The payload section **726** includes multiple ACK/BA payloads where ACK/BA payload **921** is associated with STA1, ACK/BA payload **922** is associated with STA2, ACK/BA payload **923** is associated with STA3, ACK/BA payload **924** is associated with STA4, and ACK/BA payload **925** is associated with STA5.

In this case, a similar exchange as in FIG. **7** is illustrated except that the STAs that receive payloads in the DL OFDMA PPDU **900** do not all have the same sub-band bandwidths. For example, the overall (or entire) bandwidth of DL OFDMA PPDU **900** (or UL OFDMA PPDU **920**) may be 40 MHz, where each of the three STAs (e.g., each of STA3, STA4 and STA5) has a sub-band with 10 MHz bandwidth, and each of the two STAs (e.g., each of STA1 and STA2) has a sub-band with 5 MHz bandwidth. In this example, each STA responds with an ACK or a BA frame in the same sub-band that the STA has received its payload in the DL OFDMA PPDU **900** after the SIFS **412** has elapsed. Note that due to different sizes of the sub-bands, one or more of the STAs may need to pad the respective one or more payloads for the ACK or BA frame so that all of the PSDUs formed by the participating STAs in the payload section **726** have an equal time duration. By having the STAs respond with the same sub-band bandwidth as the downlink sub-band bandwidth, the amount of processing and/or overhead may be minimized during the generation of the UL OFDMA PPDU **920** thereby increasing efficiency in the overall acknowledgment mechanism.

FIG. **10** illustrates a schematic diagram of an example of a downlink frame and an uplink frame for an OFDMA exchange among STAs. In this case, the exchange is similar to FIG. **7** and FIG. **9**, except that the STAs that receive payloads in the DL OFDMA PPDU **700** do not all have the same sub-band bandwidths and one of the STAs does not respond with an ACK or BA, for example, because the corresponding ACK policy field in the QoS control field of the DL OFDMA PPDU **700** is not set to "Normal Ack or Implicit Block Ack Request," because the DL PSDU has been received by the STA in error, or because there has been an error or failure in receipt. For example, STA3 does not transmit an uplink frame with an ACK or BA for a UL OFDMA PPDU **1000** because, among others, the STA3 determines that it is instructed not to participate in forming a MU ACK frame (e.g., STA3 did not find the ACK policy field identifying the STA3 as a participant in the MU ACK frame formation), or the associated PSDU (e.g., PSDU payload **904**) has been received in error by the STA3. A PSDU payload may not be received by the corresponding STA due to one or more reasons, including but not limited to, the PSDU was corrupted during transmission, the transmission was impacted by interference, the QoS control field indicated that the ACK policy field was not set for MU ACK participation, etc.

In one or more implementations, the AP does not detect that there is a missing PSDU in one or more received sub-bands assigned to the corresponding STAs, e.g., STA3, and may process the received signal (e.g., the UL OFDMA PPDU **1000**). However, after processing the PSDU in the sub-band location and obtaining the frame check sequence (FCS), the AP (e.g., **210** or **211** of the AP) can identify that neither ACK nor BA is present in the sub-band location. In this regard, and if the AP originally had not set the QoS control field of the DL OFDMA PPDU to "Normal Ack or Implicit Block Ack Request," the AP can determine that the corresponding PSDU (e.g., **904**) can need to be retransmitted for the associated STA (e.g., STA3), and the AP may retransmit the DL OFDMA PPDU that contains the PSDU **904**.

In the process of forming the DL OFDMA PPDU **900** and the UL OFDMA PPDU **1000**, a TXVECTOR parameter and a RXVECTOR parameter are employed (as described with reference to FIG. **2**), each of which is denoted by a subcarriers list, a sub-band list, or an RU list (e.g., SUBCARRIERS_LIST, SUBBAND_LIST, or RU_LIST). The SUBCARRIERS_LIST is a scalar value that may be used in a HE OFDMA PPDU or a HE OFDMA PPDU with a partial PLCP or PHY header. In some aspects, the SUBCARRIERS_LIST in the TXVECTOR/RXVECTOR parameters is a set of scalar values where each scalar value indicates a set of sub-carriers, or equivalently a sub-band or set of sub-bands (where each sub-band is a set of sub-carriers). In one or more implementations, a SUBCARRIERS_LIST is a predetermined list (a priori) known to the AP and all STAs. In this case, the SUBCARRIERS_LIST represents a listing of index values, where each index value represents a corresponding sub-band allocation for a subsequent acknowledgment frame. As such, the AP can only need to indicate an index of the SUBCARRIERS_LIST in order to assign a particular sub-band to a STA.

In one or more implementations, a SUBCARRIERS_LIST is included in a TXVECTOR parameter, and a MAC processor **211** (FIG. **2**) sends the TXVECTOR parameter with the SUBCARRIERS_LIST to a PHY processor **215** so that the PHY processor **215** can determine which set of sub-carriers (or set of sub-bands) is used to place the payload in a DL OFDMA PPDU **900**. In one or more implementations, a SUBCARRIERS_LIST may optionally be included in an RXVECTOR parameter, and a PHY processor **215** sends the RXVECTOR parameter with the SUBCARRIERS_LIST to a MAC processor **211** so that the MAC processor **211** can determine from which set of sub-carriers (or set of sub-bands) of the OFDMA PPDU **1000**, the received payload **726** was obtained.

In forming the UL OFDMA PPDU **1000** (or a MU ACK frame), each participating STA forms a frame in the form of a MU ACK frame, as follows: (a) the legacy PLCP, (b) the partial HE PLCP part (if utilized as shown in, e.g., FIG. **8**), and (c) a PSDU that is to be transmitted on a given sub-band. In this example, the legacy PLCP **721** consists of the STF, LTF and SIG symbols modulated with an FFT size of 64 on a 20 MHz sub-channel and duplicated for every 20 MHz sub-channel if the immediately preceding DL OFDMA PPDU **900** has a bandwidth wider than 20 MHz. In one aspect, the partial HE PLCP part consists of the HE SIG-A

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801 using an FFT size of 64 and duplicated on all of the 20 MHz sub-channels that the immediately preceding DL OFDMA PPDU **900** consists of. The payload section **726** includes PSDUs from participating STAs. A PSDU is a payload for a given STA, and is modulated using an FFT size of 256. Each participating STA forms a portion of the payload section **726** with a PSDU in the sub-band (or sub-carrier) designated by the SUBCARRIERS_LIST of the immediately preceding DL OFDMA PPDU **900**. In one or more implementations, the MU ACK frame is formed without the partial HE PLCP part (e.g., the HE SIG-A **801**).

In one or more aspects, a legacy PLCP **721** of a UL OFDMA PPDU **1000** (or a MU ACK frame) is formed as follows. All of the participating STAs that send an uplink frame that is in the form of a MU ACK frame, form the legacy PLCP **721** (e.g., with an FFT size 64 for the bandwidth of 20 MHz). In some aspects, if the immediately preceding DL OFDMA PPDU **900** has a bandwidth of 40 MHz, then the legacy PLCP **721** includes two identical parts over two 20 MHz channels for a total bandwidth of 40 MHz. In other aspects, if the immediately preceding DL OFDMA PPDU **900** has a bandwidth of 80 MHz, then the legacy PLCP **721** includes four identical parts for a total bandwidth of 80 MHz. In still other aspects, if the immediately preceding DL OFDMA PPDU **900** has a bandwidth of 160 MHz or 80+80 MHz, then the legacy PLCP **721** includes eight identical parts for a total bandwidth of 160 MHz.

The STF and LTF parts (also referred to as L-STF and L-LTF) of the legacy PLCP **721** are formed according to the IEEE 802.11 specifications for HT and VHT compliant WLAN devices. The SIG part (also referred to as L-SIG) is encoded according to the 802.11 specifications for HT and VHT compliant WLAN devices.

In some instances, a STA generates and transmits to the AP an MU ACK frame whose length corresponds or is identical to the length of a frame eliciting the response. For example, in one or more implementations, a L_LENGTH parameter in the TXVECTOR parameter associated with the MU ACK frame is set to a corresponding value indicated in a MUACK-L-LENGTH parameter of a HE control field of the immediately preceding DL OFDMA PPDU **900**. In one aspect, L_LENGTH is a length of a PSDU of a UL OFDMA PPDU **1000**. In one or more implementations, a MUACK-L-LENGTH parameter is indicated in another part of the immediately preceding DL OFDMA PPDU **900**, such as in the HE SIG-A **702** (FIG. 7) or the HE SIG-B **704** (FIG. 7) symbol(s) of the immediately preceding DL OFDMA PPDU **900**. In some aspects, the L_LENGTH parameter in the TXVECTOR parameter associated with the MU ACK frame is set to a value corresponding to MUACKMaxLength. In one or more implementations, the MUACKMaxLength is a fixed value calculated based on a maximum possible length of a BA frame when modulated with MCS0 (e.g., BPSK at coding rate of ½) or MCS1 (e.g., QPSK at coding rate of ½). In some aspects, an AP (e.g., the wireless communication device **111**) announces the parameter MUACKMaxLength during association. In other aspects, the AP announces the MUACKMaxLength in beacon frames. In some other aspects, the MUACKMaxLength parameter is set to a predetermined value (or a fixed value a priori), such that all of the STAs that participate in forming the MU ACK frame are configured to use identical values for the MUACKMaxLength parameter.

In some embodiments, the HE SIG-A **702** or the HE SIG-B **704** symbol(s) of an immediately preceding DL MU PPDU carries an indication of the frame length of the multiplexed ACK/BA responses. In other embodiments, the indication of the frame length of multiplexed ACK/BA frames may be in the form of a maximum duration of the payload of each ACK/BA frame as units of time, such as units of 4 μs or 12 μs. In still other embodiments, the indication of the frame length of multiplexed ACK/BA frames may be in the form of a maximum number of OFDM symbols that a payload of each ACK/BA frame takes. In yet other embodiments, the indication of the frame length of multiplexed ACK/BA frames may be in the form of a multiplier of a unit interval, where the unit interval may be based on the duration that the payload of an ACK frame takes (calculated with the same MCS as the MCS indicated for the given multiplexed ACK/BA responses). Note that the frame length of the multiplexed ACK/BA can be used to calculate MUACK-L-LENGTH.

In one aspect, the partial HE PLCP part of the MU ACK frame that contains the HE SIG-A **801**, if present, is formed with an FFT size 64 for the bandwidth of 20 MHz. In some aspects, only the first symbol of the HE SIG-A **801** symbols, sometimes referred to as HE SIG-A1, is present in the partial HE PLCP part of the MU ACK frame. In some aspects, if the immediately preceding DL OFDMA PPDU **900** has a bandwidth of 40 MHz, then the partial HE PLCP part has two identical parts for a total bandwidth of 40 MHz. In other aspects, if the immediately preceding DL OFDMA PPDU **900** has a bandwidth of 80 MHz, then the partial HE PLCP part has four identical parts for a total bandwidth of 40 MHz. In still other aspects, if the immediately preceding DL OFDMA PPDU **900** has 160 MHz or 80+80 MHz, then the partial HE PLCP part can have eight identical parts for a total bandwidth of 160 MHz.

In some instances, a STA generates and transmits to the AP an MU ACK frame whose channel bandwidth corresponds or is identical to the channel bandwidth of a frame eliciting the response. For example, the encoding of different fields of the HE SIG-A **801** may be with the same values that have been indicated in the immediately preceding DL OFDMA PPDU **900**. Particularly, parameters in the TXVECTOR parameter that are related to HE SIG-A **801** are set to values that are a priori known. However, a channel bandwidth (CH_BANDWIDTH) parameter in the TXVECTOR parameter is set to the same value as the CH_BANDWIDTH in the RXVECTOR parameter associated with the immediately preceding DL OFDMA PPDU **900**. In this example, the CH_BANDWIDTH parameter may represent the channel width (20 MHz or 40 MHz) in which data is transmitted and the transmission format (e.g., HE PPDU format).

In one or more implementations, the fields in the HE SIG-A **801** are encoded with a fixed value that the AP announces during association. The AP may announce the fixed value in beacon frames. Alternatively, the AP may announce the CH_BANDWIDTH parameter as fixed values such that STAs that participate in forming the MU ACK frame use identical values for all of the fields in the HE SIG-A **801** symbols.

In some instances, a STA generates and transmits to the AP an MU ACK frame whose GI corresponds or is identical to the GI type of a frame eliciting the response. For example, in one or more implementations, in forming a HE PLCP and/or PSDU part of a MU ACK frame, a participating STA (e.g., **210** or **211** of a STA) sets a GI_TYPE parameter in the TXVECTOR parameter associated with the MU ACK frame carried in the HE PPDU format (with partial PLCP or preamble header as described above) to a value corresponding to a counterpart GI_TYPE parameter in the RXVECTOR parameter of a frame eliciting the response. In some

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aspects, a STA (e.g., **210** or **211** of a STA) sets the GI_TYPE parameter in the TXVECTOR parameter associated with a MU ACK frame carried in the HE PPDU format (with partial PLCP or preamble header as described above) to a LONG_GI type, which indicates that short GI is not used in the packet. The GI_TYPE set to LONG_GI may be formed with an FFT size of 256. The LONG_GI parameter may include values such as 1.6 μs or 3.2 μs depending on implementation.

In an UL OFDMA PPDU **1000**, there may be another symbol that is called HE LTF and its role is to assist the receiver to decode the payload. In FIGS. **7-10**, HE LTF is not shown for brevity. STA creates the portion of HE LTF that is associated with its assigned sub-band. HE LTF may be in various short or long formats; however, all the STAs need to use the same format for a single UL OFDMA PPDU. Hence, there are multiple embodiments in order to align the format of the HE LTF across all STAs.

In one or more implementations, all the STAs that respond with an ACK or BA frame in the form of an UL OFDMA PPDU can select the same HE LTF format (i.e., long HE LTF or compressed HE LTF) and construct the HE LTF according to this format indication. In one embodiment, the format may be indicated by the AP in the preceding DL OFDMA PPDU or DL MU PPDU (for example in the HE SIG-B symbol of DL PPDU) and all the STAs pick this indicated format to construct the HE LTF symbol of the UL OFDMA PPDU. In another embodiment, each STA can use the same HE LTF format as in the preceding DL OFDMA PPDU or DL MU PPDU. In other words, if the preceding DL OFDMA PPDU or DL MU PPDU utilizes a long HE LTF format then each STA can use a long HE LTF format to construct the HE LTF symbol in the UL OFDMA PPDU, and if the preceding DL OFDMA PPDU or DL MU PPDU utilizes a compressed HE LTF format then each STA can use a compressed HE LTF format to construct the HE LTF symbol in the UL OFDMA PPDU. In another embodiment, the STAs may use a pre-determined format and construct the HE LTF symbol of UL OFDMA frame. There are multiple ways that such pre-determined format may be communicated. For instance, the wireless devices may have such a pre-determined duration value defined/set during manufacture. In another instance, the AP may announce such pre-determined format to each STA during association time. In another instance, the AP may periodically announce such pre-determined format in Beacon frames. In another instance, the AP may use a combination of above methods to announce such pre-determined format and change the value if necessary and re-announce it to its associated STAs.

In some instances, a STA generates and transmits to the AP an MU ACK frame whose format, number of transmit chains, and/or coding type corresponds or is identical to the format, number of transmit chains, and/or coding type of a frame eliciting the response. For example, in some aspects, a participating STA sets a FORMAT parameter in the TXVECTOR parameter associated with the UL OFDMA PPDU **1000** to a value representing HE while the STA sets a N_TX parameter in the TXVECTOR parameter to one, among others. In this example, the N_TX parameter indicates the number of transmit chains. In some implementations, the STA sets a FCC_CODING parameter in the TXVECTOR parameter to BCC_CODING (e.g., binary convolutional code encoding).

In one or more implementations, a STA sets a MCS parameter in the TXVECTOR parameter to a value of zero (e.g., MCS0). In some instances, a STA generates and transmits to the AP an MU ACK frame whose MCS is identical to the MCS of a frame eliciting the response. For example, some aspects, a STA sets the MCS parameter to a value corresponding to a MUACK-MCS parameter indicated by the AP in the immediately preceding DL OFDMA PPDU **900**. The MUACK-MCS parameter may be indicated in the MUACK-MCS field of the HE control field (e.g., see HT control field **807**) of the immediately preceding DL OFDMA PPDU **900**. The AP may announce the MUACK-MCS parameter during association or in beacon frames. In some aspects, the AP sets the MUACK-MCS parameter to a fixed value a priori, such that all of the STAs that participate in forming the MU ACK frame use identical values for the MUACK-MCS parameter.

In forming a PSDU part of the MU ACK frame, the sub-bands in the MU ACK frame that a participating STA uses to place associated PSDUs are based on of the following examples. In some aspects, the STA uses identical sub-bands from the immediately preceding DL OFDMA PPDU **900** that convey the payload for the STA. In other words, a STA that intends to send an MU ACK frame sets the SUBCARRIERS_LIST of the TXVECTOR parameter for the MU ACK frame to the same value as in the SUBCARRIERS_LIST of the RXVECTOR parameter of the immediately preceding DL OFDMA PPDU **900**. In this example, the SUBCARRIERS_LIST in the TXVECTOR parameter uniquely identifies the set of sub-carriers or equivalently the sub-bands that the STA uses.

FIG. **11** illustrates a schematic diagram of an example of a downlink frame and an uplink frame for an OFDMA exchange among WLAN devices. A similar exchange as in FIG. **7** is illustrated in FIG. **11** except that the STAs that receive payloads in the DL OFDMA PPDU **1100** do not all have the same sub-band bandwidths.

In this case, the DL OFDMA PPDU **1100** includes a header section **710** comprised of the legacy PLCP **701**, the HE SIG-A **702**, the HE STF/LTF **703** and the HE SIG-B **704**. The payload section **709** contains multiple PSDU payloads where PSDU **1101** is associated with STA1, PSDU **1102** is associated with STA2, PSDU **1103** is associated with STA3, PSDU **1104** is associated with STA4, PSDU **1105** is associated with STA5 and PSDU **1106** is associated with STA6. Here, each of the PSDUs **1101** and **1102** has a sub-band with 20 MHz bandwidth while each of the remaining PSDUs **1103**-**1106** has a respective sub-band with 10 MHz bandwidth.

The UL OFDMA PPDU **1120** includes a legacy PLCP **721** and a payload section **726**. The payload section **726** includes multiple ACK/BA payloads where ACK/BA payload **1121** is associated with STA1, ACK/BA payload **1122** is associated with STA2, ACK/BA payload **1124** is associated with STA4 and ACK/BA payload **1126** is associated with STA6. In this example, each of the ACK/BA payloads **1121**, **1122**, **1124** and **1126** has a sub-band with 20 MHz bandwidth.

In this example, the bandwidth of the DL OFDMA PPDU **1100** and the bandwidth of the subsequent MU ACK frame **1120** are the same; however, in some situations the bandwidths may be different. Not all of the STAs, which have an associated payload in the DL OFDMA PPDU **1100**, respond with an ACK or BA frame, and some of STAs are not expected, or not instructed, to respond since the corresponding ACK policy field in the QoS control field is not set to "Normal Ack or Implicit Block Ack Request." In addition, the sub-bands, where the ACK/BA frames of the responding STAs are placed within the payload section **726**, are assigned to the STAs in a predetermined manner, which may be different from the received order of the sub-bands in the immediately preceding DL OFDMA PPDU **1100**. For

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example, the set of sub-bands allocated for the ACK/BA frames of the participating STAs is signaled by indexing in the immediately preceding DL OFDMA PPDU **1100**.

In some aspects, this indication by the AP is generated and placed in the HE SIG-A **702** or the HE SIG-B **704** symbols (part of the header **710**) of the immediately preceding DL OFDMA PPDU **1100**. In turn, the STA then sets the SUBCARRIERS_LIST in the TXVECTOR parameter of the MU ACK frame based on the received indication. In such implementations, the STA is responding with a MU ACK frame containing the ACK or BA frame of that STA. Such indexing may be signaled in HE SIG-B symbol of the preceding DL OFDMA PPDU, where the AP indicates the sub-band assignment within the DL OFDMA or DL MU frame and additionally indicates the sub-band index for the upcoming ACK or BA frame within the UL OFDMA frame. For the STA(s) that no immediate ACK or BA is expected, e.g., the QoS control field of the DL OFDMA PPDU is not set to "Normal Ack or Implicit Block Ack Request," a reserved value such as sub-band zero is signaled, indicating that no sub-band is assigned.

It can be noted that the term MU ACK frame as used in the preceding sentence refers to an uplink frame generated by one STA, and such uplink frame comprises a header (e.g., **721**) and one PSDU (e.g., **1121**), where the PSDU is associated with that STA and is associated with its corresponding sub-band. Such uplink frame is in a "form" of a MU ACK frame but does not include PSDUs from other STAs. Thus, in such a situation, a MU ACK frame may refer to an uplink frame (comprising a header and one PSDU) generated by one STA to participate in forming the ultimate MU ACK frame (e.g., **1120**) through RF combination. In another case, the term MU ACK frame may refer to the ultimate uplink frame (e.g., **1120**), which is formed by aggregating and multiplexing multiple uplink frames from multiple STAs. In this latter case, the MU ACK frame (e.g., **1120**) comprises a header and multiple PSDUs. Therefore, the term MU ACK frame can be understood in context, and it may refer to an uplink frame generated by one STA to participate in forming the ultimate MU ACK frame, or it may refer to the ultimate uplink frame formed by aggregating multiple uplink frames generated by multiple STAs.

In one or more aspects, STAs transmit their respective uplink frames at the same time, and these uplink frames are RF combined or aggregated to form a single, ultimate uplink frame (or a single, ultimate MU ACK frame). The AP receives and detects this single, ultimate MU ACK frame.

In some implementations, a STA obtains a MUACK-Sub-band parameter from the HE SIG-A **702** or HE SIG-B **704** symbols of the immediately preceding DL OFDMA PPDU **1100**. In this regard, the STA then sets the SUBCARRIERS_LIST parameter in the TXVECTOR parameter of the MU ACK frame with a value corresponding to the obtained MUACK-Sub-band parameter. In such implementations, the AP (e.g., **210** or **215** of an AP) sets the MUACK-Sub-band field in the HE SIG-A **702** or the HE SIG-B **704** symbol of the DL OFDMA PPDU **1100** to a value that can represent the sub-band allocation for that STA in a subsequent MU ACK frame. In other implementations, the STA (e.g., **210** or **211** of the STA) obtains the MUACK-Sub-band parameter from the RXVECTOR parameter of the immediately preceding DL OFDMA PPDU **1100**.

In one or more implementations, if the AP (e.g., **210** or **211** of an AP) does not set the ACK policy field in the QoS control field to "Normal Ack or Implicit Block Ack Request," then the AP (e.g., **210** or **215** of an AP) sets the MUACK-Sub-band field in the HE SIG-A **702** or HE SIG-B **704** symbol of the DL OFDMA PPDU **1100** to an invalid or reserved value, which implies that the receiving STA does not have a sub-band allocated for sending an ACK or BA in the next MU ACK frame.

On the other hand, if the AP (e.g., **210** or **211** of an AP) sets the ACK policy field in the QoS control field to "Normal Ack or Implicit Block Ack Request" of the frame (e.g., PSDU payload) that is carried for a STA, then the AP (e.g., **210** or **215** of an AP) sets the MUACK-Sub-band field in the HE SIG-A **702** or the HE SIG-B **704** symbol in the DL OFDMA PPDU **1100** to a valid value, which represents a sub-band having been allocated for the ACK or BA frame of that STA.

In one or more implementations, the MUACK-Sub-band parameter included in the HE SIG-A **702** or the HE SIG-B **704** symbol of the DL OFDMA PPDU **1100**, which may carry respective payloads intended for two STAs, is not set to the same value unless the ACK policy field in the QoS control field of the associated frames carried to the two STAs are different than "Normal Ack or Implicit Block Ack Request." The size of the MUACK-Sub-band field may vary depending on implementation, but the size may be set to index all of the allocated sub-bands within a given PPDU bandwidth. For instance, for sub-bands where each sub-band has a bandwidth of 5 MHz, the MUACK-Sub-band field has 2-bit length for PPDUs with 20 MHz bandwidth, has 3-bit length for PPDUs with 40 MHz bandwidth, has 4-bit length for PPDUs with 80 MHz bandwidth, and has 5-bit length for PPDUs with 160 MHz bandwidth.

In some aspects, an implicit indication is used instead of the MUACK-Sub-band parameter to inform each STA which sub-band has been assigned to that STA for placing a corresponding ACK/BA frame.

In one aspect, an AP may identify the number and position of the sub-bands that are allocated for MU ACK frame transmission. This implicit indication may be generated within the HE SIG-B **704** field of the DL OFDMA PPDU **1100** (by, e.g., a PHY processor **215**), where the indication relates to an identification of the number of sub-bands. Note that actual location of the sub-bands may be known a priori by the AP and the STAs, given the bandwidth of the MU ACK frame. For instance, the MU ACK frame may have a 20 MHz bandwidth with nine sub-bands (where each sub-band has a 2 MHz bandwidth), or four sub-bands (where each sub-band has a 4 MHz bandwidth). In this regard, so long as the number of acknowledgment frames (which from the above example is either 9 or 4), or alternatively the bandwidth of acknowledgment sub-bands, is specified by the AP (e.g., by its baseband processor) in the DL OFDMA PPDU **1100**, the STAs can be notified of the location of the sub-bands and corresponding order.

In some aspects, the order may be determined by some convention such as the sub-band with lowest frequency (or smallest sub-carrier or sub-band identification) is assigned index 1, and other sub-bands have an index incremented from index 1. For instance, the MU ACK frame has four sub-bands and, based on a predetermined convention between the AP and STAs, the top sub-band is indexed 1, and the next sub-band is indexed 2, etc., and the bottom sub-band is indexed 6.

Alternatively, the number of sub-bands for ACK/BA frames may be known a priori. For instance, if the AP expects to receive the MU ACK frame with a 20 MHz bandwidth, and each sub-band is expected to have a respective 2 MHz bandwidth, then such a priori convention between the AP and the STAs implicitly identifies the number of sub-bands for ACK/BA multiplexing. Similarly,

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an implicit order of the sub-bands may be understood between the AP and the STAs.

Once the number of the sub-bands for ACK/BA multiplexing and an inherent order of the sub-band are known between the AP and the STAs, then each STA can select the ACK/BA sub-band that has the same index/order as the index/order assigned to the payload of the STA via the HE SIG-B **704** of the preceding DL OFDMA PPDU **1100**. For instance, the MU ACK frame has four sub-bands where the sub-bands from top to bottom are indexed 1, 2, 3 and 4 respectively. The STA whose sub-band assignment in the preceding DL OFDMA PPDU **1100** is listed first can use the ACK/BA sub-band with index 1 in the MU ACK frame. The STA whose sub-band assignment in the preceding DL OFDMA PPDU **1100** is listed second can use the ACK/BA sub-band with index 2 in the MU ACK frame. The STA whose sub-band assignment in the preceding DL OFDMA PPDU **1100** is listed third can use the ACK/BA sub-band with index 3 in the MU ACK frame. Finally, the STA whose sub-band assignment in the preceding DL OFDMA PPDU **1100** is listed fourth can use the ACK/BA sub-band with index 4 in the MU ACK frame.

In another embodiment, each STA uses one of the sub-bands among the set of sub-bands that is assigned to the STA in the preceding DL OFDMA PPDU. For instance, each STA may use the first sub-band with a given bandwidth (e.g., 2 MHz, or 4 MHz or 5 MHz) from the sub-bands that has been assigned to the STA in the preceding DL OFDMA PPDU. In another embodiment, each STA may use the first 2 MHz sub-band from the sub-bands that has been assigned to the STA in the preceding DL OFDMA PPDU. In another embodiment, each STA may use the first 4 MHz sub-band from the sub-bands that has been assigned to the STA in the preceding DL OFDMA PPDU, and if a STA has a narrower sub-band in the preceding DL OFDMA PPDU, then the STA chooses the same sub-band as in the preceding DL OFDMA sub-band. The AP can either indicate that the 2 MHz or 4 MHz sub-band designation for ACK and BA frames within a UL OFDMA PPDU, or in the preceding DL OFDMA PPDU, or broadcasted within Beacon frames, or let each STA know about such designation during association time.

Note that while the bandwidth of the UL OFDMA PPDU **1120** may be the same as the DL OFDMA PPDU **1100**, the bandwidth of the UL OFDMA PPDU **1120** may be narrower than the bandwidth of the DL OFDMA PPDU **1100**. For example, while a DL OFDMA PPDU **1100** has a bandwidth of 80 MHz (e.g., primary 40 MHz and secondary 40 MHz), the UL OFDMA PPDU **1120** may have a bandwidth of 40 MHz only (e.g., primary 40 MHz only). In some aspects, the AP establishes the bandwidth of the MU ACK frame in advance such that the participating STAs are notified of the bandwidth prior to formation of the MU ACK frame. In some examples, the bandwidth of the MU ACK frame may be fixed to a bandwidth of 20 MHz irrespective of the bandwidth of the DL OFDMA PPDU **1100**. In other examples, the bandwidth of the MU ACK frame may be fixed to 40 MHz when the DL OFDMA PPDU **1100** has a bandwidth of 40 MHz or more.

In one or more implementations, the indication of the bandwidth for the MU ACK frame may be performed in one of the following ways: (a) the UL bandwidth may be identified by an indication to all of the STAs either in beacon frames or during association time, or (b) the UL bandwidth may be identified in each DL OFDMA frame within the HE SIG-A **702** or the HE SIG-B **704**. In some implementations, where the bandwidth for all of the sub-bands assigned to ACK or BA frame have been identified to be the same, the total number of the sub-bands for ACK/BA multiplexing is given as part of the indication.

In some implementations, the AP (e.g., **210** or **211** of the AP) partitions the sub-bands for a MU ACK frame such that multiple relatively narrow sub-bands are assigned to ACK frames while multiple relatively wider sub-bands are assigned to BA frames. For example, a sub-band for an ACK frame is narrower than a sub-band for a BA frame. This is due to the fact that the ACK frame is typically shorter than a BA frame. Information relating to such partition may be announced by the AP during association time or in Beacon frames. For instance, in a MU ACK frame with 20 MHz bandwidth, the AP may assign two sub-bands (each sub-band with 4 MHz bandwidth) for BA frames, and five sub-bands (each sub-band with 2 MHz bandwidth) for ACK frames. Such partitioning may allow for more efficient MU ACK frame transmission.

In the above embodiments, the AP assigns sub-bands to the STAs (that have a payload addressed in a DL MU frame and are expected to send an ACK or BA frame in the immediately following MU ACK) in an implicit way so that the STAs place their ACK or BA frames in a unique sub-band (with no chance that another STA picks the same sub-band, hence no chance of collision). However, in the above embodiment, the bandwidth of the sub-band assignment for any ACK frame is the same as any BA frame. Since the ACK frames are typically shorter than BA frames, one outcome of assigning the same bandwidth to these frames causes the STAs that are sending an ACK frame to pad their ACK frame (where padding happens in MAC and/or PHY entities) enough so that the resulted ACK frame has the same length as the BA frame. In another embodiment, the above-mentioned indication may be altered so that different bandwidths are assigned to ACK and BA frames. Such indication may work as follows: First the AP assigns a base bandwidth that is applicable to all STAs. The base bandwidth may be assigned to a sub-field denoted as ACKBABaseBW. In this embodiment those STAs that are going to send an ACK frame use the same base bandwidth; however, those STAs that are going to send a BA frame use twice that bandwidth. For instance, the AP may set ACKBABaseBW to 2 MHz (26-tone sub-band or RU), in which case the STAs that are going to send an ACK frame can use sub-bands with 2 MHz bandwidth and the STAs that are going to send a BA frame can use sub-bands with 4 MHz bandwidth (52-tone RU). To specifically indicate this bandwidth assignment, the AP can assign a sub-field to each STA which is denoted by ACKBW. In some embodiments this sub-field is binary, where the TRUE value indicates that the STA intends to send an ACK frame, hence the STA can use a sub-band with bandwidth ACKBABaseBW. If ACKBW is set to a FALSE value, the ACKBW sub-field then indicates that the STA intends to send a BA frame, hence the STA can use a sub-band with bandwidth twice that of ACKBABaseBW. Since the ACKBW sub-field for each STA appears in the HE SIG-B field of the DL MU frame, each STA gathers the value ACKBW for all the STAs and knows what is the bandwidth used by each STA. Hence, combining that with the order of appearance of the STA sub-band info in the HE SIG-B, each STA can uniquely identify which sub-band to select in order to place its ACK or BA frame.

For instance, the MU ACK frame may have a 20 MHz bandwidth with nine sub-bands each with a 2 MHz bandwidth, or four sub-bands each with s 4 MHz bandwidth. In this example, the AP sets ACKBABW to 2 MHz, 6 STAs have payloads in the DL MU frame, and the third and fourth STAs are expected to respond with a BA frame (hence the

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AP sets the ACKBW sub-field for these STAs to a FALSE value), while the remaining STAs are expected to respond with an ACK frame (hence the AP sets the ACKBW sub-field for these STAs to a TRUE value). Given the above settings, and given that each STA reads the ACKBW of all the STAs, then the following is the sub-band orders that the STAs select (note that the reference of sub-bands to be chosen for ACK/BA is a priori known and for instance starts from the highest-frequency sub-band or from lowest-frequency sub-band depending on implementation):

- The first STA whose sub-band info appears in the HE SIG-B field chooses the first 2 MHz sub-band (given that ACKBW is set to TRUE)
- The second STA whose sub-band info appears in the HE SIG-B field chooses the second 2 MHz sub-band, given that ACKBW is set to TRUE, and prior ACKBW values are: TRUE
- The third STA whose sub-band info appears in the HE SIG-B field chooses a 4 MHz sub-band (i.e., the third and fourth 2 MHz sub-band), given that ACKBW is set to FALSE, and prior ACKBW values are: TRUE, TRUE
- The fourth STA whose sub-band info appears in the HE SIG-B field chooses a 4 MHz sub-band (i.e., the fifth and sixth 2 MHz sub-band), given that ACKBW is set to FALSE, and prior ACKBW values are: TRUE, TRUE, FALSE
- The fifth STA whose sub-band info appears in the HE SIG-B field chooses a 2 MHz sub-band (i.e., the seventh 2 MHz sub-band), given that ACKBW is set to TRUE, and prior ACKBW values are: TRUE, TRUE, FALSE, FALSE
- The sixth STA whose sub-band info appears in the HE SIG-B field chooses a 2 MHz sub-band (i.e., the eighth 2 MHz sub-band), given that ACKBW is set to TRUE, and prior ACKBW values are: TRUE, TRUE, FALSE, FALSE, TRUE.
- In above, each prior TRUE value of ACKBW counts as one (order of sub-bands with ACKBABW=2 MHz) and each prior FALSE value of ACKBW counts as two (order of sub-bands with ACKBABW=2 MHz, e.g., twice that bandwidth hence 4 MHz).

In the above embodiment, ACKBW is a binary sub-field and takes two values. However, in general, ACKBW may take more than two values. For instance, a 2-bit representation of ACKBW may be structured as follows: value 00 indicates that there is no sub-band assigned to the DL payload, value 01 indicates that the sub-band assigned to the DL payload has the same bandwidth as indicated in ACKBABW, value 10 indicates that the sub-band assigned to the DL payload has twice the bandwidth as indicated in ACKBABW, and value 11 indicates that the sub-band assigned to the DL payload has three times the bandwidth as indicated in ACKBABW. Similar to the example described above, each STA that has a payload may determine its sub-band by observing the ACKBW values for all the STAs whose DL payload has been indicated earlier in the HE SIG-B of the DL MU frame. Note that the value 00 for ACKBW as described above is used when the ACK Policy field in the QoS control field in a DL payload is set to "No Ack" or "Block Ack."

With respect to FIGS. **7-11**, it is possible to convey the necessary information for carrying the information for ACK/BA responses for all STAs in a separate frame that is assigned to a sub-band. Such frame is denoted as a Trigger frame and it has information such as: the duration of the MU ACK (or the multiplexed ACK/BA responses as shown in FIGS. **7-11**), the sub-band assignments for each of the payloads, the MCS/NSS for each of the STAs, etc.). The presence of a Trigger frame may be indicated in HE SIG-A or HE SIG-B as well as the sub-band of the Trigger frame. All the STAs that have a payload in the DL MU frame first decode and interpret HE SIG-A and HE SIG-B and find out whether there is a Trigger frame and then the STAs process and decode their own payload (as indicated in HE SIG-B) as well as the Trigger frame. Then the STAs find out from the Trigger the above-mentioned details that they need in order to multiplex their ACK or BA frame in the subsequent MU ACK frame. In some embodiments, as long as the AP indicates there is a Trigger frame inside the DL MU frame, all the STAs that have captured the DL MU frame can process and decode the Trigger frame and can find out whether there is any assignment for the STA. This means that a STA that has a DL payload can process and decode the Trigger frame (in which case the Trigger frame indicates the information to multiplex their ACK/BA response), as well as the STAs that do not have payloads can process and decode the Trigger frame (in which case the Trigger frame indicates the information to multiplex a data, management, or control frame).

FIG. **12** illustrates a schematic diagram of an example of a downlink frame with a trigger frame in a payload of the downlink frame and an uplink frame. In this case, a DL OFDMA PPDU **1200** includes a header section **1209** comprised of the legacy PLCP **1201** (including the HE SIG-A), the HE SIG-B **703** and the HE STF/LTF **704**. The payload section **1208** contains multiple PSDU payloads where PSDU **1204** is associated with STA1, PSDU **1205** is associated with STA2, PSDU **1206** is associated with STA3 and PSDU **1207** is associated with STA4. Here, each of the PSDUs **1205** and **1207** has a sub-band that is larger than the sub-band of each of the remaining PSDUs **1204** and **1206**.

The UL OFDMA PPDU **1220** includes a legacy PLCP **1221** (with the HE SIG symbol) and a payload section **1226**. The payload section **1226** includes multiple ACK/BA payloads where BA payload **1224** is associated with STA1, BA payload **1223** is associated with STA2, ACK payload **1225** is associated with STA3 and ACK payload **1222** is associated with STA4. In this example, each of the ACK payloads **1222** and **1225** has a sub-band with a bandwidth that is smaller than the sub-band bandwidths of each of the BA payloads **1223** and **1224**.

In some embodiments, the above-mentioned Trigger frame appears in the same sub-band as the DL payload (e.g., as an MPDU within the AMPDU) where the Trigger frame is essentially a single-STA Trigger frame. The Trigger frame provides the above-mentioned information (e.g., the duration and the sub-band assignment, etc. for the same STA that has the payload in that DL sub-band. In some embodiments, the Trigger frame (e.g., **1216**) appears as the first MPDU inside the A-MPDU after which the data/management MPDU follows. In FIG. **12**, the Trigger frame/MPDU is shown as a gray box inside each DL payload in each sub-band. The Trigger frame may identify one or more resource units (or sub-bands) assigned to each of the STAs for transmitting its uplink frame. A STA (e.g., STA1) that receives and processes the DL MU frame (e.g., **1200**) may determine whether there is a payload in a sub-band destined to the STA (e.g., **1204**). The STA first decodes the Trigger frame (e.g., **1216**) and when it obtains the content of the Trigger frame, the STA prepares for sending the ACK or BA (e.g., BA **1224**) or any other appropriate response frame in the sub-band that is indicated in the Trigger frame (and according to other properties mandated by the Trigger frame

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such as the duration/length of the ACK/BA frame). Then the STA processes and decodes the remaining MPDUs in the payload (e.g., **1204**). As described herein, the Trigger frame may thus include scheduling information for a PPDU that carries an immediate acknowledgment. Note that in some embodiments, the STA may perform above-mentioned processing in parallel.

In some aspects, if a BA frame (e.g., **1223**, **1224**) is sent as an immediate response to either an implicit BA request that was carried in an HE OFDMA PPDU (e.g., **1200**), the MU ACK frame (that contains the BA frame) can be carried in a HE PPDU with the setting as described above. The rate and bandwidth of the BA is selected as described above using CODING, MCS, GI parameters of the RXVECTOR parameters of the HE DL OFDMA PPDU in order to set CODING, MCS, GI parameters of the TXVECTOR parameters of the MU ACK frame.

In some aspects, if an ACK frame (e.g., **1222**, **1225**) is sent as an immediate response to either an implicit BA request that was carried in an HE OFDMA PPDU (e.g., **1200**), the MU ACK frame can be carried in HE PPDU with the setting as described above. The rate and bandwidth of the BA is selected as described above using CODING, MCS, GI parameters of the RXVECTOR parameters of the HE DL OFDMA PPDU to set CODING, MCS, GI parameters of the TXVECTOR parameters of the MU ACK frame.

While receiving an MU ACK frame transmitted in the HE PPDU format with details described above, the AP (e.g., **210** or **211** of the AP) uses the RXVECTOR parameter SUBCARRIERS_LIST to identify which STA has responded with ACK and BA frames. The MAC entity (e.g., the MAC processor **211** or the MAC software processing unit **212** and/or the MAC hardware processing unit **213** of the MAC processor **211**) compares the RXVECTOR parameter SUBCARRIERS_LIST with the TXVECTOR parameter SUBCARRIERS_LIST of the preceding HE OFDMA PPDU and identifies which of the STAs has participated in forming the MU ACK. Specifically for ACK frames, the AP does not know which STA has sent the ACK frame since there is no TA field in the received ACK frame (e.g., ACK frame only has RA address). However, in some embodiments where the SUBCARRIERS_LIST of the TX VECTOR of a HE OFDMA PPDU and the SUBCARRIERS_LIST of the TXVECTOR of the immediately following MU ACK are the same for each STA that receives a payload in the HE OFDMA PPDU and participates in forming the MU ACK frame, the AP can compare to verify the presence of the SUBCARRIERS_LIST in the RX VECTOR of the received MU ACK frame. If the BA or ACK frame is not present in the given SUBCARRIERS_LIST of the received MU ACK frame, the AP infers that the STA with the given SUBCARRIERS_LIST (in the DL OFDMA and MU ACK exchange) has not sent an ACK or BA frame. If a BA or ACK frame is present in the given SUBCARRIERS_LIST of the received MU ACK frame, and if the frame is an ACK frame, then the AP can further infer which STA has sent the ACK frame (see FIG. **10**).

While receiving an MU ACK frame transmitted in the HE PPDU format with details described above, an AP transfers a payload (DATA) from a PHY to a local MAC entity with the below PHY-DATA.indication primitive. The primitive provides the following parameter: PHY-DATA.indication (DATA, USER_INDEX). The DATA parameter may be an octet of value X'00' to X'FF'. The USER_INDEX parameter (typically identified as u for a HE STA) is present for a HE UL OFDMA PPDU or a HE UL MU PPDU, and indicates the index of the user in the RXVECTOR to which the accompanying DATA octet applies. Otherwise, USER_INDEX parameter is not present. The PHY-DATA.indication primitive is generated by a receiving PHY entity (e.g., the PHY processor **215** or the RX signal processing unit **290** of the PHY processor **215**) to transfer the received octet of data to the local MAC entity. The time between receipt of the last bit of the last provided octet from the WM and the receipt of the PHY-DATA.indication primitive by the MAC entity is aRxPHYDelay. The effect of receipt of this primitive by the MAC is unspecified.

FIG. **13** illustrates an example of an extended control field **1320** in a HT control field **1300** of a data frame. For convenience, the extended control field **1320** is sometimes referred to as an HE Control extended subfield/field or an HE control subfield/field.

In some embodiments, an AP may use the QoS control field in the MAC header of each MPDU and an extended HT control field (denoted as HE Control Extension (HECE) in the HT control field) in a DL payload to notify a STA (that has a payload in the DL MU frame) about the sub-band that the STA can use to place its ACK or BA frame in the immediately multiplexed-ACK/BA frame. As described herein, the HT control field **1300** may be located in a MAC header of a trigger MPDU within a payload of a multi-user downlink frame (e.g., DL OFDMA PPDU or DL MU MIMO PPDU). In some aspects, the trigger MPDU is a control frame that carries the HT control field **1300** in a payload of the trigger MPDU. In other aspects, the HT control field **1300** is a High Efficiency control field within the MAC header of the trigger MPDU.

In one or more implementations, a STA may use both the QoS control field and the HT control field **1300** (having the HECE subfield **1320**) to convey information relating to the queue size and/or frequency selectivity status of the STA to its associated AP. The HT control field **1300** may include a HE control extension indication (HECEI) field **1311**, which may be located in an HT control middle section **1310** of the HT control field **1300**. The HT control field **1300** includes the HECE subfield **1320**.

Still referring to FIG. **13**, in one aspect, if the HECEI field is set to one, then the HECE subfield **1320** exists; otherwise the HECE does not exist. In one or more implementations, the HECE subfield **1320** carries one or more of the following information: ACK/BA sub-band, LTF Set Index, ULDL, bandwidth, sub-band resolution, length information, MCS and NSS per sub-band (or per each of the sub-bands with the mentioned sub-band resolution), buffer-status or queue size per TID, or alternatively, buffer-status or queue size per AC, quality indicator of the full-band or sub-bands, and sub-channel medium status report. The HECE subfield **1320** may also include an identification subfield to indicate what subset of the listed subfields in **1320** are carried in a specific instance of an HECE in a frame. For each payload in a DL MU frame, an AP may use HECE in the MAC header and fill the designated "ACK/BA sub-band(s)" field with the sub-band(s) that the STA may use to send its ACK or BA frame. The "ACK/BA sub-band(s)" field in HECE may be interpreted as follows: it is present in MAC headers of the MPDUs that are conveyed in a DL MU PPDU. If present, it indicates the sub-band or sub-bands that the AP assigns to the STA in order to place its ACK/BA frame in the multiplexed or MU ACK/BA frame in uplink direction. A sub-band may be referred to as a resource unit. An AP may schedule which STAs to use which sub-bands; hence, an AP may provide uplink multi-user response scheduling information. As described herein, the HECE subfield **1320** may include scheduling information for a trigger-based PPDU

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that carries an immediate acknowledgment. Note that the HECE sub-field **1320** may have additional sub-fields such as "Number of sub-bands," where collectively these sub-fields explicitly identify all the sub-bands that the STA intends to use to place its ACK/BA frame in the UL multiplexed ACK/BA frame. The "sub-channel medium status report" in the HECE subfield **1320** indicates the status of each of the 20 MHz sub-channels that the STA senses before sending a frame that carries the HT control field **1300** and HECE subfield **1320** (or a response frame to an eliciting frame that may request the sub-channel medium status). The frame may occupy the Primary 20 MHz channel, or it may occupy a sub-band or RU within a 20 MHz sub-channel (in an UL MU PPDU). Depending on the immediately preceding frame that elicits the response frame and the bandwidth of the eliciting frame, the STA may perform carrier sensing (CS) or energy detection (ED) on one or more 20 MHz sub-channels that the eliciting frame occupies after which the STA reports the medium status of each of the sensed 20 MHz sub-channels within the HECE subfield **1320** of the response frame. The medium status report may indicate whether the medium is IDLE or BUSY as defined in an IEEE 802.11 specification, or may indicate whether the signal or energy that is sensed in each 20 MHz sub-channel is less than a specified threshold (e.g., an OBSS_PD threshold, or one or more thresholds indicated in the eliciting frame, for instance one or more thresholds from the set of {−82 dBm, −72 dBm, −62 dBm, . . . }). In an embodiment, one or more sub-channel medium status reports may be reported for each 20 MHz sub-channel, where each report corresponds to a predetermined threshold (e.g., a report indicates whether the signal or energy that is sensed in a 20 MHz sub-channel is less than a first threshold and another report indicates whether the signal or energy that is sensed in the same 20 MHz sub-channel is less than a second threshold. In another embodiment, the basis for sub-channel medium status might be a narrower or wider bandwidth than 20 MHz, either as a pre-determined bandwidth basis, or as an indicated bandwidth basis in the eliciting frame. In another embodiment, the basis for sub-channel medium status report is Primary 20 MHz, Primary 40 MHz, Primary 80 MHz, and Secondary 80 MHz where a STA reports the status of one or more of these sub-channels. In an example, an AP may send a trigger frame to a set of STAs. Within the trigger frame the AP may request each STA to send its buffer status in the following UL MU PPDU and/or the AP may request each STA to send sub-channel medium status. Each responding STA then sends its buffer status (per AC or per TID or for all TIDs) in a HE Control (HEC) field of the response frame and/or sends the sub-channel medium status (for each 20 MHz sub-channel) within the same HEC field or in an HEC field of another MPDU within the same response frame (or both reports carried in the HEC field of a QoS Null frame). In an embodiment, a responding STA may send unsolicited sub-channel medium status (for each 20 MHz sub-channel) within the HEC field of an MPDU of the same response frame (or carried in HEC field of a QoS Null frame). In above example, the AP uses the sub-channel medium status reports from each STA to schedule the upcoming DL SU or MU frames or UL MU frames. In an embodiment, the AP does not schedule any DL payload or schedule any UL transmission on one or more 20 MHz sub-channels for a STA, if the STA indicates unfavorable medium status in those sub-channels (e.g., if the report indicates a BUSY status, or if the STA indicates the energy level on the sub-channels is larger than a specified threshold).

As indicated above, length information may be indicated in the HECE subfield **1320**. This length information may be utilized by the receiving STA to indicate the length of the response frame (e.g., the UL MU frame). For example, in one or more implementations, a L_LENGTH parameter in the TXVECTOR parameter associated with the MU ACK frame is set to a corresponding value indicated in a MUACK-L-LENGTH parameter of a HE control field of the immediately preceding DL PPDU. In one aspect, L_LENGTH is a length of a PSDU of a UL OFDMA PPDU. In some aspects, the L_LENGTH parameter in the TXVECTOR parameter associated with the MU ACK frame is set to a value corresponding to MUACKMaxLength. In one or more implementations, the MUACKMaxLength is a fixed value calculated based on a maximum possible length of a BA frame when modulated with MCS0 (e.g., BPSK at coding rate of ½) or MCS1 (e.g., QPSK at coding rate of ½). In some aspects, an AP announces the parameter MUACK-MaxLength during association.

Note that one or more of the above-identified subfields in the HECE subfield **1320** are optional, or may appear based on some indication. Depending on an indicator that appears at a given location, e.g., the beginning of the HECE subfield **1320**, the reported parameters in the remaining portion of the HECE subfield **1320** is indicated, e.g., the HECE subfield **1320** includes a subset of the attributes listed above. For example, with a reserved value appearing in the indicator, the queue size and/or buffer status per AC or all ACs is reported in the HECE subfield **1320**. In another example, with another reserved values appearing in the indicator, an additional indication of the queue size per AC or per TID is reported in the HECE subfield **1320**. In another example, with another reserved value appearing in the indicator, MCS, NSS or some quality indicator (such as SNR or RSSI) is reported in the HECE subfield **1320**. In another example, with another reserved value appearing in the indicator, duration or sub-band assignment of a subsequent response frame is reported in the HECE subfield **1320**. Accordingly, the indicator value in the HECE subfield **1320** indicates the parameters in the HECE subfield **1320**.

When the ULDL subfield in the HECE subfield **1320** is set to one, the indicated values for the MCS and NSS per sub-band in the HECE subfield **1320** are values that the STA intends to employ for each specified sub-band in the next (or one or more subsequent) UL OFDMA PPDUs or UL MIMO PPDUs.

The values provided in the HECE subfield **1320** may be used when an STA intends to participate in forming an upcoming UL OFDMA PPDU or UL MU MIMO PPDU, and the STA intends to notify the AP on which MCS and NSS values are intended to be used in the specified sub-bands provided that the AP creates an assignment for the STA in any of the sub-bands. In this case, the MCS and NSS values may be used by the AP in creating the STA assignment, sub-band assignment, and spatial-stream (SS) assignment of the one or more subsequent UL OFDMA PPDUs or UL MIMO PPDUs. In some aspects, if the AP assigns more than one sub-band with the specified resolution to the STA in the next UL OFDMA PPDU or UL MU MIMO PPDU, then the STA may use the more robust MCS and NSS values across two or more sub-bands.

When the ULDL subfield in the HECE subfield **1320** is set to zero, the indicated values in the HECE subfield **1320** are recommended values directed to the MCS and NSS or some other quality indicators (such as RSSI or SNR) per sub-band for the AP to use in the next (or one or more subsequent) DL OFDMA PPDUs. For example, the MCS and NSS values

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may be a recommendation to the AP on which MCS or NSS values to use for the next DL OFDMA or DL MU MIMO PPDUs. The recommendation of the MCS and NSS values may be interpreted by the AP as solicited or unsolicited values by the AP, depending on the other subfields in the HT control field **1300**. In some aspects, the AP may determine not to include the STA in a next (or one or more subsequent) UL MIMO PPDU or UL OFDMA PPDU based on information reported in the HECE subfield **1320**, particularly with respect to the MCS, NSS and/or queue size values, irrespective of the ULDL value.

In some embodiments, in the MU (or multiplexed) ACK/BA frame that immediately follows a DL MU PPDU, the AP that sends the DL MU PPDU may not assign all the sub-bands to the expecting ACK/BA frames. When the AP leaves some sub-bands unassigned, the AP identifies the unassigned sub-bands in the HE SIG-B of the DL MU PPDU, along with some other attributes of the MU ACK/BA frame such as its duration. Other STAs that have received the DL MU PPDU and decoded the HE SIG-B section of the frame successfully can realize what sub-bands are going to be available in the upcoming MU ACK/BA frame that immediately follows the DL MU PPDU. These STAs can be allowed to send control/management frames (such as Uplink-Request frame, PS-Poll frame, or even a delayed BA from an earlier exchange with AP) or data frame (which may be a QoS null frame that carries queue size and may have the HECE sub-field **1320**) in the unassigned sub-band only if the duration of the frame fits the specified duration of the MU ACK/BA frame.

In other embodiments, the AP that sends the DL MU PPDU may not assign all the sub-bands to the expecting ACK/BA frames and some sub-bands may be assigned to other STAs from which the AP expects to receive a frame (this may be based on prior exchanges the AP had with the STA, based on which the AP expects a short data frame or some control or management frames from the STA). The AP indicates the unassigned sub-bands in the HE SIG-B of the DL MU PPDU, along with some other attributes of the MU ACK/BA frame such as the AID/PAID of the STA assigned with a sub-band by the AP, the duration of the MU ACK/BA frame, etc. The STA whose AID/PAID appears in an MU ACK/BA frame (but did not have a DL payload in the immediately preceding DL MU frame) can be allowed to send control/management frames (such as Uplink-Request frame, PS-Poll frame, or even a delayed BA from an earlier exchange with AP) or data frame (which may be a QoS Null frame that carries queue size and may have the HECE sub-field **1320**) in the assigned sub-band only if the duration of the frame fits the specified duration of the MU ACK/BA frame.

It some embodiments, an MU ACK is invoked for frames other than DL MU frames. For instance, a MU ACK response may be invoked as a response to a frame that is sent as multicast frame where multiple STAs receive the same payload from another STA, e.g., an AP. In such cases, while the DL payload is the same for all (hence the reason sent in multicast format), the STAs may each have a different experience on whether they have decoded the MPDU or MPDUs successfully. While it is more robust if each STA sends its ACK and BA frames in response to multicast frames, it is more efficient if the STAs multiplex their ACK or BA frames with the same principle as described above. Note that since the payload for all the STAs that receive a multicast frame is the same, hence it is expected that either all the STAs respond with ACK frame (if the multicast payload has only one MPDU) or all the STAs respond with BA frame (if the multicast payload has multiple MPDUs).

In some embodiments, after a multicast frame, a MU block acknowledgment request (BAR) frame follows where the AP identifies the list of STAs that expects an acknowledgment response, and assigns to each STA a sub-band to be used for multiplexing their ACK or BA response. Note that the list of STAs identified in the MU BAR may include all the STAs that belong to the multicast group, or may include a subset of the STAs that belong to the multicast group. A sub-band may be referred to as a resource unit. In one or more embodiments, multicast transmission may be associated with group-cast with retry (GCR) service, and a multicast group may refer to a GCR group.

In some embodiments, after a multicast frame, a MU BAR frame follows where the AP identifies the list of STAs that expects an acknowledgment response. Note that the list of STAs identified in the MU BAR may include all the STAs that belong to the multicast group, or may include a subset of the STAs that belong to the multicast group. The AP also identifies the bandwidth (in a field denoted by AcknowledgmentBW) that can be used for multiplexing the ACK or BA response. In this embodiment, the AP does not identify the specific sub-bands for each STA. Rather, given the value of AcknowledgmentBW, each STA is implicitly assigned with a sub-band (among all the sub-bands with bandwidth AcknowledgmentBW) that has the same order as the order of the STA in the above-mentioned list of the STAs (e.g., if the identification of the STA appears in the nth order in the list of the STAs in the MU BAR frame, then the STA chooses the sub-band with bandwidth AcknowledgmentBW that has the order 'n').

In some embodiments, after a multicast frame, the MU ACK frame (or multiplexed ACK frames or multiplex BA frames) follow after an IFS interval. In such embodiments, the multicast group that has been announced by the AP has an inherent order of the STAs. Such inherent order is used to assign the sub-bands to individual STAs for multiplexing their ACK/BA response (in a similar manner as explained above). However, the AP identifies the bandwidth that can be used for multiplexing the ACK or BA response (denote this parameter by MulticastACKBW), where the value of MulticastACKBW may be a priori known to the STAs that belong to a multicast group, e.g., during the announcement of the multicast group. Alternatively, the AP may announce a fixed MulticastACKBW value for all multicast groups (either within the Beacon frame or during association).

In some of the above embodiments, after a multicast frame that has a single MPDU (whether a MU BAR frame is present or not), a MU ACK frame may follow that is multiplexed with several ACK frames. Note that the STAs that have not decoded the multicast payload correctly may not send an ACK frame. The AP (the sender of the multicast payload) can conclude from the presence of an ACK frame in a given sub-band whether a STA has sent the ACK frame. In some of the above embodiments, after a multicast frame that has multiple MPDUs (whether a MU BAR frame is present or not), a MU ACK frame may follow that is multiplexed with several BA frames.

In some embodiments, the MU BAR frame has the same structure as an 802.11-based BlockAckReq frame or Multi-TID BlockAck frame but with the following differences: (a) If Multi-TID BlockAck frame is used, the "Per-TID info" has the identification of each STA (AID or PAID) that is expected to respond. In some embodiments, this field is the only field present in each "BAR Information field." In some of the above embodiments where the identification of STAs

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is not included in a MU BAR frame, the 802.11-based BlockAckReq frame is used, (b) The "BAR Control" field includes AcknowledgmentBW, (c) The "BAR Control" field may include an identification of the multicast group, denoted by MulticastID, (d) The "BAR Control" field includes "Block ACK starting sequence control." Note that "Block ACK starting sequence control" applies to all the STAs that are expected to respond with a BA frame (hence it is present in "BAR Control" instead of each "BA Information field"). Note that in the above embodiments, the "BAR Control" field may have 2-4 octets length in order to accommodate AcknowledgmentBW, MulticastID, and "Block ACK starting sequence control" fields. A frame with the above fields may be denoted as Multicast BAR and may be assigned a new frame sub-type in the MAC header. The RA address of such frame is set to Broadcast address. In the above embodiments, the "BAR ACK Policy" in the "BAR Control" field is set to a FALSE value, which means that the STAs do not set an acknowledgment to the BAR frame. In the above embodiments, the "Multi-TID" bit in the "BAR Control" field may be a reserved field. In some embodiments where the same BAR frame with the same sub-type is used, the Multi-TID bit may be set to a TRUE value to indicate that the BAR frame is a MulticastBAR frame.

FIG. **14** illustrates a schematic diagram of an example of a downlink OFDMA frame **1400** and an uplink MU frame **1420** (or MU ACK frame) from a set of STAs. A similar exchange as in FIG. **7** is illustrated in FIG. **14** except that the STAs that receive payloads in the DL OFDMA PPDU **1400** send an UL MU PPDU. FIG. **7** shows that the MU ACK frame is sent in UL OFDMA format where FIG. **14** shows that the ACK frames are sent in UL MU MIMO format where there are restrictions on the number of spatial streams that each STA uses in the MU ACK frame (more details explained below). Note that in the HE SIG A or HE SIG-B part of the DL OFDMA frame **1400**, the AP indicates whether the ACK/BA frames can be multiplexed with UL OFDMA format or UL MU format.

In FIG. **14**, a DL OFDMA transmission is followed by a PPDU that includes ACKs and/or BAs in the UL MU MIMO format from the STAs that have a payload in the DL OFDMA frame **1400**, where their ACK policy field in the QoS control field is set to 00 or "Normal Ack or Implicit Block Ack Request." First, an AP transmits a DL OFDMA PPDU (e.g., **1400**) in a HE PPDU format. The HE PPDU format is composed of a header **1401** having the Legacy PLCP, the HE PLCP (e.g., HE SIG-A, HE SIG-B) and the PSDU (e.g., **1401**). The AP transmits the payloads through sub-bands of possibly varying bandwidth, and possibly non-contiguous bands for a given STA. After the SIFS from receiving the DL OFDMA PPDU, all the STAs that have their ACK Policy field in the QoS control field is set to 00 or "Normal Ack or Implicit Block Ack Request," transmit their ACK or BA frames simultaneously in UL MU MIMO format, which collectively is called MU ACK. The MU ACK frame (e.g., **1420**) is composed of the Legacy PLCP (e.g., **1421**) including the HE SIG-A symbol, which is transmitted by all the STAs that participate in forming the MU ACK, and the PSDU (e.g., **1424**). Since the ACK/BA frames are sent in the UL MU MIMO format, there are some restrictions on the number of spatial streams (SS) that each STA can use, which are explained below. Note that in the HE SIG A or HE SIG-B part (e.g., **1401**) of the DL OFDMA frame **1400**, the AP indicates whether the ACK/BA frames can be multiplexed with a UL OFDMA format or a UL MU format.

FIG. **15** illustrates a schematic diagram of an example of a downlink frame **1500** and an uplink frame **1420** for a multiuser exchange among WLAN devices. A similar exchange as in FIG. **14** is illustrated in FIG. **15** except that the downlink transmission has a DL MU MIMO format.

FIG. **15** illustrates a DL MU MIMO transmission which is followed by a PPDU that includes ACKs and/or BAs in the UL MU MIMO format from the STAs that have a payload in the DL MU MIMO frame **1500**, where their ACK Policy field in the QoS control field is set to 00 or "Normal Ack or Implicit Block Ack Request." First, an AP transmits a DL MU MIMO frame (e.g., **1500**) in a HE PPDU format. The HE PPDU format is composed of a header **1401** having the Legacy PLCP, the HE PLCP (e.g., HE SIG-A, HE SIG-B) and the PSDU (e.g., **1501**). After the SIFS from receiving the DL MU MIMO PPDU (e.g., **1500**), all the STAs that have their ACK policy field in the QoS control field set to 00 or "Normal Ack or Implicit Block Ack Request," transmit their ACK or BA frames simultaneously in the UL MU MIMO format, which collectively is called a MU ACK. The MU ACK frame (e.g., **1420**) is composed of the Legacy PLCP (e.g., **1421**) including the HE SIG-A symbol, which is transmitted by all the STAs that participate in forming the MU ACK, and the PSDU (e.g., **1424**). Particularly, the MU ACK frame in the UL MU MIMO format has several HE LTF symbols that are denoted as "Set of LTFs" and are explained below. Since the ACK/BA frames are sent in the UL MU MIMO format, there are some restrictions on the number of spatial streams (SS) that each STA can use, which are explained below. Note that in the HE SIG A or HE SIG-B part (e.g., **1401**) of the DL MU MIMO frame **1500**, the AP indicates whether the ACK/BA frames can be multiplexed with the UL OFDMA format or the UL MU format.

In forming the MU ACK frame (e.g., **1420**), the partial HE PLCP part of the frame which consists of HE SIG-A, if present, is formed as with FFT size 64 for the bandwidth of 20 MHz. If the immediately preceding DL OFDMA PPDU (e.g., **1500**) has 40 MHz, then the partial HE PLCP part can have two identical parts with total bandwidth of 40 MHz. If the immediately preceding DL OFDMA PPDU has 80 MHz, then the partial HE PLCP part can have four identical parts with total bandwidth of 40 MHz. If the immediately preceding DL OFDMA PPDU has 160 MHz or 80+80 MHz, then the partial HE PLCP part can have eight identical parts with total bandwidth of 160 MHz. The encoding of different fields of the SIG-A part can be with the same values that has been indicated in the immediately preceding DL OFDMA frame. Particularly, all the parameters in the TXVECTOR that relate to the HE SIG-A are set to values that are a priori known but the parameter CH_BANDWIDTH in the TXVECTOR is set to the same value as in CH_BANDWIDTH in the RXVECTOR of the immediately preceding DL OFDMA PPDU. In other embodiments, the fields in HE SIG-A are encoded with a fixed value that the AP announces, or fixed values such that all the STAs that participate in forming the MU ACK frame can use identical values for all of the fields in the HE SIG-A symbols. In some other embodiments, only the first symbol of the HE SIG-A symbols, sometimes known as HE SIG-A1, is only present in the partial HE PLCP in the MU ACK frame.

In forming the PSDU part of an MU ACK frame, a STA can set the TXVECTOR parameter GI_TYPE of a MU ACK frame carried in the HE PPDU format (with partial PLCP or preamble header as described above) to the RXVECTOR parameter GI_TYPE of a frame eliciting the response. In other embodiments, a STA can set the TXVECTOR parameter GI_TYPE of a MU ACK frame carried in the HE PPDU format (with partial PLCP or preamble header as described

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above) to the LONG_GI (for the FFT size of 256, the LONG_GI may have values such as 1.6 μs or 3.2 μs).

In forming the PSDU part of an MU ACK frame, a STA may set the TXVECTOR parameter FORMAT to HE, set the TXVECTOR parameter N_TX to one, and set the TXVECTOR parameter FCC_CODING to BCC_CODING. The STA also may set the TXVECTOR parameter MCS to value 0 (or MCS0). In other embodiments, a STA may set the TXVECTOR parameter MCS to the value of a MUACK-MCS parameter that has been indicated by the AP in the immediately preceding DL OFDMA frame (e.g., **1400**). The MUACK-MCS parameter is indicated in the MUACK-MCS field of the HE control field of the immediately preceding DL OFDMA frame (e.g., **1400**). In other embodiments, the MCS parameter in the TXVECTOR of the MU ACK frame can be set to the parameter MUACKMCS. The AP announces the parameter MUACKMCS during association, or in Beacon frames. In other embodiments, the parameter MUACKMCS is set to a fixed value a priori, such that all the STAs that participate in forming the MU ACK frame can use identical values for this parameter.

In the embodiments, such as the examples shown in FIG. **14** and FIG. **15**, instead of SUBCARRIERS_LIST, there is a need to indicate what set of LTFs each STA can use to send its ACK/BA frame in the UL MU MIMO format. Each STA that has a payload in the DL MU MIMO frame (e.g., **1500**) and intends to place its ACK/BA frame in the MU ACK/BA after the DL MU MIMO frame, can select a unique index denoted by LTF_index (which is not shared by other STAs in the same DL MU frame) and intends to use this index to define the set of HE LTF symbols (e.g., **1422**) that the STA can place at the beginning of its MU ACK/BA frame as shown in FIG. **14** and FIG. **15**.

In the case of FIG. **15** where the DL MU frame is a DL MU MIMO frame (e.g., **1500**), there is a GID indication in HE SIG-A or HE SIG-B (e.g., **1401**) where it indicates all the STAs that are part of the GID and may have a payload in the DL PPDU. Additionally, there is an order associated per STA in the GID, and if the NSS associated with this order is non-zero, the GID indicates that the STA has a payload in the DL MU MIMO PPDU. Given the GID, the order of each STA in the GID, and whether the associated NSS in the GID is zero or non-zero, each STA that has a payload in the DL MU MIMO frame can select an index, LTF_index, which is used to define the set of HE LTF symbols (e.g., **1422**) that they use.

In some aspects, a HE STA receives a HE DL MU MIMO PPDU (e.g., **1500**) that includes a GID associated with the HE STA and a non-zero NSS associated with the same order as the order of the HE STA in the GID. If the transmitter of the HE DL MU MIMO PPDU has indicated in the HE SIG (e.g., **1401**) that the MU ACK frame can be in the UL MU MIMO format, then the HE STA creates the set of HE LTF symbols (e.g., **1422**) for the MU ACK based on a row index of a P matrix for the LTF symbols where the row index is the same order as the order of the HE STA in the GID of the HE DL MU MIMO PPDU. The row index is the LTF_index and is used to prepare the set of HE LTF symbols that they use.

In the case of FIG. **15** where the DL MU PPDU is a DL OFDMA PPDU (e.g., **1500**), each STA that has a payload in the DL MU MIMO frame and intends to place its ACK/BA frame in the MU ACK/BA after the DL MU frame, selects a unique index (which is not shared by other STAs in the same DL MU frame) and uses the selected index to define the set of HE LTF symbols that the STA can place at the beginning of its MU ACK/BA frame as shown in FIG. **15**. However, unlike FIG. **14**, where there is an explicit index associated with each STA in the GID, there is no such indexing similarly defined in FIG. **15**. In some embodiments, an implicit indication may be used to inform each STA of their LTF_index to be used for a MU ACK/BA frame. Such implicit indication works as follows.

In some aspects, a HE STA that receives a HE DL OFDMA PPDU (e.g., **1400**), where the AID/PAID or any related ID of the HE STA is indicated in the HE SIG-B field (e.g., **1401**) of the HE OFDMA PPDU. If the transmitter of the HE DL OFDMA PPDU has indicated in the HE SIG (e.g., **1401**) that the MU ACK frame (e.g., **1420**) can be in the UL MU MIMO format, then the HE STA creates the set of HE LTF symbols for the MU ACK based on a row index of the P matrix for the LTF symbols, where the row index is the order where the sub-band assignment of the HE STA appears in the DL OFDMA PPDU.

In other aspects, a HE STA that receives a HE DL OFDMA PPDU (e.g., **1400**), where the AID/PAID or any related ID of the HE STA is indicated in the HE SIG-B field (e.g., **1401**) of the HE OFDMA PPDU. If the transmitter of the HE DL OFDMA PPDU has indicated in the HE SIG (e.g., **1401**) that the MU ACK frame (e.g., **1420**) can be in the UL MU MIMO format, the HE SIG symbol of the DL OFDMA PPDU may carry a value called LTF_row (with size of 3 or 4 bits) for each STA whose sub-band assignment appears in the HE SIG-B. Note that if LTF_row is set to a reserved value, then the LTF_row reflects that the HE STA may not send an MU ACK/BA frame. In turn, the HE STA creates the set of HE LTF symbols for the MU ACK based on a row index of the P matrix for the LTF symbols where the row index is the same value as the associated LTF_row for the HE STA (that appears in the HE SIG symbol of the HE DL OFDMA PPDU).

Once the LTF_index is obtained by a HE STA that intends to participate in forming an MU ACK frame, the HE STA prepares the set of LTF symbols (e.g., **1422**) to be used as in FIG. **14** and FIG. **15** as follows. The STA creates a set of HE LTF symbols with possibly 4 μs symbol length (per each LTF symbol) or possibly with 8 μs or 12 μs length depending on implementation. The set of HE LTF symbols are going to be N_LTF symbols, where N_LTF is either the same number as the number of LTF symbols in the previous DL MU MIMO frame, or it is explicitly indicated in the HE SIG symbol of the previous DL MU MIMO frame. In turn, the STA selects the set of LTF symbols from the LTF_index row that are created based on an orthogonal matrix that is denoted by P (Orthogonal P matrix). The Orthogonal P matrix may have many forms. In one embodiment, the P matrix with size four has the following rows: First row of the P matrix is: 1, −1, 1, 1; second row of the P matrix is: 1, 1, −1, 1; third row of the P matrix is: 1, 1, 1, −1; and fourth row of the P matrix is: −1, 1, 1, 1. In another embodiment, the P matrix with size eight has the following rows: First row of the P matrix is: 1, −1, 1, 1, 1, −1, 1, 1; second row of the P matrix is: 1, 1, −1, 1, 1, 1, −1, 1; third row of the P matrix is: 1, 1, 1, −1, 1, 1, 1, −1; fourth row of the P matrix is: −1, 1, 1, 1, −1, 1, 1, 1; fifth row of the P matrix is: 1, −1, 1, 1, −1, 1, −1, −1; sixth row of the P matrix is: 1, 1, −1, 1, −1, −1, 1, −1; seventh row of the P matrix is: 1, 1, 1, −1, −1, −1, −1, 1; and eighth row of the P matrix is: −1, 1, 1, 1, 1, −1, −1, −1. Once a row of the orthogonal P matrix is selected, a HE STA arranges several HE LTF symbols sequentially but the set of LTF symbols get multiplied by the row of the orthogonal P matrix. This set of LTF symbols appear as "Set of HE LTFs" (e.g., **1422**) as in FIG. **14** and FIG. **15**. This operation causes that the set of HE LTF symbols created using two different rows of an orthogonal matrix can be orthogonal.

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Note that while in FIGS. **7**, **14** and **15**, the bandwidth of the MU ACK frame is the same as the DL OFDMA frame, in general it is possible that the bandwidth of the MU ACK is narrower than the BW of the DL OFDMA frame. However, it is expected that the AP establishes the understanding of the bandwidth of the MU ACK ahead of time so that all of the STAs know the bandwidth of the MU ACK that they are going to participate in forming. In one instance, the bandwidth of the MU ACK may be fixed to 20 MHz regardless of the bandwidth of the DL OFDMA frame, or the bandwidth of the MU ACK may be fixed to 40 MHz when DL OFDMA PPDUs has a bandwidth of 40 MHz or more. The indication of the bandwidth of the MU ACK frame can be performed in multiple ways: (a) it may be identified as an indication to all STAs either in Beacon frames or during association time, (b) or it may be identified in each DL OFDMA frame within the HE SIG-A or HE SIG-B, the AP notifies the STAs (that are expecting a DL payload from the AP) of the bandwidth for the expected MU ACK frame. Given the bandwidth of the MU ACK frame, the bandwidth of all the sub-bands assigned to an ACK or a BA frame are the same, and the total number of sub-bands for ACK/BA multiplexing is given in some embodiments.

In forming the partial HE PLCP and/or PSDU part of an MU ACK frame, a STA can set the TXVECTOR parameter GI_TYPE of a MU ACK frame carried in the HE PPDU format (with partial PLCP or preamble header as described above) to the RXVECTOR parameter GI_TYPE of a frame eliciting the response. In other embodiments, a STA can set the TXVECTOR parameter GI_TYPE of a MU ACK frame carried in the HE PPDU format (with partial PLCP or preamble header as described above) to the LONG_GI (for the FFT size of 256, LONG_GI may have values such as 1.6 μs or 3.2 μs). If a BA frame is sent as an immediate response to either an implicit BA request carried in an HE MU PPDU, the MU ACK frame (that contains the BA frame) can be carried in HE PPDU with the setting as described above. The rate and bandwidth of the BA is selected as described above using CODING, MCS, GI parameters of the RXVECTOR parameters of the HE DL OFDMA PPDU in order to set CODING, MCS, GI parameters of the TXVECTOR parameters of the MU ACK frame. If an ACK frame is sent as an immediate response to either an implicit BA request carried in an HE OFDMA PPDU, the MU ACK frame (that contains the BA frame) can be carried in HE PPDU with the setting as described above. The rate and bandwidth of the BA is selected as described above using CODING, MCS, GI parameters of the RXVECTOR parameters of the HE DL OFDMA PPDU in order to set CODING, MCS, GI parameters of the TXVECTOR parameters of the MU ACK frame.

While receiving an MU ACK frame transmitted in the HE PPDU format with details described above, the AP uses the RXVECTOR parameter LTF_Set_Index to identify which STA has responded with ACK and BA frames. The MAC entity compares the RXVECTOR parameter LTF_Set_Index with the order of the TXVECTOR parameter SUBCARRIERS_LIST of the preceding HE OFDMA PPDU sent, and identifies which of the STAs has participated in forming the MU ACK. Specially for ACK frames, the AP does not know which STA has sent the ACK frame since there is no TA field in the received ACK frame (ACK frame only has RA address). However, in some embodiments where the LTF_Set_Index of the TX VECTOR of a HE OFDMA PPDU and the order of SUBCARRIERS_LIST of the TXVECTOR of the immediately following MU ACK are the same for each STA that receives a payload in the HE OFDMA PPDU and that participates in forming the MU ACK frame, the AP can verify the presence of LTF_Set_Index in the RX VECTOR of the received MU ACK frame. If the ACK or BA frame is not present in the given SUBCARRIERS_LIST of the received MU ACK frame, the AP infers the STA that has not sent an ACK or BA frame using the given order of the SUBCARRIERS_LIST (in the DL OFDMA and MU ACK exchange). If a BA or ACK frame is present in the given SUBCARRIERS_LIST of the received MU ACK frame and if the frame is an ACK frame, then the AP can further infer which STA has sent the ACK frame (see FIG. **15**).

Referring back to FIG. **13**, an AP may use both the QoS control field and the HECE sub-field **1320** in a DL payload to inform the STA, that has a payload in the DL MU frame, on where to locate the sub-band that the STA intends to use to place its ACK or BA frame in the immediately multiplexed-ACK/BA frame. To do so, for each payload in a DL MU frame, an AP uses the HECE sub-field **1320** in the MAC header and fills the designated "LTF Set Index" field. Note that the LTF Set Index field may have additional sub-fields such as "Size of LTF Set," where collectively these sub-fields explicitly identify all the right set of LTF symbols that the STA intends to use to place its ACK/BA frame in the UL multiplexed ACK/BA frame. Yet in other embodiments, the AP may add an Action Management frame to the DL data payload (hence forming an AMPDU) where the management frame identifies the sub-bands that the STA intends to use to place its ACK/BA frame in the UL multiplexed ACK/BA frame. The structure of the HT Control (HTC) field and its possible extension is shown in FIG. **13**. When the HECEI field **1311** in the HT Control Middle **1310** is set to 1, then the HECE sub-field exists, otherwise the HECE sub-field does not exist. The HECE sub-field **1320** carries the following information: ACK/BA Sub-bands, LTF Set Index, ULDL, Bandwidth, sub-band resolution, MCS and NSS per all the sub-bands with the mentioned sub-band resolution, queue size per TID, or alternatively queue size per AC. Note that some of above sub-fields are optional or may be skipped since it is also reported in HTC or QoS fields. For instance, in one embodiment, the queue size may only be reported (per an AC or all ACs) in the QoS control field and no indication of queue size is reported in HECE sub-field **1320**. However, in another embodiment, it may be beneficial to have the queue size per AC or per TID, hence these values are reported in the HECE sub-field **1320**.

FIGS. **16A-16C** illustrate flow charts of examples of multi-user aggregation methods for data and control frames. For explanatory and illustration purposes, the example processes **1610**, **1620** and **1630** may be performed by the wireless communication devices **111-115** of FIG. **1** and their components such as a baseband processor **210**, a MAC processor **211**, a MAC software processing unit **212**, a MAC hardware processing unit **213**, a PHY processor **215**, a transmitting signal processing unit **280** and/or a receiving signal processing unit **290**; however, the example processes **1610**, **1620** and **1630** are not limited to the wireless communication devices **111-115** of FIG. **1** or their components, and the example processes **1610**, **1620** and **1630** may be performed by some of the devices shown in FIG. **1**, or other devices or components. Further for explanatory and illustration purposes, the blocks of the example processes **1610**, **1620** and **1630** are described herein as occurring in serial or linearly. However, multiple blocks of the example processes **1610**, **1620** and **1630** may occur in parallel. In addition, the blocks of the example processes **1610**, **1620** and **1630** need not be performed in the order shown and/or one or more of the blocks/actions of the example processes **1610**, **1620** and **1630** need not be performed. Various examples of aspects of

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the disclosure are described below as clauses for convenience. These are provided as examples, and do not limit the subject technology. As an example, some of the clauses described below are illustrated in FIGS. **16A** through **16C**.

Clause A. A station for facilitating multi-user communication in a wireless network, the station comprising: one or more memories; and one or more processors coupled to the one or more memories, the one or more processors configured to cause: determining a control field within a first frame of a downlink transmission for a plurality of stations, wherein the control field is located in a payload section of the first frame, wherein the control field indicates scheduling information for transmitting a second frame; generating the second frame, for a multi-user uplink transmission with the plurality of stations, based on the scheduling information; and providing for transmission of the second frame based on the control field of the first frame as part of the multi-user uplink transmission with the plurality of stations.

Clause B. A non-transitory computer-readable storage medium storing computer-executable instructions that, when executed by one or more processors, cause one or more processors to perform operations, the operations comprising: identifying scheduling information for a plurality of stations to transmit an uplink frame as part of a multi-user uplink transmission with the plurality of stations; generating a downlink frame of a downlink transmission for the plurality of stations, wherein the downlink frame includes a control field located in a payload section of the downlink frame, wherein the control field indicates the scheduling information; and providing for transmission of the downlink frame.

Clause C. A computer-implemented method of facilitating multi-user communication in a wireless network, the method comprising: generating a multi-user frame for downlink transmission directed to a plurality of stations, wherein the multi-user frame includes a control field located in a payload section of the multi-user frame, wherein the control field indicates scheduling information for each of the plurality of stations to transmit an uplink frame as part of a multi-user uplink transmission with the plurality of stations; and providing for transmission the multi-user frame.

In one or more aspects, additional clauses are described below.

A method comprising one or more methods or operations described herein.

An apparatus comprising one or more memories (e.g., **240**, one or more internal, external or remote memories, or one or more registers) and one or more processors (e.g., **210**) coupled to the one or more memories, the one or more processors configured to cause the apparatus to perform one or more methods or operations described herein.

An apparatus comprising means (e.g., **210**) adapted for performing one or more methods or operations described herein.

A computer-readable storage medium (e.g., **240**, one or more internal, external or remote memories, or one or more registers) comprising instructions stored therein, the instructions comprising code for performing one or more methods or operations described herein.

The embodiments provided herein have been described with reference to a wireless LAN system; however, it can be understood that these solutions are also applicable to other network environments, such as cellular telecommunication networks, wired networks, etc.

An embodiment of the present disclosure may be an article of manufacture in which a non-transitory machine-readable medium (such as microelectronic memory) has stored thereon instructions which program one or more data processing components (generically referred to here as a "processor" or "processing unit") to perform the operations described herein. In other embodiments, some of these operations may be performed by specific hardware components that contain hardwired logic (e.g., dedicated digital filter blocks and state machines). Those operations may alternatively be performed by any combination of programmed data processing components and fixed hardwired circuit components.

In some cases, an embodiment of the present disclosure may be an apparatus (e.g., an AP STA, a non-AP STA, or another network or computing device) that includes one or more hardware and software logic structure for performing one or more of the operations described herein. For example, as described above, the apparatus may include a memory unit, which stores instructions that may be executed by a hardware processor installed in the apparatus. The apparatus may also include one or more other hardware or software elements, including a network interface, a display device, etc.

In one aspect, a method may be an operation, an instruction, or a function and vice versa. In one aspect, a clause may be amended to include some or all of the words (e.g., instructions, operations, functions, or components) recited in other one or more clauses, one or more sentences, one or more phrases, one or more paragraphs, and/or one or more claims.

To illustrate the interchangeability of hardware and software, items such as the various illustrative blocks, modules, components, methods, operations, instructions, and algorithms have been described generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application.

A reference to an element in the singular is not intended to mean one and only one unless specifically so stated, but rather one or more. For example, "a" module may refer to one or more modules. An element proceeded by "a," "an," "the," or "said" does not, without further constraints, preclude the existence of additional same elements.

Headings and subheadings, if any, are used for convenience only and do not limit the invention. The word exemplary is used to mean serving as an example or illustration. To the extent that the term include, have, or the like is used, such term is intended to be inclusive in a manner similar to the term comprise as comprise is interpreted when employed as a transitional word in a claim. Relational terms such as first and second and the like may be used to distinguish one entity or action from another without necessarily requiring or implying any actual such relationship or order between such entities or actions.

Phrases such as an aspect, the aspect, another aspect, some aspects, one or more aspects, an implementation, the implementation, another implementation, some implementations, one or more implementations, an embodiment, the embodiment, another embodiment, some embodiments, one or more embodiments, a configuration, the configuration, another configuration, some configurations, one or more configurations, the subject technology, the disclosure, the present disclosure, other variations thereof and alike are for convenience and do not imply that a disclosure relating to such phrase(s) is essential to the subject technology or that such disclosure applies to all configurations of the subject technology. A disclosure relating to such phrase(s) may apply to all configurations, or one or more configurations. A

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disclosure relating to such phrase(s) may provide one or more examples. A phrase such as an aspect or some aspects may refer to one or more aspects and vice versa, and this applies similarly to other foregoing phrases.

A phrase "at least one of" preceding a series of items, with the terms "and" or "or" to separate any of the items, modifies the list as a whole, rather than each member of the list. The phrase "at least one of" does not require selection of at least one item; rather, the phrase allows a meaning that includes at least one of any one of the items, and/or at least one of any combination of the items, and/or at least one of each of the items. By way of example, each of the phrases "at least one of A, B, and C" or "at least one of A, B, or C" refers to only A, only B, or only C; any combination of A, B, and C; and/or at least one of each of A, B, and C.

It is understood that the specific order or hierarchy of steps, operations, or processes disclosed is an illustration of exemplary approaches. Unless explicitly stated otherwise, it is understood that the specific order or hierarchy of steps, operations, or processes may be performed in different order. Some of the steps, operations, or processes may be performed simultaneously. The accompanying method claims, if any, present elements of the various steps, operations or processes in a sample order, and are not meant to be limited to the specific order or hierarchy presented. These may be performed in serial, linearly, in parallel or in different order. It can be understood that the described instructions, operations, and systems can generally be integrated together in a single software/hardware product or packaged into multiple software/hardware products.

The disclosure is provided to enable any person skilled in the art to practice the various aspects described herein. In some instances, well-known structures and components are shown in block diagram form in order to avoid obscuring the concepts of the subject technology. The disclosure provides various examples of the subject technology, and the subject technology is not limited to these examples. Various modifications to these aspects will be readily apparent to those skilled in the art, and the principles described herein may be applied to other aspects.

All structural and functional equivalents to the elements of the various aspects described throughout the disclosure that are known or later come to be known to those of ordinary skill in the art are expressly incorporated herein by reference and are intended to be encompassed by the claims. Moreover, nothing disclosed herein is intended to be dedicated to the public regardless of whether such disclosure is explicitly recited in the claims. No claim element is to be construed under the provisions of 35 U.S.C. § 112, sixth paragraph, unless the element is expressly recited using a phrase means for or, in the case of a method claim, the element is recited using the phrase step for.

The title, background, brief description of the drawings, abstract, and drawings are hereby incorporated into the disclosure and are provided as illustrative examples of the disclosure, not as restrictive descriptions. It is submitted with the understanding that they will not be used to limit the scope or meaning of the claims. In addition, in the detailed description, it can be seen that the description provides illustrative examples and the various features are grouped together in various implementations for the purpose of streamlining the disclosure. The method of disclosure is not to be interpreted as reflecting an intention that the claimed subject matter requires more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive subject matter lies in less than all features of a single disclosed configuration or operation. The following claims are hereby incorporated into the detailed description, with each claim standing on its own as a separately claimed subject matter.

The claims are not intended to be limited to the aspects described herein, but are to be accorded the full scope consistent with the language claims and to encompass all legal equivalents. Notwithstanding, none of the claims are intended to embrace subject matter that fails to satisfy the requirements of the applicable patent law, nor can they be interpreted in such a way.

What is claimed is:

1. A station for facilitating multi-user communication in a wireless network, the station comprising:
   - one or more memories; and
   - one or more processors coupled to the one or more memories, the one or more processors configured to cause:
     - receiving a first frame of a downlink transmission for a plurality of stations;
     - obtaining a control extension indication from a control field included in the first frame;
     - determining whether the control extension indication included in the first frame indicates whether the control field includes a scheduling extension;
     - obtaining scheduling information from the control field when the control extension indication indicates that the control field includes the scheduling extension;
     - generating a second frame for a multi-user uplink transmission with the plurality of stations based on the scheduling information included in the scheduling extension; and
     - transmitting the second frame as part of the multi-user uplink transmission with the plurality of stations.

2. The station of claim 1, wherein the scheduling extension corresponds to a control extension subfield that contains the scheduling information.

3. The station of claim 2, wherein the control extension subfield includes scheduling information for a trigger-based response frame that carries an immediate acknowledgment.

4. The station of claim 2, wherein the control extension subfield of the first frame includes length information that is indicative of a length of the second frame to be transmitted by the station in response to the first frame.

5. The station of claim 2, wherein the control extension subfield contains one or more subfields that correspond to one or more of sub-band allocation information, long-training-field (LTF) set index, uplink-downlink indication, bandwidth information, sub-band resolution, length information, modulation and coding scheme (MCS), buffer status per traffic identifier (TID), queue size per TID, buffer status per access category (AC), queue size per AC, quality indicator of a full-band or one or more sub-bands, and a sub-channel medium status report.

6. The station of claim 5, wherein the control extension subfield includes an identification subfield that indicates what subset of the one or more subfields are carried in a specific instance of the control extension subfield in the first frame.

7. The station of claim 2, wherein the one or more processors are configured to cause:
   - determining whether the scheduling extension exists based on a setting of the control extension indication.

8. The station of claim 7, wherein the one or more processors are configured to cause:
   - determining that the scheduling extension exists when the control extension indication is set to a first value; and

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determining that the scheduling extension does not exist when the control extension indication is set to a second value different from the first value.

9. The station of claim **2**, wherein the control extension subfield of the first frame indicates one or more sub-bands assigned to the station.

10. The station of claim **1**, wherein the second frame includes a first control field and a second control field to convey information relating to one or more of a queue size or a frequency selectivity status of the station to an access point.

11. The station of claim **10**, wherein the first control field corresponds to a quality-of-service (QoS) control field and the second control field corresponds to a high-throughput (HT) control field.

12. The station of claim **10**, wherein the second control field includes a control extension indication field and a control extension subfield that follows the control extension indication field in a header of the second frame.

13. The station of claim **12**, wherein the one or more processors are configured to cause:

determining a medium status on each of one or more sub-bands that the first frame occupies using one or more of carrier sensing or energy detection; and

providing an indication of the determined medium status in a sub-channel medium status report subfield included in the control extension subfield of the second frame.

14. The station of claim **1**, wherein the control field is located in a payload section of the first frame.

15. The station of claim **1**, wherein the control field of the first frame is located in a media access control (MAC) header of a trigger MAC PDU (MPDU) within a payload of the first frame.

16. A non-transitory computer-readable storage medium storing computer-executable instructions that, when executed by one or more processors, cause one or more processors to perform operations, the operations comprising:

generating a downlink frame of a downlink transmission for a plurality of stations, wherein the downlink frame comprises a control field including a control extension indication, wherein the control extension indication indicates whether the control field includes a scheduling extension, and wherein the scheduling extension includes scheduling information for one or more stations of the plurality of stations to transmit a corresponding uplink frame as part of a multi-user uplink transmission; and

providing for transmission of the downlink frame.

17. The non-transitory computer-readable storage medium of claim **16**, wherein the scheduling extension corresponds to a control extension subfield that contains the scheduling information, and

wherein the control extension subfield includes length information that is indicative of a length of an uplink frame to be transmitted by one or more stations of the plurality of stations in response to the downlink frame.

18. The non-transitory computer-readable storage medium of claim **16**, wherein the scheduling extension corresponds to a control extension subfield that contains the scheduling information, and

wherein the control extension subfield contains one or more subfields that correspond to one or more of sub-band allocation information, long-training-field (LTF) set index, uplink-downlink indication, bandwidth information, sub-band resolution, length information, modulation and coding scheme (MCS), buffer status per traffic identifier (TID), queue size per TID, buffer status per access category (AC), queue size per AC, quality indicator of a full-band or one or more sub-bands, and a sub-channel medium status report.

19. The non-transitory computer-readable storage medium of claim **18**, wherein the control extension subfield includes an identification subfield that indicates what subset of the one or more subfields are carried in a specific instance of the control extension subfield in the downlink frame.

20. A station for facilitating multi-user communication in a wireless network, the station comprising:

one or more memories; and

one or more processors coupled to the one or more memories, the one or more processors configured to cause:

generating a multi-user frame for downlink transmission directed to a plurality of stations, wherein the multi-user frame comprises a control field including a control extension indication, wherein the control extension indication indicates whether the control field includes a scheduling extension, and wherein the scheduling extension includes scheduling information for one or more stations of the plurality of stations to transmit a corresponding uplink frame as part of a multi-user uplink transmission; and

providing for transmission the multi-user frame.

* * * * *

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EXHIBIT 7A

Docket No.: 122247-5085 (PATENT)

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of: Ahmad Reza HEDAYAT	Customer No.: 157354
Application No.: 16/203,501	Confirmation No.: 1539
Filed: November 28, 2018	Art Unit: 2412
For: MULTIPLEXING ACKNOWLEDGMENT MESSAGES IN RESPONSE TO DOWNLINK FRAMES	Examiner: Kyaw Z. SOE

Mail Stop – Amendment
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

RESPONSE

Commissioner:

In response to the Office Action dated December 26, 2019, reconsideration and further examination of the above-identified application are respectfully requested based on the following:

Amendments to the Claims are reflected in the listing of claims, which begins on page 2 of this paper.

Remarks begin on page 7 of this paper.

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AMENDMENTS TO THE CLAIMS

This listing of claims will replace all prior versions, and listings, of claims in the application.

LISTING OF CLAIMS:

1. (Currently Amended) A station for facilitating multi-user communication in a wireless network, the station comprising:

one or more memories; and

one or more processors coupled to the one or more memories, the one or more processors configured to cause:

receiving a first frame of a downlink transmission for a plurality of stations;

obtaining ~~scheduling information~~a control extension indication from a control field included in the first frame;

determining whether [[a]] the control extension indication ~~field~~ included in the first frame indicates whether the control field includes [[an]] a scheduling extension;

obtaining ~~additional~~ scheduling information from the control field when the control extension indication ~~field~~ indicates that the control field includes the scheduling extension;

generating a second frame for a multi-user uplink transmission with the plurality of stations based on the scheduling information ~~and~~ included in the ~~additional~~ scheduling ~~information~~extension; and

transmitting the second frame as part of the multi-user uplink transmission with the plurality of stations.

2. (Currently Amended) The station of claim 1, wherein the scheduling extension corresponds to a control extension subfield that contains the ~~additional~~ scheduling information.

3. (Original) The station of claim 2, wherein the control extension subfield includes scheduling information for a trigger-based response frame that carries an immediate acknowledgment.

4. (Original) The station of claim 2, wherein the control extension subfield of the first frame includes length information that is indicative of a length of the second frame to be transmitted by the station in response to the first frame.

5. (Currently Amended) The station of claim 2, wherein the control extension subfield contains one or more subfields that correspond to one or more of sub-band allocation information ~~for acknowledgment/block acknowledgment frames~~, long-training-field (LTF) set index, uplink-downlink indication, bandwidth information, sub-band resolution, length information, modulation and coding scheme (MCS) ~~and number of spatial streams (NSS) per sub-band~~, buffer status per traffic identifier (TID), queue size per TID, buffer status per access category (AC), queue size per AC, quality indicator of a full-band or one or more sub-bands, and a sub-channel medium status report.

6. (Original) The station of claim 5, wherein the control extension subfield includes an identification subfield that indicates what subset of the one or more subfields are carried in a specific instance of the control extension subfield in the first frame.

7. (Currently Amended) The station of claim 2, wherein the one or more processors are configured to cause:

determining whether the ~~control~~ scheduling extension ~~subfield~~ exists based on a setting of the control extension indication ~~field~~.

8. (Currently Amended) The station of claim 7, wherein the one or more processors are configured to cause:

determining that the ~~control~~ scheduling extension ~~subfield~~ exists when the control extension indication ~~field~~ is set to a first ~~binary~~ value; and

determining that the ~~control~~ scheduling extension ~~subfield~~ does not exist when the control extension indication ~~field~~ is set to a second ~~binary~~ value different from the first ~~binary~~ value.

9. (Original) The station of claim 2, wherein the control extension subfield of the first frame indicates one or more sub-bands assigned to the station.

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10. (Original) The station of claim 1, wherein the second frame includes a first control field and a second control field to convey information relating to one or more of a queue size or a frequency selectivity status of the station to an access point.

11. (Original) The station of claim 10, wherein the first control field corresponds to a quality-of-service (QoS) control field and the second control field corresponds to a high-throughput (HT) control field.

12. (Original) The station of claim 10, wherein the second control field includes a control extension indication field and a control extension subfield that follows the control extension indication field in a header of the second frame.

13. (Original) The station of claim 12, wherein the one or more processors are configured to cause:

determining a medium status on each of one or more sub-bands that the first frame occupies using one or more of carrier sensing or energy detection; and

providing an indication of the determined medium status in a sub-channel medium status report subfield included in the control extension subfield of the second frame.

14. (Original) The station of claim 1, wherein the control field is located in a payload section of the first frame.

15. (Original) The station of claim 1, wherein the control field of the first frame is located in a media access control (MAC) header of a trigger MAC PDU (MPDU) within a payload of the first frame.

16. (Currently Amended) A non-transitory computer-readable storage medium storing computer-executable instructions that, when executed by one or more processors, cause one or more processors to perform operations, the operations comprising:

generating a downlink frame of a downlink transmission for a plurality of stations, wherein the downlink frame comprises a control field including a control extension indication, wherein the control extension indication indicates whether the control field includes a scheduling extension, and wherein the scheduling extension includes scheduling information for one or more stations of the plurality of stations to transmit a corresponding uplink frame as part of a multi-user uplink transmission ~~wherein the downlink frame includes a first control field and a second control field included within the first control field, wherein the first control field includes first scheduling information for the plurality of stations to transmit an uplink frame as part of a multi-user uplink transmission with the plurality of stations and the second control field includes second scheduling information indicating one or more sub-bands assigned to the station, wherein the first control field includes an indication to the plurality of stations that indicates whether the first control field contains the second control field~~; and

providing for transmission of the downlink frame.

17. (Currently Amended) The non-transitory computer-readable storage medium of claim 16, wherein the scheduling extension corresponds to a control extension subfield that contains the scheduling information, and

wherein the control extension subfield ~~second control field~~ includes length information that is indicative of a length of an uplink frame to be transmitted by one or more stations of the plurality of stations in response to the downlink frame.

18. (Currently Amended) The non-transitory computer-readable storage medium of claim 16, wherein the scheduling extension corresponds to a control extension subfield that contains the scheduling information, and

wherein the control extension subfield ~~second control field~~ contains one or more subfields that correspond to one or more of sub-band allocation information ~~for acknowledgment/block acknowledgment frames~~, long-training-field (LTF) set index, uplink-downlink indication, bandwidth information, sub-band resolution, length information, modulation and coding scheme (MCS) ~~and number of spatial streams (NSS) per sub-band~~, buffer status per traffic identifier (TID), queue size per TID, buffer status per access category (AC),

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queue size per AC, quality indicator of a full-band or one or more sub-bands, and a sub-channel medium status report.

19. (Currently Amended) The non-transitory computer-readable storage medium of claim 18, wherein the control extension subfield ~~second control field~~ includes an identification subfield that indicates what subset of the one or more subfields are carried in a specific instance of the control extension subfield ~~second control field~~ in the downlink frame.

20. (Currently Amended) ~~A computer-implemented method of facilitating multi-user communication in a wireless network, the method comprising:~~ A station for facilitating multi-user communication in a wireless network, the station comprising:

one or more memories; and

one or more processors coupled to the one or more memories, the one or more processors configured to cause:

generating a multi-user frame for downlink transmission directed to a plurality of stations, wherein the multi-user frame comprises a control field including a control extension indication, wherein the control extension indication indicates whether the control field includes a scheduling extension, and wherein the scheduling extension includes scheduling information for one or more stations of the plurality of stations to transmit a corresponding uplink frame as part of a multi-user uplink transmission~~wherein the multi-user frame includes a first control field and a second control field included within the first control field, wherein the first control field is located in a media access control (MAC) header of a trigger MAC PDU (MPDU) within a payload section of the multi-user frame, wherein the first control field includes first scheduling information for the plurality of stations to transmit an uplink frame as part of a multi-user uplink transmission with the plurality of stations and the second control field includes second scheduling information indicating one or more sub-bands assigned to the station, wherein the first control field includes an indication to the plurality of stations that indicates whether the first control field contains the second control field~~; and

providing for transmission the multi-user frame.

REMARKS

After entry of the foregoing, claims 1-20 are pending in the application, of which claims 1, 16, and 20 are independent claims. Claims 1, 2, 5, 7, 8, and 16-20 are amended herein. These amendments are made without prejudice or disclaimer of subject matter and without conceding the correctness of any rejections, and Applicant respectfully reserves the right to pursue the original, previously presented, or canceled subject matter in this application or continuing applications.

Support for the amendment is found in the original disclosure, including, for example, paragraphs [0170]-[0173] and [0204] and FIG. 13 along with the corresponding description in the specification.

By way of illustration, but not limiting the scope of the claims, FIG. 13 and [0170]-[0173] describe a control field (e.g., 1300) that includes a control extension indication (e.g., 1311). The control field (e.g., 1300) includes a scheduling extension that corresponds to a control extension subfield (e.g., 1320). Paragraph [0204] states, "When the HECEI field 1311 in the HT Control Middle 1310 is set to 1, then the HECE sub-field exists, otherwise the HECE sub-field does not exist."

FIG. 3 of the application is reproduced below simply for convenience.

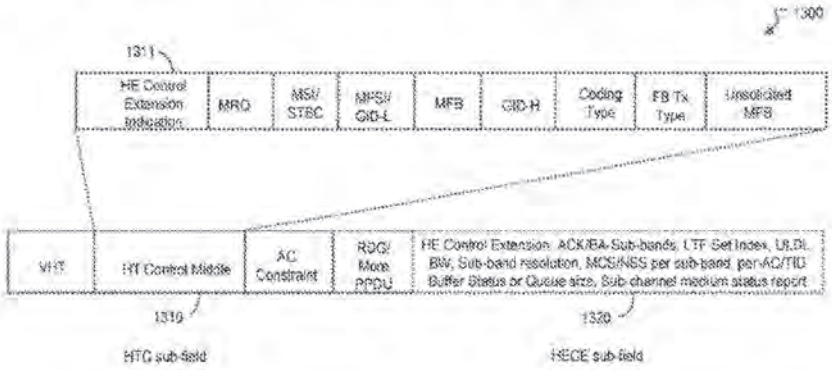


FIG. 13

No new matter is added herein. Reconsideration and further examination are respectfully requested.

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Interview Summary

Applicant would like to thank the Examiner for the thoughtful courtesies extended to Applicant's representative in the telephonic interview held on February 18, 2020. During the interview, the Office Action and the claims as substantially presented herein were discussed, and the Examiner indicated that the claims as substantially presented herein appeared to be in condition for allowance.

Allowable Subject Matter

Applicant would like to thank the Examiner for the indication that claims 1-20 contain allowable subject matter and would be allowable if the double patenting rejections are overcome. As a terminal disclaimer is submitted herein, Applicant respectfully submits that all claims are in condition for allowance.

Double Patenting

Claims 1, 16, and 20 are rejected on the ground of non-statutory double patenting over claims 1, 12, and 18 of U.S. Patent No. 10,181,930 B2. Applicant recognizes that in accordance with 37 CFR § 1.321(c), a terminal disclaimer may be filed to overcome the non-statutory double patenting rejection. Since the application is otherwise believed to be in condition for allowance, in order to expedite prosecution, and without addressing or conceding the merits of the non-statutory double patenting rejections, a terminal disclaimer with respect to U.S. Patent No. 10,181,930 B2 is submitted herewith.

The submission of the terminal disclaimer herewith is not an admission by the Applicant of the propriety of the non-statutory double patenting rejections or that any claims of the present application are not patentably distinct from any claims of U.S. Patent No. 10,181,930 B2. See *Quad Environmental Technologies Corp. v. Union Sanitary District*, 946 F.2d 870, 20 USPQ2d 1392 (Fed. Cir. 1991). Furthermore, Applicant expressly reserves the right to address at a later time, if necessary, whether or not any claims of the present application are patentably distinct from any claims of U.S. Patent No. 10,181,930 B2.

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CONCLUSION

Applicant respectfully submits that the entire application is in condition for allowance, and such action is respectfully requested at the Examiner's earliest convenience. Should the Examiner have any questions, please call the undersigned at the phone number listed below so that any such questions may be promptly resolved.

Any remarks in support of patentability of one claim should not be imputed to any other claim, even if similar terminology is used. Any language or remarks referring to only a portion of a claim should not necessarily be understood to base patentability on solely that portion; rather, patentability rests on each claim taken as a whole.

Applicant respectfully submits that to the extent any disclaimers or statements were made previously during prosecution with respect to the scope of the claimed invention, such disclaimers and statements are hereby rescinded.

Applicant respectfully reserves the right to traverse any of the rejections, assertions and submissions made in connection with the application, even if not discussed herein, including the right to challenge later whether any of the cited references is prior art. The absence of a reply to a specific rejection, issue, or comment does not signify agreement with or concession of that rejection, issue, or comment. In addition, because any arguments made may not be exhaustive, there may be other reasons that have not been expressed for patentability of any or all claims. When amendments are made to any claims, no acquiescence or estoppel is implied thereby; such amendments are made only to expedite prosecution of the present application and are without prejudice to the presentation or assertion, in the future, of claims directed to subject matter that is same as or similar to that previously presented. Nothing in this paper should be construed as an intent to concede, or actual concession of, any issue with regard to any claim, or to any cited art, except as specifically stated in this paper, and the amendment or cancellation of any claim does not necessarily signify concession of unpatentability of the claim prior to its amendment or cancellation.

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To the extent necessary, a petition for an extension of time under 37 C.F.R. 1.136 is hereby made. Please charge any shortage in fees due in connection with the filing of this paper, including extension of time fees, to Deposit Account 50-0310 and please credit any excess fees to such deposit account.

Respectfully submitted,

MORGAN, LEWIS & BOCKIUS LLP

/Soyeon Pak (Karen) Laub/
Soyeon Pak (Karen) Laub, Reg. # 39,266

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ATLAS-00020539

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Application Number:	16203501
International Application Number:	
Confirmation Number:	1539
Title of Invention:	MULTIPLEXING ACKNOWLEDGMENT MESSAGES IN RESPONSE TO DOWNLINK FRAMES
First Named Inventor/Applicant Name:	Ahmad Reza HEDAYAT
Customer Number:	157354
Filer:	Soyeon P. Laub
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Attorney Docket Number:	122247-5085
Receipt Date:	25-MAR-2020
Filing Date:	28-NOV-2018
Time Stamp:	19:57:57
Application Type:	Utility under 35 USC 111(a)

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1		122247-5085_Amendment.pdf	270149 [illegible]	yes	10

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(5) The full width of a distribution measured at half the maximum ordinate. For a normal distribution, FWHM = 2 · (2 ln 2)1/2 = 2.355 times the standard deviation, *s*. (NPS) 325-1996

full width at one-tenth maximum (FW.1M) The full width of a distribution measured at one tenth of the maximum ordinate measured above the background. (NPS) 300-1988r

full width at tenth maximum (FWTM) (x-ray energy spectrometers) Same as full width at half maximum (FWHM), except measurement is made at one tenth of the maximum ordinate rather than one half. (NPS/NID) 759-1984r

full width (duration) half maximum (fiber optics) A measure of the extent of a function. Given by the difference between the two extreme values of the independent variable at which the dependent variable is equal to half of its maximum value. The term "duration" is preferred when the independent variable is time. *Note:* Commonly applied to the duration of pulse waveforms, the spectral extent of emission or absorption lines, and the angular or spatial extent of radiation patterns. (Std100) 812-1984w

fullword *See:* computer word; word.

fully concatenated key *See:* concatenated key.

fully connected network A network in which each node is directly connected with every other node. (LM/COM) 168-1956w

fully decoded EAROM organization An EAROM organization in which rows and columns of memory cells are addressable through on-chip decoding circuitry. (ED) 641-1987w

fully inverted file An file that has been inverted on all secondary keys in the file. *Contrast:* partially inverted file. (C) 610.5-1990w

fully qualified software_spec A `software_spec` that always identifies a software object unambiguously. (C/PA) 1387.2-1995

fully relational Pertaining to a database management system that supports a relational database and a language that provides the functionality of the relational algebra. (C) 610.5-1990w

fume-resistant So constructed that it will not be injured readily by exposure to the specified fume. (SWG/PE/IA/ICTL/IAC) C37.100-1981s, [56], [60]

function (1) (general) When a mathematical quantity u depends on a variable quantity x so that to each value of x (within the interval of definition) there correspond one or more values of u, then u is a function of x written $u = f(x)$. The variable x is known as the independent variable or the argument of the function. When a quantity u depends on two or more variables $x_1, x_2, \ldots x_n$ so that for every set of values of $x_1, x_2, \ldots x_n$ (within given intervals for each of the variables) there correspond one or more values of u, then u is a function of $x_1, x_2, \ldots x_n$ and is written $u = f(x_1, x_2, \ldots x_n)$. The variables $x_1, x_2, \ldots x_n$ are the independent variables or arguments of the function. (Std100) 270-1966w

(2) (vector) When a scalar or vector quantity u depends upon a variable vector V so that if for each value of V (within the region of definition) there correspond one or more values of u, then u is a function of the vector V. (Std100) 270-1966w

(3) (test, measurement, and diagnostic equipment) The action or purpose which a specific item is intended to perform or serve. (MIL) [2]

(4) (A) (software) A defined objective or characteristic action of a system or component. For example, a system may have inventory control as its primary function. **(B) (software)** A software module that performs a specific action, is invoked by the appearance of its name in an expression, may receive input values, and returns a single value. *See also:* subroutine. (C) 610.12-1990

(5) (mathematics of computing) A mathematical entity whose value is uniquely determined by the value of one or more independent variables. (C) 610.2-1987

(6) Normal or characteristic action of a component or the system of which it is a part. (PE/EDPG) 803.1-1992

(7) A task, action, or activity expressed as a verb-noun combination (e.g., Brake Function: stop vehicle) to achieve a defined outcome. (C/SE) 1220-1994s

(8) (software user documentation) A specific purpose of an entity or its characteristic action. (SE/C) 1063-1987r, 1074-1995s

(9) A programming language construct, modeled after the mathematical concept. A function encapsulates some behavior. It is given zero or more arguments as input, performs some processing, and returns some results. Functions are also known as procedures, subprograms, or subroutines. (C/PA) 1327.2-1993w, 1224.2-1993w, 1326.2-1993w, 1328.2-1993w

(10) A logical component of a unit that operates mostly independently. A function is independent of bus interface and node topology: a unit has registers that are externally accessible in the bus address space, a function may or may not. For example, a multi-function node may contain SCSI controller, LAN interface, and terminal interface Functions that are accessed via a shared DMA multiplex Unit. A function may also be a software entity (e.g., a Function driver), especially when messages are used for Processor-to-Processor communication. (C/MM) 1212.1-1993

(11) A primitive operation on system-controlled resources. This standard defines a collection of functions together with suitable input and output parameters. (C/MM) 855-1990

(12) A task, action, or activity that must be accomplished to achieve a desired outcome. (C/SE) 1233-1998

(13) A single-valued mapping. The mapping `M` from `D` to `R` is a *function* if for any `X` in `D` and `Y` in `R`, there is at most one pair [`X`, `Y`] in `M`. *Synonym:* single-valued. *Contrast:* multivalued. (C/SE) 1320.2-1998

(14) A transformation of inputs to outputs, by means of some mechanisms, and subject to certain controls, that is identified by a function name and modeled by a box. *Synonyms:* activity; task; process; operation. (C/SE) 1320.1-1998

(15) (scheme programming language) *See also:* procedure. (C/MM) 1178-1990r

functional A link interface becomes functional when the start-up procedure has successfully completed and the link interface is ready to transmit data. (C/BA) 1355-1995

functional address (FA) (1) The portion of a full data transport address that specifies the read or write function that is to be performed. (IM/ST) 1451.2-1997

(2) (local area networks) A bit-significant address used in the ISO/IEC 8802-5 MAC format to identify well-known functional groups. (C) 8802-12-1998

functional address instruction An instruction whose format contains no operation field because the operation is implicitly specified by its address fields. (C) 610.10-1994w

functional adjectives (A) (pulse terminology) Linear. Pertaining to a feature whose magnitude varies as a function of time in accordance with the following relation or its equivalent:

$$m = a + bt$$

(B) (pulse terminology) Exponential. Pertaining to a feature whose magnitude varies as a function of time in accordance with either of the following relations or their equivalents:

$$m = ae^{-bt}$$

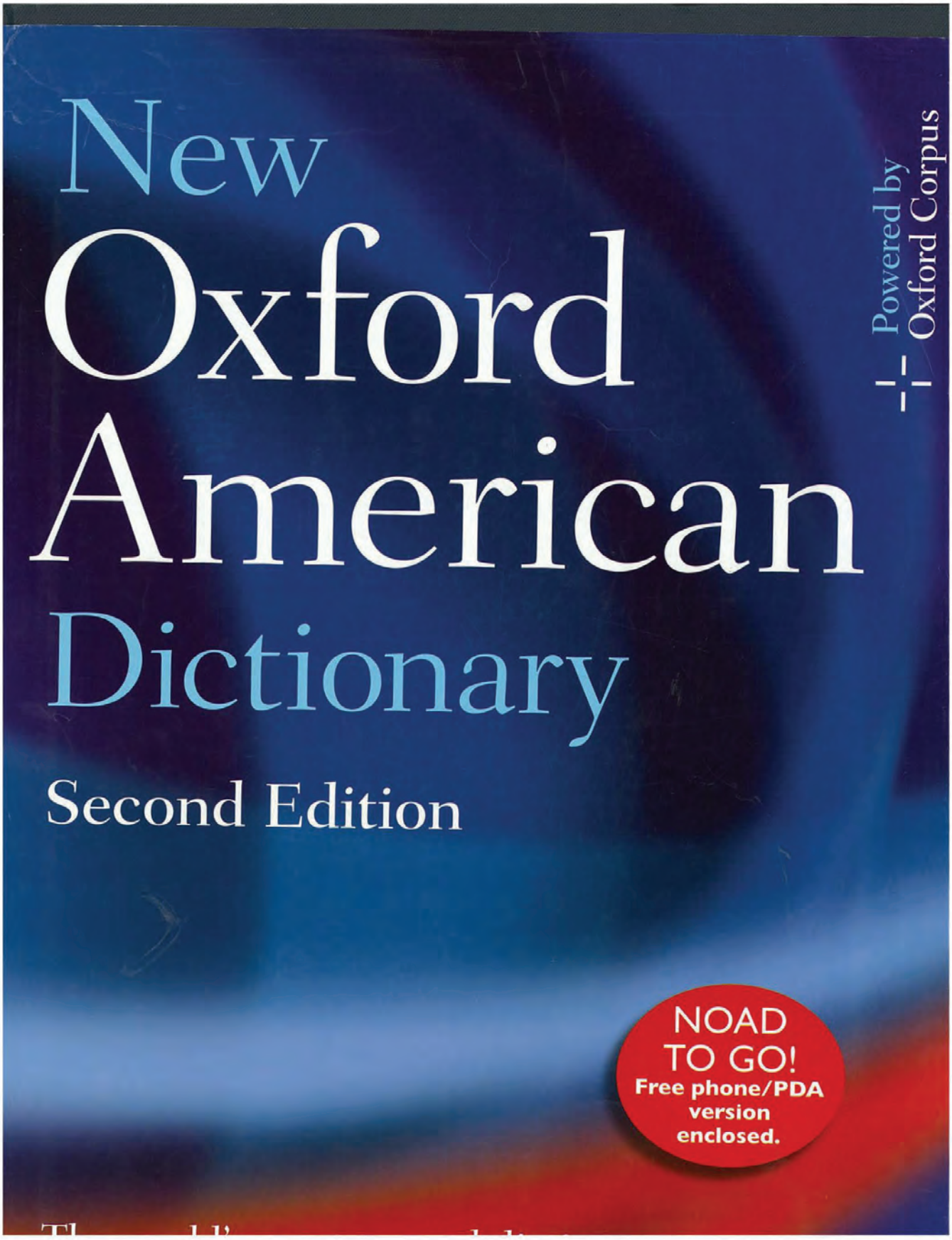
$$m = a\,(1 - e^{-bt})$$

(C) (pulse terminology) Gaussian. Pertaining to a waveform or feature whose magnitude varies as a function of time in accordance with the following relation or its equivalent:

$$m = ae^{-b\,(t-c)^2},\ b > 0$$

(D) (pulse terminology) Trigonometric. Pertaining to a waveform or feature whose magnitude varies as a function of time in accordance with a specified trigonometric function or by a specified relationship based on trigonometric functions (for example, cosine squared). (IM/WM&A) 194-1977

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Ful·ton /'fo͝oltn/, Robert (1765–1815), U.S. inventor; pioneer of the steamship. He constructed a steam-propelled "diving-boat" in 1800, which he submerged to a depth of 25 feet (7.6 m). In 1806, he built the first successful paddle steamer, the *Clermont*. Eighteen other steamships were subsequently built, inaugurating the era of commercial steam navigation.

ful·vic ac·id /'fo͝olvik; 'fo͝ol-/ ▸*n.* a highly soluble organic phenol found in humus that chelates elemental mineral nutrients.

ful·vous /'fo͝olvəs; 'fəl-/ ▸*adj.* reddish yellow; tawny. ▷mid 17th cent.: from Latin *fulvus* + **-ous**.

Fu Man·chu /'fo͞o man'CHo͞o/ (in full **Fu Manchu mustache**) ▸*n.* a long narrow mustache in which the ends taper and droop down to the chin. ▷mid 20th cent.: the kind of mustache worn by *Fu Manchu*, a master criminal in the novels of British writer Sax Rohmer (1883–1959).



Fu Manchu

fu·mar·ic ac·id /fyo͞o'marik/ ▸*n.* *Chemistry* a crystalline acid, isomeric with maleic acid, present in fumitory and many other plants. • Alternative name: ***trans*-butenedioic acid**; chem. formula: HOOCCH=CHCOOH. ▷mid 19th cent.: *fumaric* from modern Latin *Fumaria* 'fumitory' + **-ic**. —**fu·ma·rate** /'fyo͞oməˌrāt/ *n.*

fu·ma·role /'fyo͞oməˌrōl/ ▸*n.* an opening in or near a volcano, through which hot sulfurous gases emerge. ▷early 19th cent.: from obsolete Italian *fumariuolo*, from late Latin *fumariolum* 'vent, hole for smoke,' a diminutive based on Latin *fumus* 'smoke.' —**fu·ma·rol·ic** /ˌfyo͞oməˈrälik/ *adj.*

fum·ble /'fəmbəl/ ▸*v.* [*intrans.*] use the hands clumsily while doing or handling something: *she fumbled with the lock.* ■ (of the hands) do or handle something clumsily: *her hands fumbled with the waistband of his trousers.* ■ **(fumble around/about)** move clumsily in various directions using the hands to find one's way: *Greg fumbled around in the closet and found his black jacket.* ■ [*trans.*] use the hands clumsily to move (something) as specified: *she fumbled a cigarette from her bag.* ■ [*trans.*] *Football* drop or lose control of (the ball), sometimes causing a turnover: *he seldom fumbled a ball.* ■ [*trans.*] (in other ball games) fail to catch or field (the ball, a pass, a shot, etc.) cleanly. ■ express oneself or deal with something clumsily or nervously: *asked for explanations, Michael had fumbled for words.*

▸*n.* [usu. *in sing.*] an act of using the hands clumsily while doing or handling something: *just one fumble during a tire change could separate the winners from the losers.* ■ *Football* an act of dropping or losing control of the ball, sometimes causing a turnover: *his fumble was recovered on the 6-yard line.* ■ (in other ball games) an act of failing to catch or field the ball cleanly. ■ an act of managing or dealing with something clumsily: *we are not talking about subtle errors of judgment, but major fumbles.* ▷late Middle English: from Low German *fommeln* or Dutch *fommelen*. —**fum·bler** /'fəmb(ə)lər/ *n.* —**fum·bling·ly** /'fəmb(ə)liNGlē/ *adv.*

fume /fyo͞om/ ▸*n.* (usu. **fumes**) gas, smoke, or vapor that smells strongly or is dangerous to inhale: *clouds of exhaust fumes spewed by cars.* ■ a pungent odor of a particular thing or substance: *he breathed fumes of wine into her face.* ■ *poetic/literary* a watery vapor, steam, or mist rising from the earth or sea.

▸*v.* [*intrans.*] **1** emit gas, smoke, or vapor: *fragments of lava hit the ground, fuming and sizzling.* ■ [*trans.*] [usu. as *adj.*] **(fumed)** expose (esp. wood) to ammonia fumes in order to produce dark tints: *the fumed oak sideboard.* **2** feel, show, or express great anger: *he is fuming over the interference in his work.* ▷late Middle English: from Old French *fumer* (verb), from Latin *fumare* 'to smoke.' —**fum·ing·ly** /'fyo͞omiNGlē/ *adv.* —**fum·y** /'fyo͞omē/ *adj.*

fume hood ▸*n.* a ventilated enclosure in a chemistry laboratory, in which harmful volatile chemicals can be used or kept.

fu·met /fyo͞o'mā; 'fyo͞omət/ ▸*n.* a concentrated stock, esp. of game or fish, used as flavoring. ▷early 18th cent. (in the senses 'smell of game' and 'game flavor'): from French, from *fumer* 'to smoke.' The current sense dates from the early 20th cent.

fu·mi·gate /'fyo͞omaˌgāt/ ▸*v.* [*trans.*] apply the fumes of certain chemicals to (an area) to disinfect it or to rid it of vermin. ▷mid 16th cent. (in the sense 'to perfume'): from Latin *fumigat-* 'fumigated,' from the verb *fumigare*, from *fumus* 'smoke.' —**fu·mi·gant** /-gənt/ *n.* —**fu·mi·ga·tion** /ˌfyo͞omə'gāSHən/ *n.* —**fu·mi·ga·tor** /-ˌgātər/ *n.*

fu·mi·to·ry /'fyo͞omaˌtôrē/ ▸*n.* an Old World plant with spikes of small tubular pink or white flowers and finely divided grayish leaves, often considered a weed. • Genus *Fumaria*, family Fumariaceae. ▷late Middle English: from Old French *fumeterre*, from medieval Latin *fumus terrae* 'smoke of the earth' (because of its grayish leaves).

fun /fən/ ▸*n.* enjoyment, amusement, or lighthearted pleasure: *the children were having fun in the play area | anyone who turns up can join in the fun.* ■ a source of this: *people-watching is great fun.* ■ playful behavior or good humor: *she's full of fun.* ■ behavior or an activity that is intended purely for amusement and should not be interpreted as having serious or malicious purposes: *it was nothing serious; they just enjoyed having some harmless fun.* ■ [*attrib.*] (of a place or event) providing entertainment or leisure activities for children: *a 33-acre movie-themed fun park.*

▸*adj.* **(fun·ner fun·nest)** *informal* amusing, entertaining, or enjoyable: *it was a fun evening | what's the funnest part of wakeboarding for you?*

▸*v.* *informal* joke or tease: [*intrans.*] *no need to get sore—I was only funning* | [*trans.*] *they are just funning you.* ▷late 17th cent. (denoting a trick or hoax): from obsolete *fun* 'to cheat or hoax,' dialect variant of late Middle English *fon* 'make a fool of, be a fool,' related to *fon* 'a fool,' of unknown origin. Compare with **FOND**.

▸*PHRASES* ◻ **for fun** (or **for the fun of it**) in order to amuse oneself and not for any more serious purpose. ◻ **fun and games** amusing and enjoyable activities: *teaching isn't all fun and games.* ◻ **someone's idea of fun** used to emphasize one's dislike for an activity or to mock someone else's liking for it: *being stuck behind a desk all day isn't my idea of fun.* ◻ **in fun** not intended seriously; as a joke: *remember when you meet the press to say that your speech was all in fun.* ◻ **like fun** *dated* an ironic exclamation of contradiction or disbelief in response to a statement. ◻ **make fun of** (or **poke fun at**) tease, laugh at, or joke about (someone) in a mocking or unkind way. ◻ **not much (or a lot of) fun** used to indicate that something strikes one as extremely unpleasant and depressing: *it can't be much fun living next door to him.* ◻ **what fun!** used to convey that an activity or situation sounds amusing or enjoyable.

USAGE The use of fun as an adjective meaning 'enjoyable,' as in *we had a fun evening*, is not fully accepted in standard English and should only be used in informal contexts. There are signs, however, that this situation is changing, given the recent appearance in U.S. English of comparative and superlative forms funner and funnest, formed as if fun were a normal adjective. The adjectival forms funner and funnest have not 'arrived' in all the dictionaries, however, and if employed at all, they should be used sparingly and not in formal written English.

Fu·na·ba·shi /ˌfo͞onäˈbäSHē/ a city in central Japan, on eastern Honshu Island, a suburb of Tokyo; pop. 533,000.

Fu·na·fu·ti /ˌf(y)o͞onəˈf(y)o͞otē/ the capital of Tuvalu, on an island of the same name; pop. 2,500.

fu·nam·bu·list /fyo͞oˈnambyəlist/ ▸*n.* a tightrope walker. ▷late 18th cent.: from French *funambule* or Latin *funambulus* (from *funis* 'rope' + *ambulare* 'to walk') + **-IST**.

Fun·chal /fo͞onˈSHäl; fən-/ the capital and chief port of Madeira, on the south coast of the island; pop. 110,000.

func·tion /'fəNGkSHən/ ▸*n.* **1** an activity or purpose natural to or intended for a person or thing: *bridges perform the function of providing access across water | Vitamin A is required for good eye function.* ■ practical use or purpose in design: *building designs that prioritize style over function.* ■ a basic task of a computer, esp. one that corresponds to a single instruction from the user. **2** *Mathematics* a relationship or expression involving one or more variables: *the function (bx + c).* ■ a variable quantity regarded in relation to one or more other variables in terms of which it may be expressed or on which its value depends. ■ *Chemistry* a functional group. **3** a thing dependent on another factor or factors: *class shame is a function of social power.* **4** a large or formal social event or ceremony: *he was obliged to attend party functions.*

▸*v.* [*intrans.*] work or operate in a proper or particular way: *her liver is functioning normally.* ■ **(function as)** fill the purpose or task of (a specified thing): *the museum intends to function as an educational and study center.* ▷mid 16th cent.: from French *fonction*, from Latin *functio(n-)*, from *fungi* 'perform.' —**func·tion·less** *adj.*

func·tion·al /'fəNGkSHənəl/ ▸*adj.* **1** of or having a special activity, purpose, or task; relating to the way in which something works or operates: *there are important functional differences between left and right brains.* ■ designed to be practical and useful, rather than attractive: *she had assumed the apartment would be functional and simple.* ■ working or operating: *the museum will be fully functional from the opening of the festival.* ■ (of a disease) affecting the operation, rather than the structure, of an organ: *functional diarrhea.* ■ (of a mental illness) having no discernible organic cause: *functional psychosis.* **2** *Mathematics* of or relating to a variable quantity whose value depends on one or more other variables. —**func·tion·al·ly** *adv.* [*sentence adverb*] *functionally, the role of the library service is clearly educational.*

func·tion·al food ▸*n.* *chiefly Brit.* another term for **NUTRACEUTICAL**.

func·tion·al gram·mar ▸*n.* a theory of grammar concerned with how the social, cognitive, and pragmatic functions of language relate to structure.

func·tion·al group ▸*n.* *Chemistry* a group of atoms responsible for the characteristic reactions of a particular compound.

func·tion·al il·lit·er·ate ▸*n.* a person whose level of ability to read and write is below that needed to do the ordinary tasks required to function normally in society.

func·tion·al·ism /'fəNGkSHənlˌizəm/ ▸*n.* belief in or stress on the practical application of a thing, in particular: ■ (in the arts) the doctrine that the design of an object should be determined solely by its function, rather than by aesthetic considerations; and that anything practically designed will be inherently beautiful. ■ (in the social sciences) the theory that all aspects of a society serve a function and are necessary for the survival of that society. ■ (in the philosophy of mind) the theory that mental states can be sufficiently defined by their cause, their effect on other mental states, and their effect on behavior. —**func·tion·al·ist** *n.* & *adj.*

func·tion·al·i·ty /ˌfəNGkSHəˈnalətē/ ▸*n.* **1** the quality of being suited to serve a purpose well; practicality: *I like the feel and functionality of this bakeware.* ■ the purpose that something is designed or expected to fulfill: *manufacturing processes may be affected by the functionality of the product.* **2** the range of operations that can be run on a computer or other electronic system: *new software with additional functionality.*

func·tion·al med·i·cine ▸*n.* medical practice or treatments that focus on optimal functioning of the body and its organs, usually involving systems of holistic or alternative medicine: *you don't have to wait for a disease to benefit from functional medicine.*

func·tion·al shift ▸*n.* a shift in the use of a word to a new grammatical function, such as the use of the nouns *contact* and *impact* as verbs.

func·tion·ar·y /'fəNGkSHəˌnerē/ ▸*n.* (*pl.* **-ar·ies**) a person who has to perform official functions or duties; an official.

func·tion key ▸*n.* *Computing* a button on a computer keyboard, distinct from the main alphanumeric keys, to which software can assign a particular function.

func·tion word ▸*n.* *Linguistics* a word whose purpose is more to signal grammatical relationship than the lexical meaning of a sentence, e.g., *do* in *do you live here?*.

func·tor /'fəNGktər/ ▸*n.* *Logic & Mathematics* a function; an operator. ■ *Linguistics* another term for **FUNCTION WORD**. ▷1930s: from **FUNCTION**, on the pattern of words such as *factor*.

fund /fənd/ ▸*n.* a sum of money saved or made available for a particular purpose: *he had set up a fund to coordinate economic investment.* ■ **(funds)** financial resources: *the misuse of public funds.* ■ a large stock or supply of something: *a vast fund of information.* ■ **(the funds)** *Brit.* the stock of the national debt as a mode of investment). ■ an organization set up for the administration and management of a monetary fund.

▸*v.* [*trans.*] provide with money for a particular purpose: *the World Bank refused to fund the project | [in combination] government-funded research.* ▷mid 17th cent.: from Latin *fundus* 'bottom, piece of land'

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