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Sun et al.

(54) **ACCESS POINT-AIDED COEXISTENCE/CONCURRENCY AT MOBILE DEVICES**

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(73) Assignee: **QUALCOMM Incorporated**, San Diego, CA (US)

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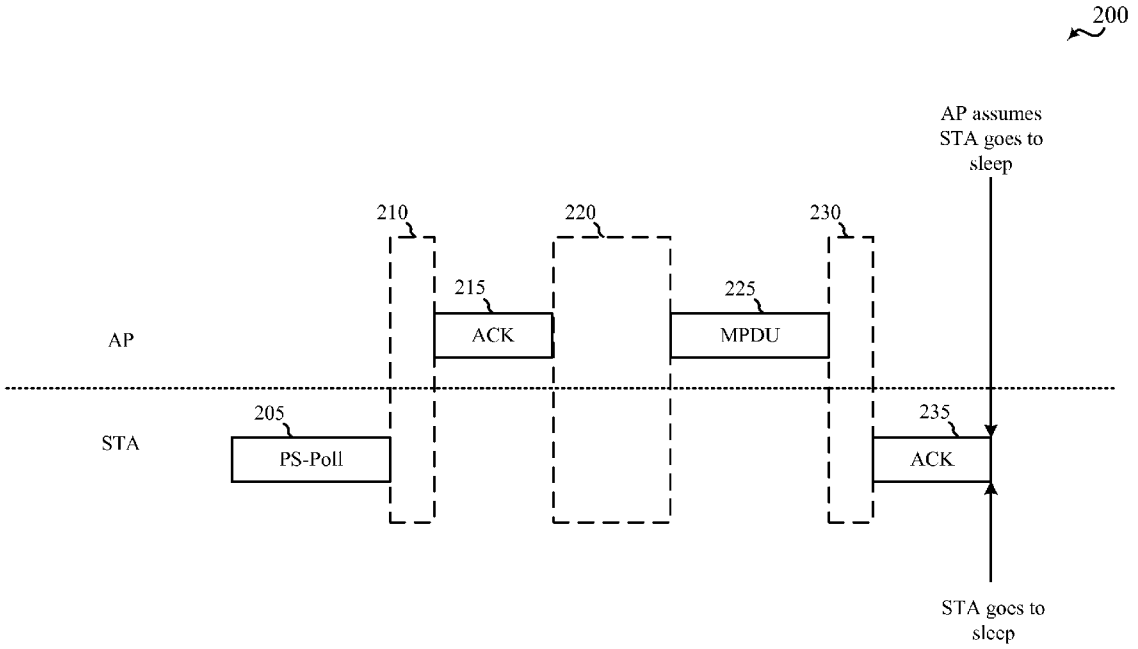
(52) **U.S. Cl.**

CPC ***H04W 52/0238*** (2013.01); ***H04W 72/02*** (2013.01)

USPC **370/311**

(57) **ABSTRACT**

Methods, systems, and devices are described that enable a WLAN access point (AP) to schedule packet transmissions to (or from) a mobile device taking into consideration the schedule of various other coexisting transmission/reception (Tx/Rx) activities on the mobile device. Various approaches may increase throughput at the mobile device. Various approaches also may benefit other stations associated with the same AP.



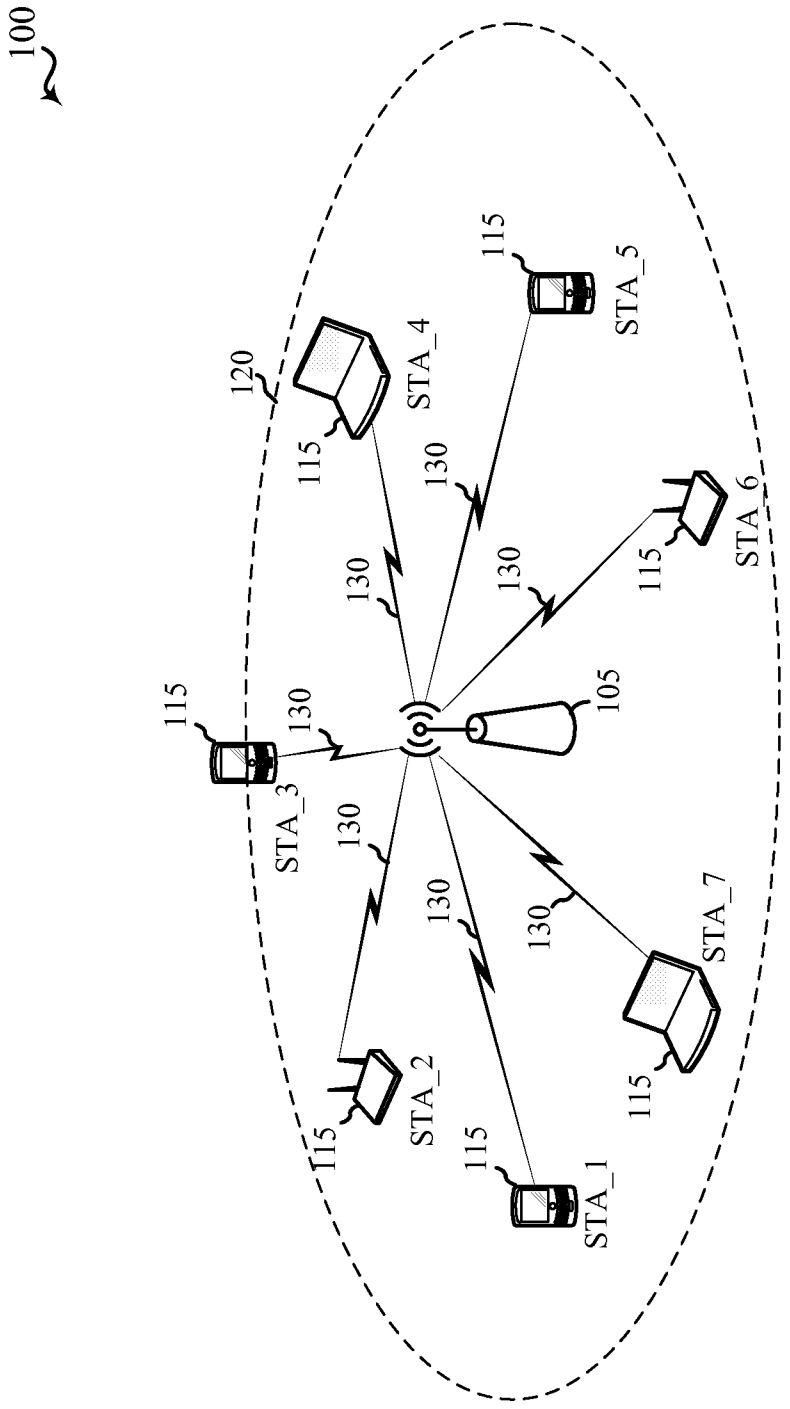


FIG. 1

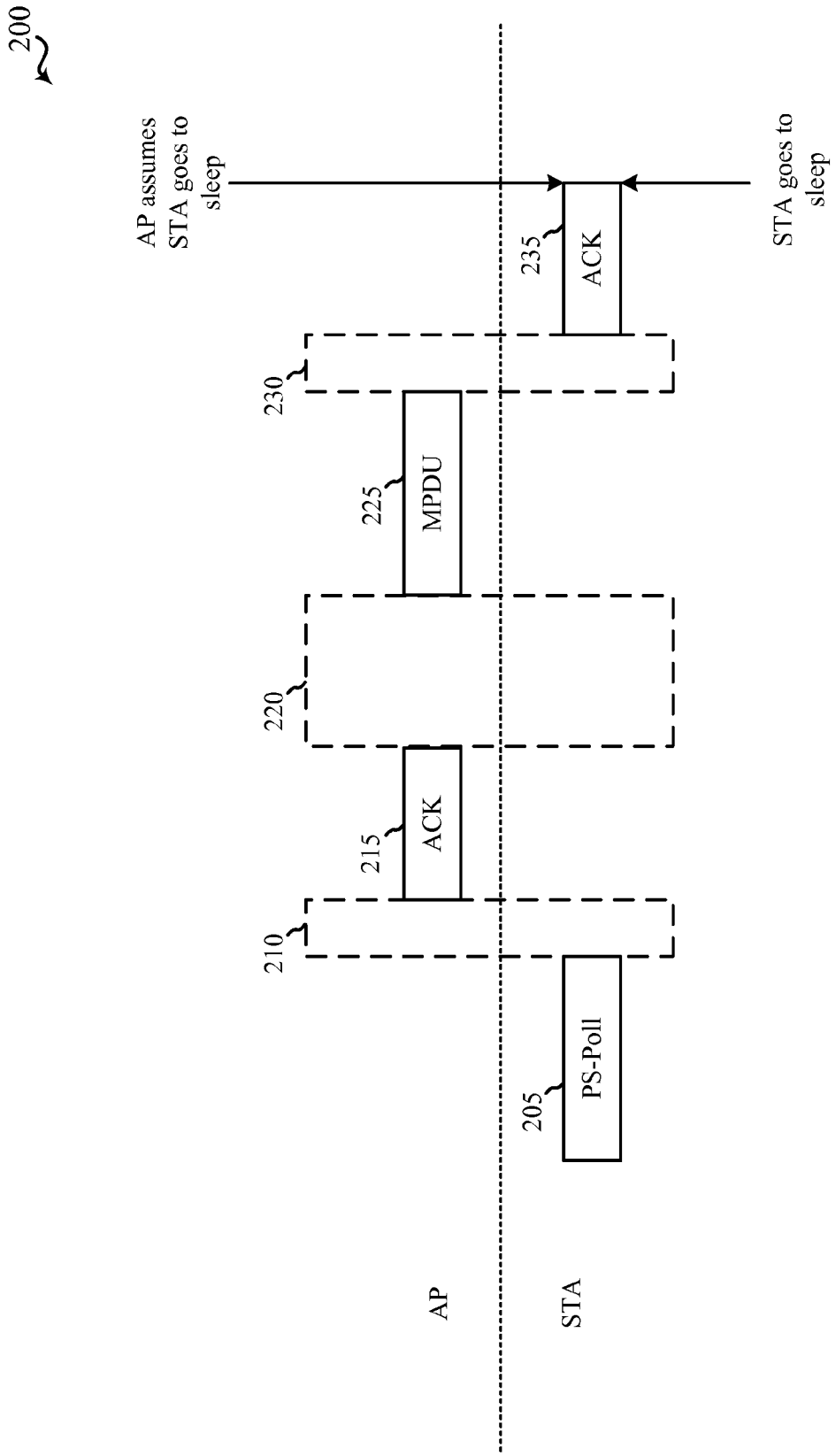

200
AP assumes STA goes to sleep
STA goes to sleep
235
ACK
230
225
MPDU
220
215
ACK
210
205
PS-Poll
AP
STA

FIG. 2

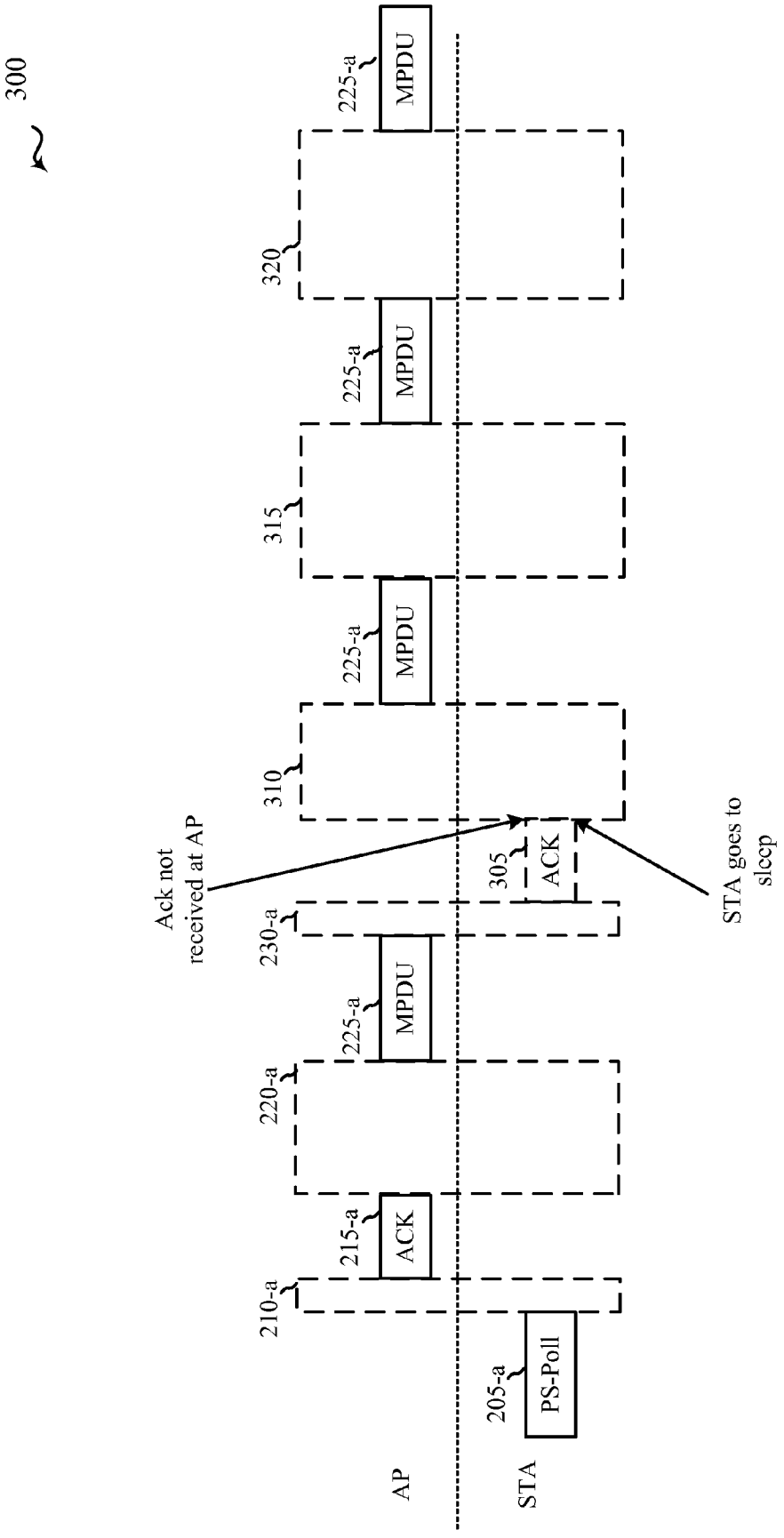

300
AP
STA
205-a
PS-Poll
210-a
215-a
ACK
220-a
225-a
MPDU
230-a
305
ACK
310
315
320
Ack not received at AP
STA goes to sleep

FIG. 3

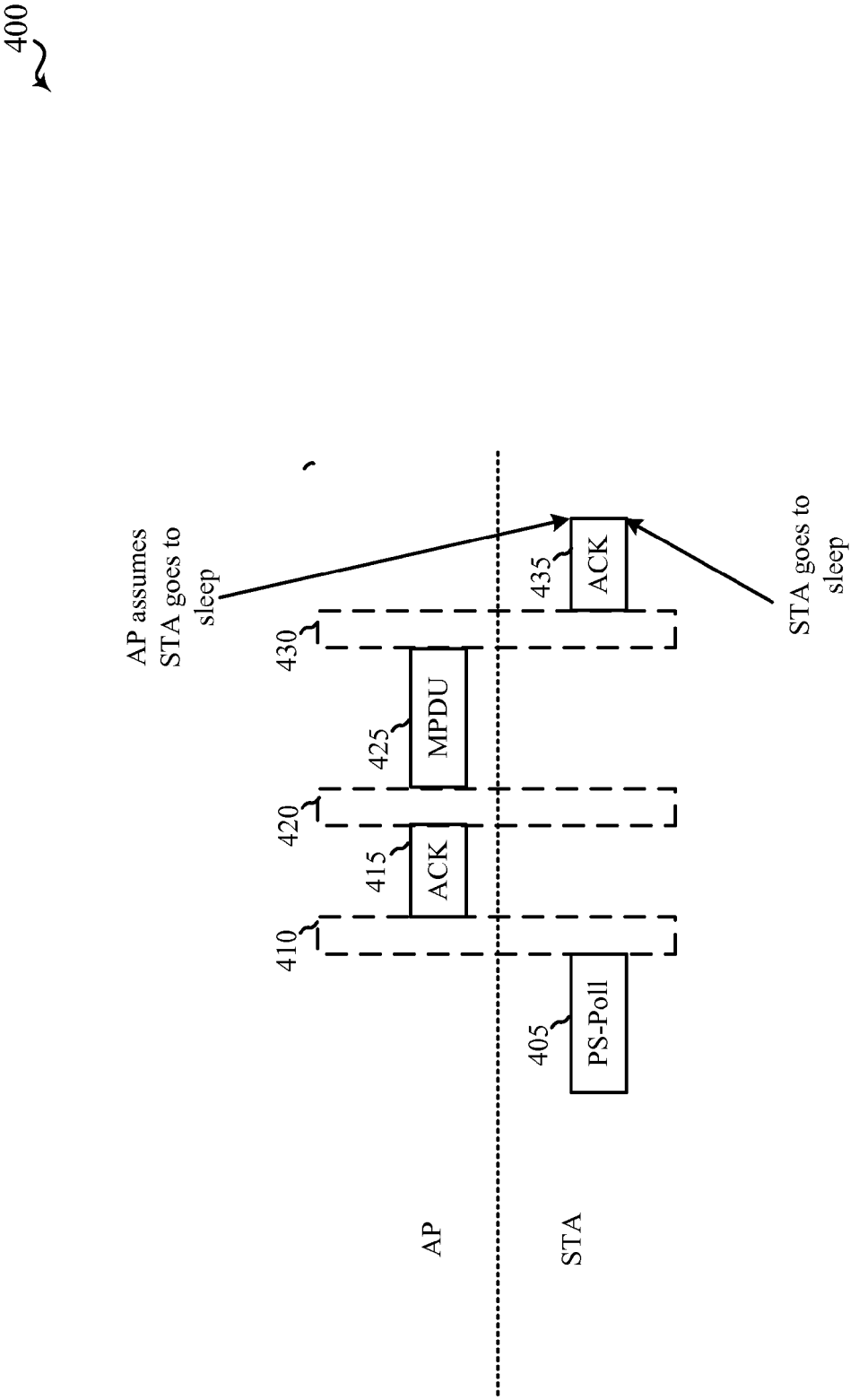

400
AP assumes STA goes to sleep
STA goes to sleep
435
ACK
430
425
MPDU
420
415
ACK
410
405
PS-Poll
AP
STA

FIG. 4

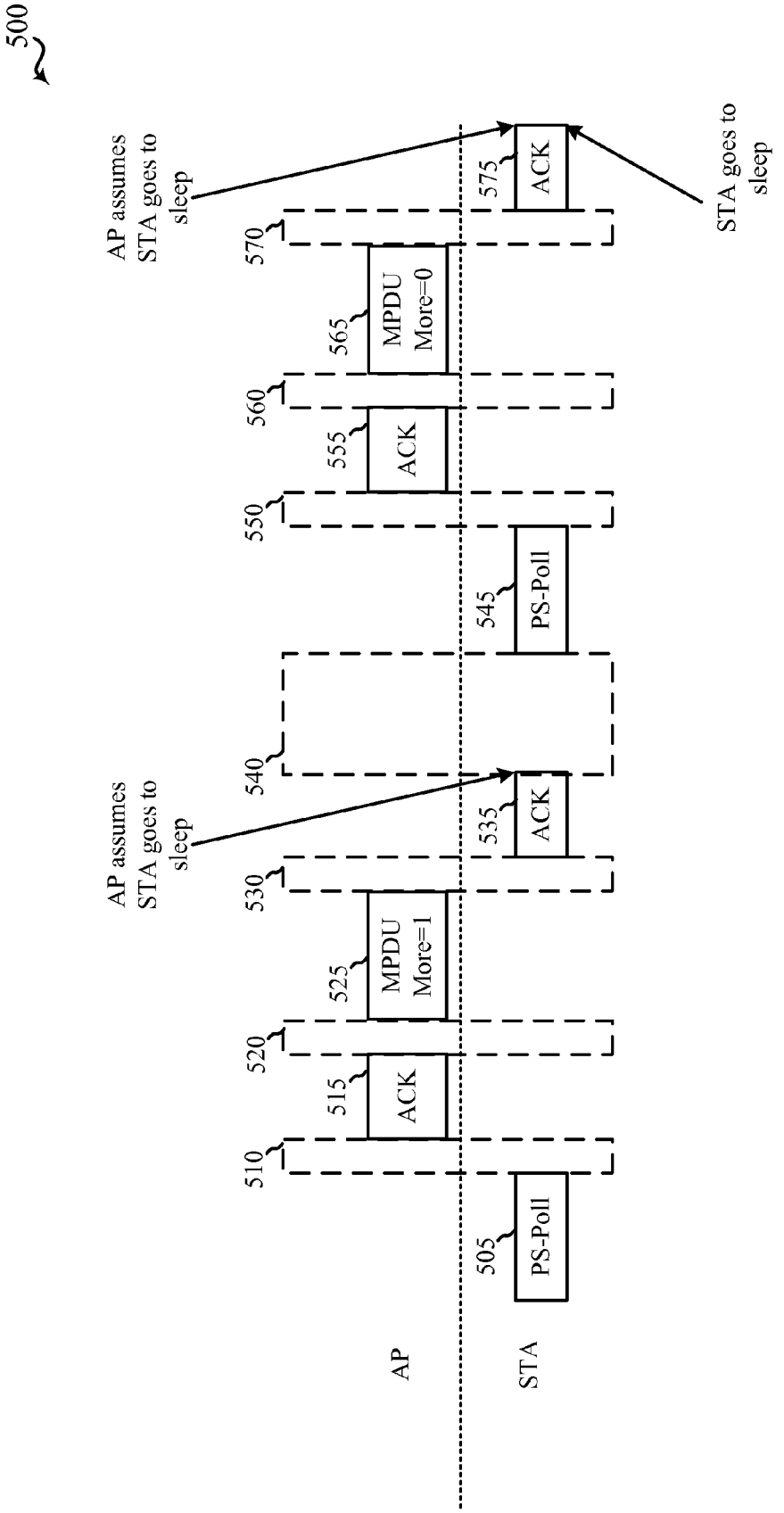

500
AP
STA
505
PS-Poll
510
515
ACK
520
525
MPDU
More=1
530
535
ACK
540
AP assumes
STA goes to
sleep
545
PS-Poll
550
555
ACK
560
565
MPDU
More=0
570
575
ACK
STA goes to
sleep
AP assumes
STA goes to
sleep

FIG. 5

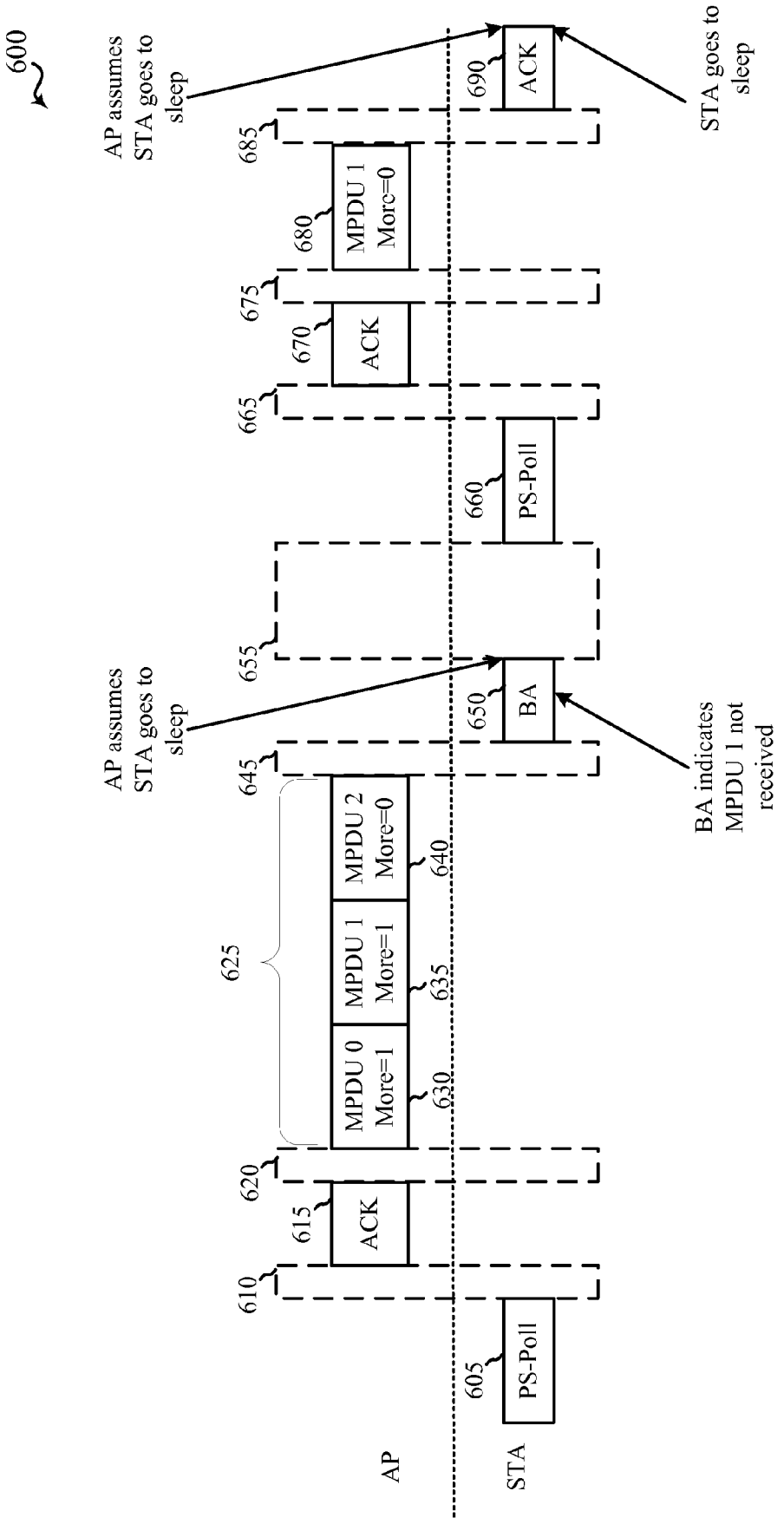

600
AP
STA
605
PS-Poll
610
615
ACK
620
625
630
MPDU 0
More=1
635
MPDU 1
More=1
640
MPDU 2
More=0
645
650
BA
655
AP assumes
STA goes to
sleep
BA indicates
MPDU 1 not
received
660
PS-Poll
665
670
ACK
675
680
MPDU 1
More=0
685
690
ACK
AP assumes
STA goes to
sleep
STA goes to
sleep

FIG. 6

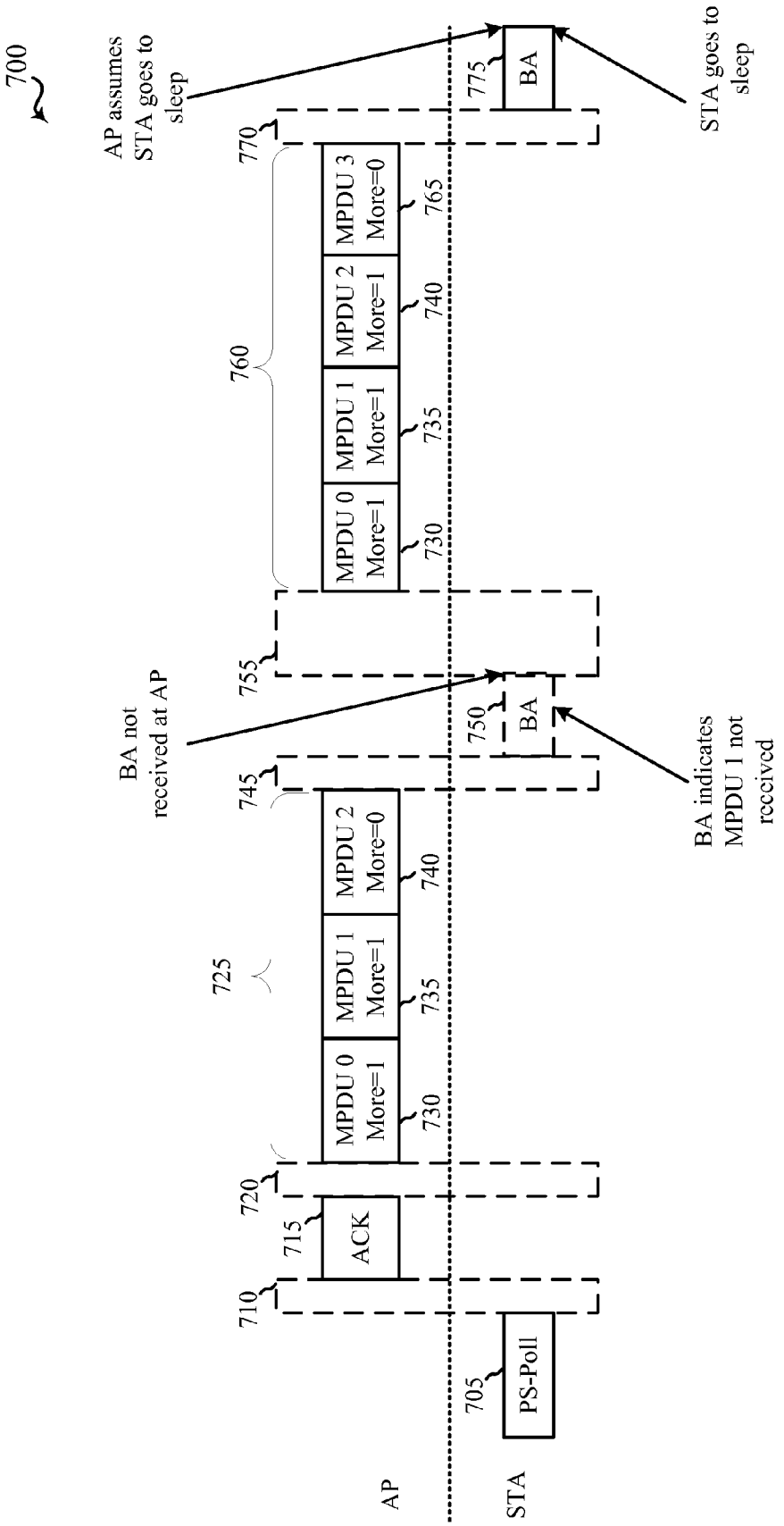

700
AP assumes STA goes to sleep
STA goes to sleep
BA not received at AP
BA indicates MPDU 1 not received
AP
STA
PS-Poll
ACK
BA
BA
MPDU 0 More=1
MPDU 1 More=1
MPDU 2 More=0
MPDU 3 More=0
705
710
715
720
725
730
735
740
745
750
755
760
765
770
775

FIG. 7

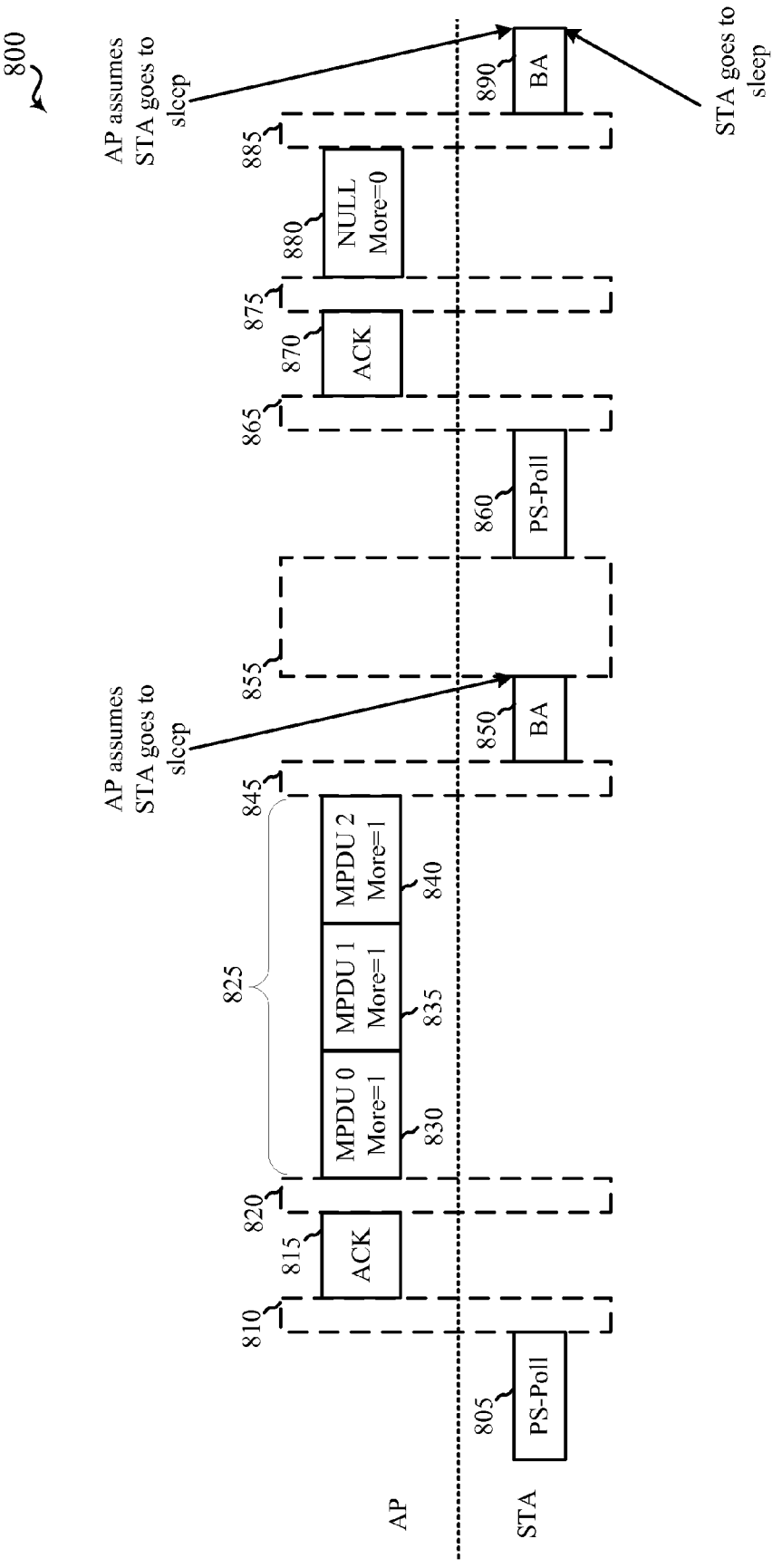

800
AP
STA
805
PS-Poll
810
815
ACK
820
825
830
MPDU 0
More=1
835
MPDU 1
More=1
840
MPDU 2
More=1
845
850
BA
AP assumes
STA goes to
sleep
855
860
PS-Poll
865
870
ACK
875
880
NULL
More=0
885
890
BA
STA goes to
sleep

FIG. 8

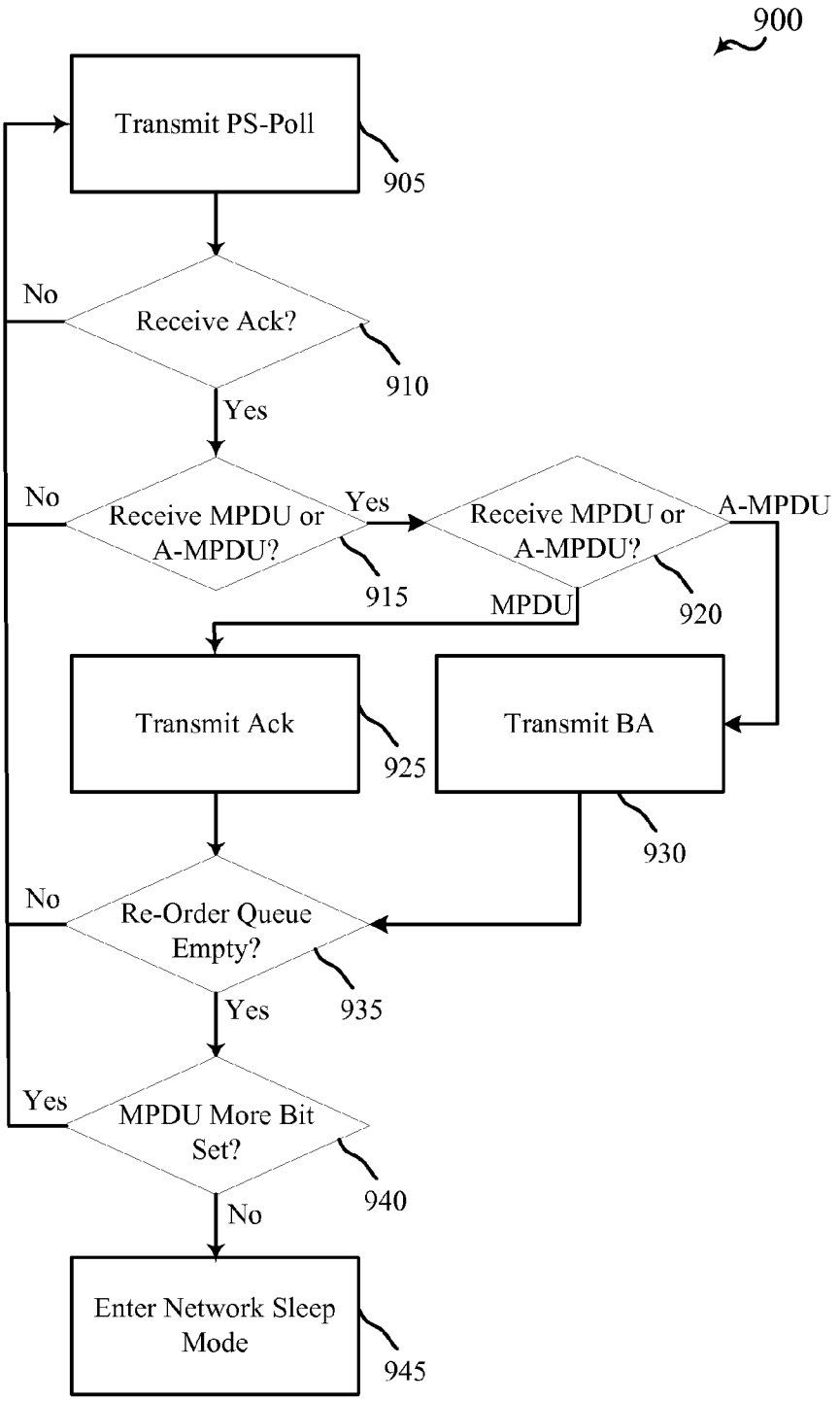

900
Transmit PS-Poll
905
No
Receive Ack?
910
Yes
No
Receive MPDU or A-MPDU?
915
Yes
Receive MPDU or A-MPDU?
920
A-MPDU
MPDU
Transmit Ack
925
Transmit BA
930
No
Re-Order Queue Empty?
935
Yes
Yes
MPDU More Bit Set?
940
No
Enter Network Sleep Mode
945

FIG. 9

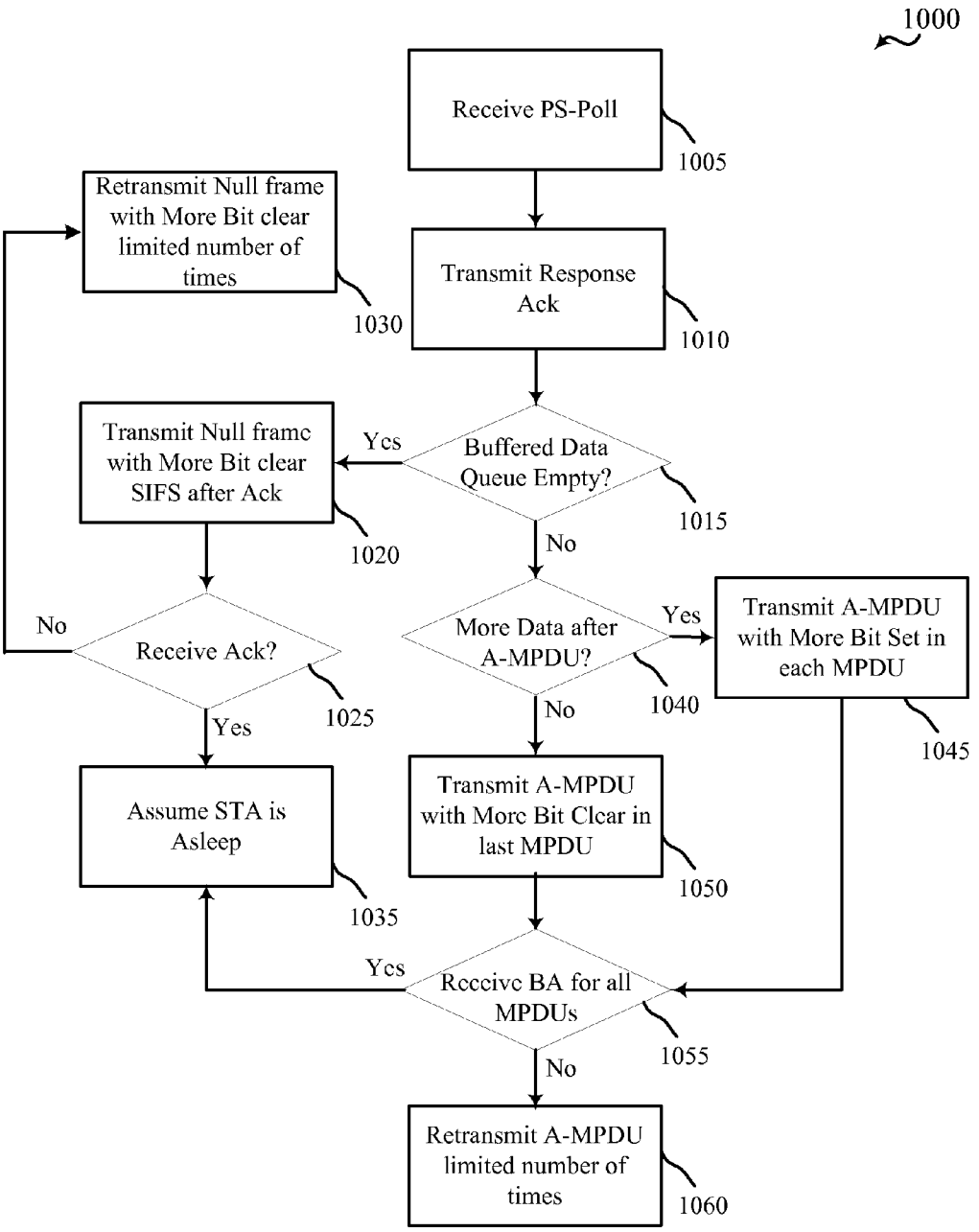

1000
Receive PS-Poll
1005
Transmit Response Ack
1010
Buffered Data Queue Empty?
1015
Yes
Transmit Null frame with More Bit clear SIFS after Ack
1020
No
More Data after A-MPDU?
1040
Yes
Transmit A-MPDU with More Bit Set in each MPDU
1045
No
Transmit A-MPDU with More Bit Clear in last MPDU
1050
Receive BA for all MPDUs
1055
Yes
No
Retransmit A-MPDU limited number of times
1060
Receive Ack?
1025
No
Yes
Assume STA is Asleep
1035
Retransmit Null frame with More Bit clear limited number of times
1030

FIG. 10

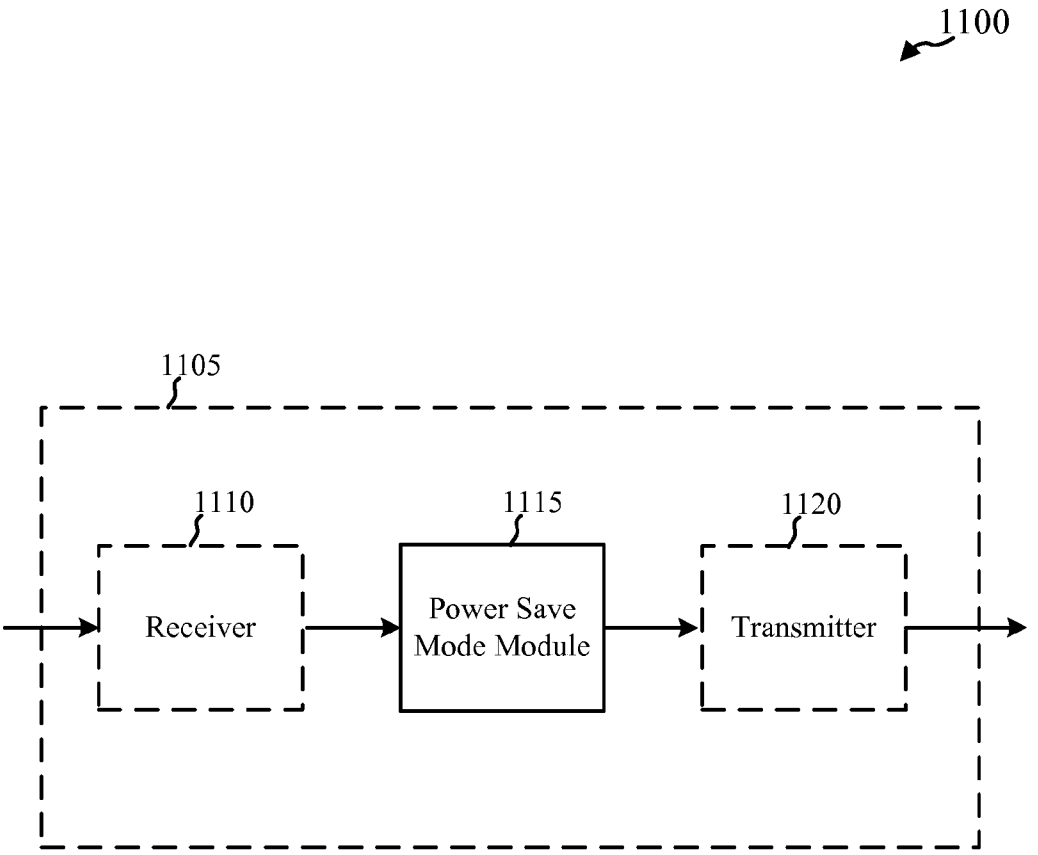

1100
1105
1110
1115
1120
Receiver
Power Save Mode Module
Transmitter

FIG. 11

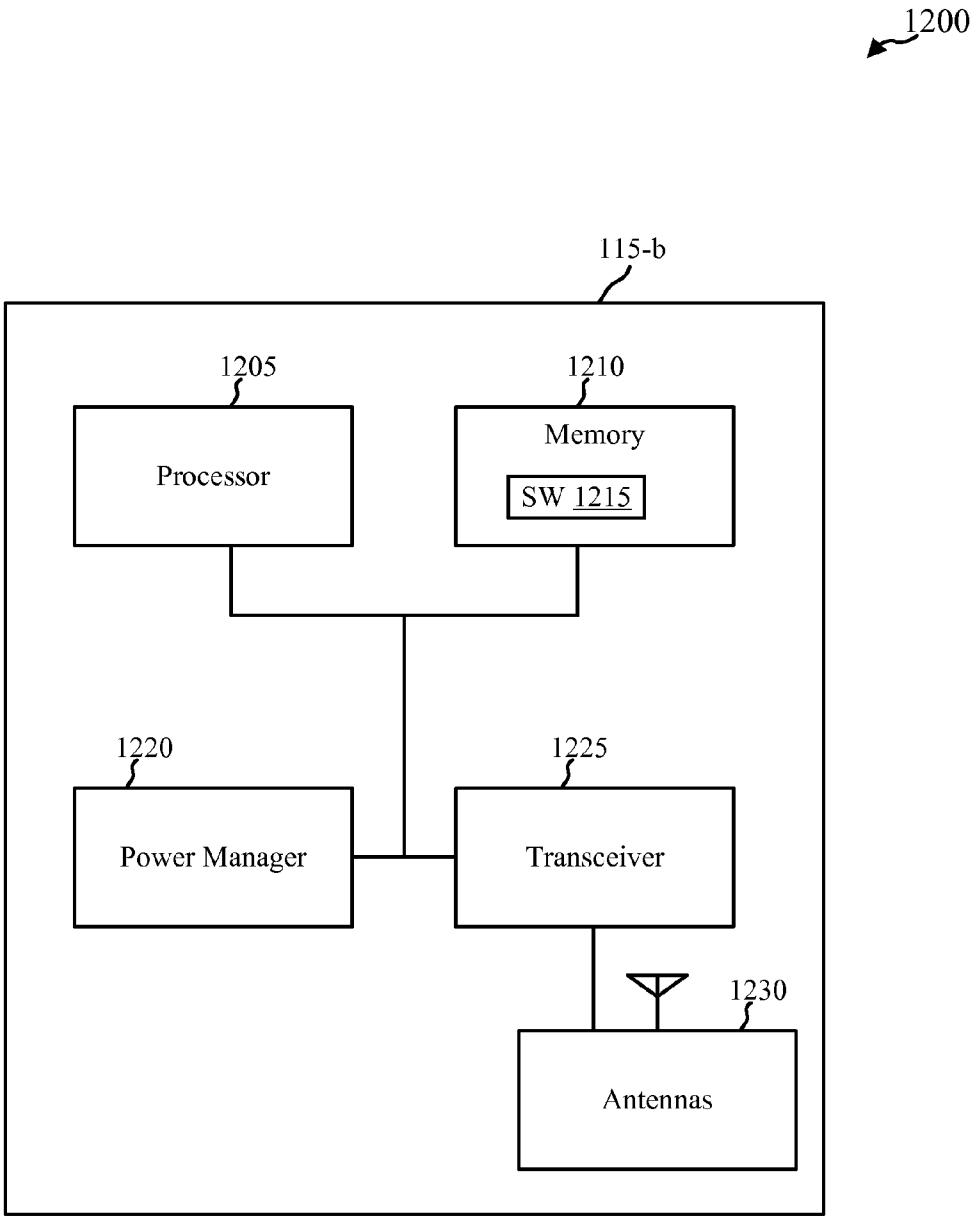

1200
115-b
1205
Processor
1210
Memory
SW 1215
1220
Power Manager
1225
Transceiver
1230
Antennas

FIG. 12

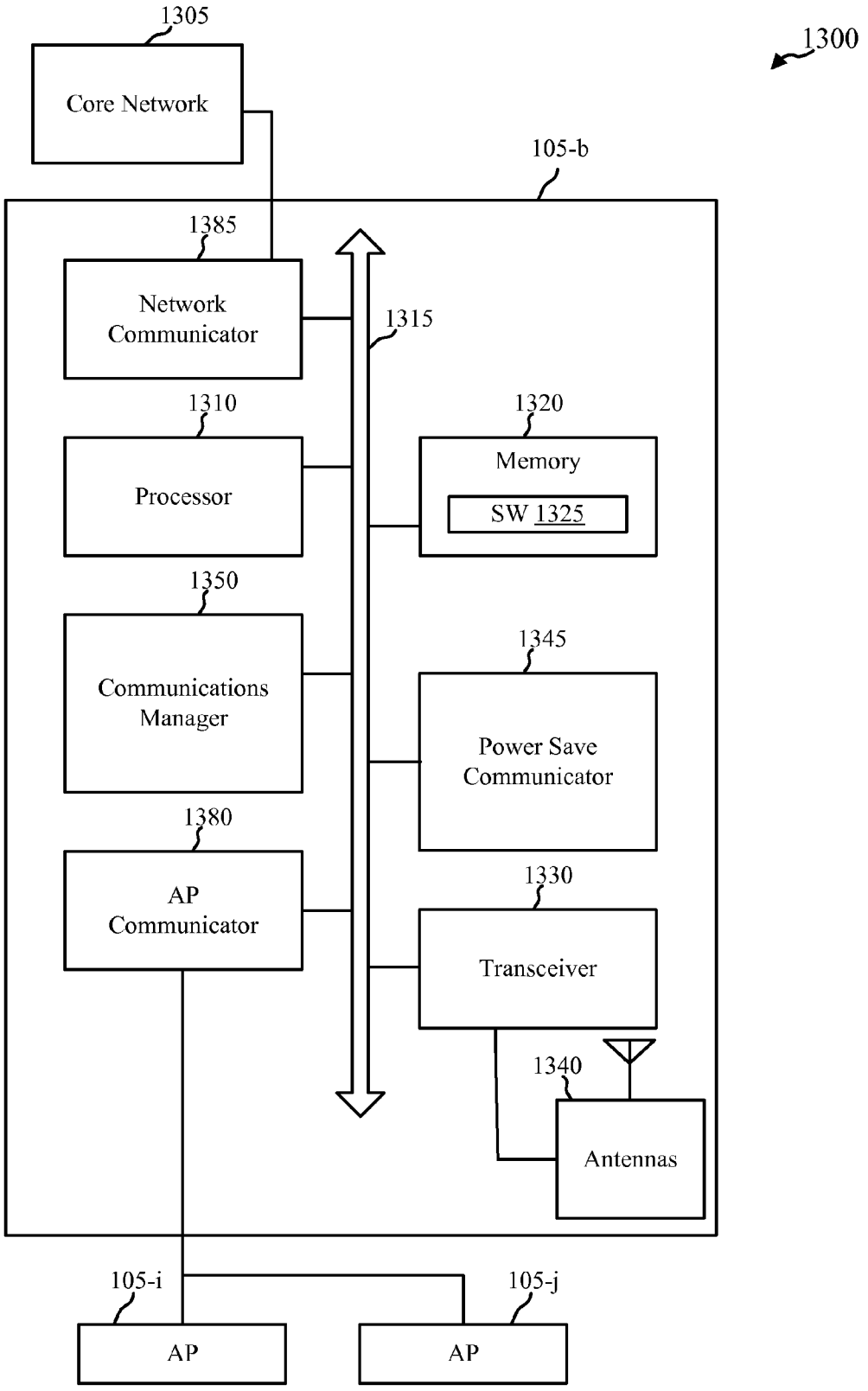

1305
Core Network
1300
105-b
1385
Network Communicator
1315
1310
Processor
1320
Memory
SW 1325
1350
Communications Manager
1345
Power Save Communicator
1380
AP Communicator
1330
Transceiver
1340
Antennas
105-i
AP
105-j
AP

FIG. 13

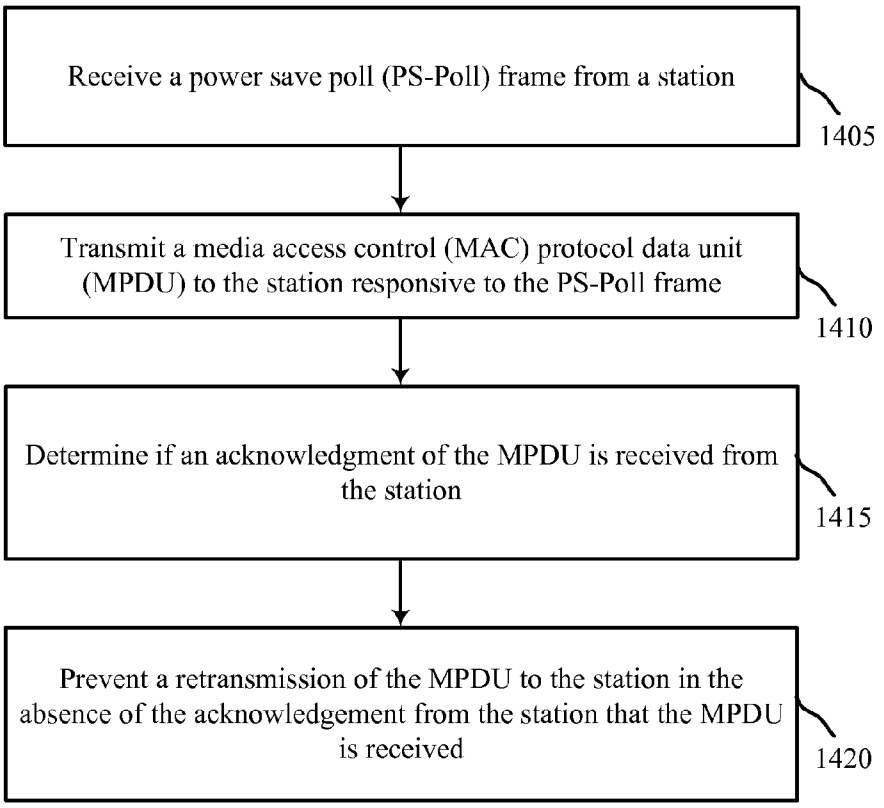

1400
Receive a power save poll (PS-Poll) frame from a station
1405
Transmit a media access control (MAC) protocol data unit (MPDU) to the station responsive to the PS-Poll frame
1410
Determine if an acknowledgment of the MPDU is received from the station
1415
Prevent a retransmission of the MPDU to the station in the absence of the acknowledgement from the station that the MPDU is received
1420

FIG. 14

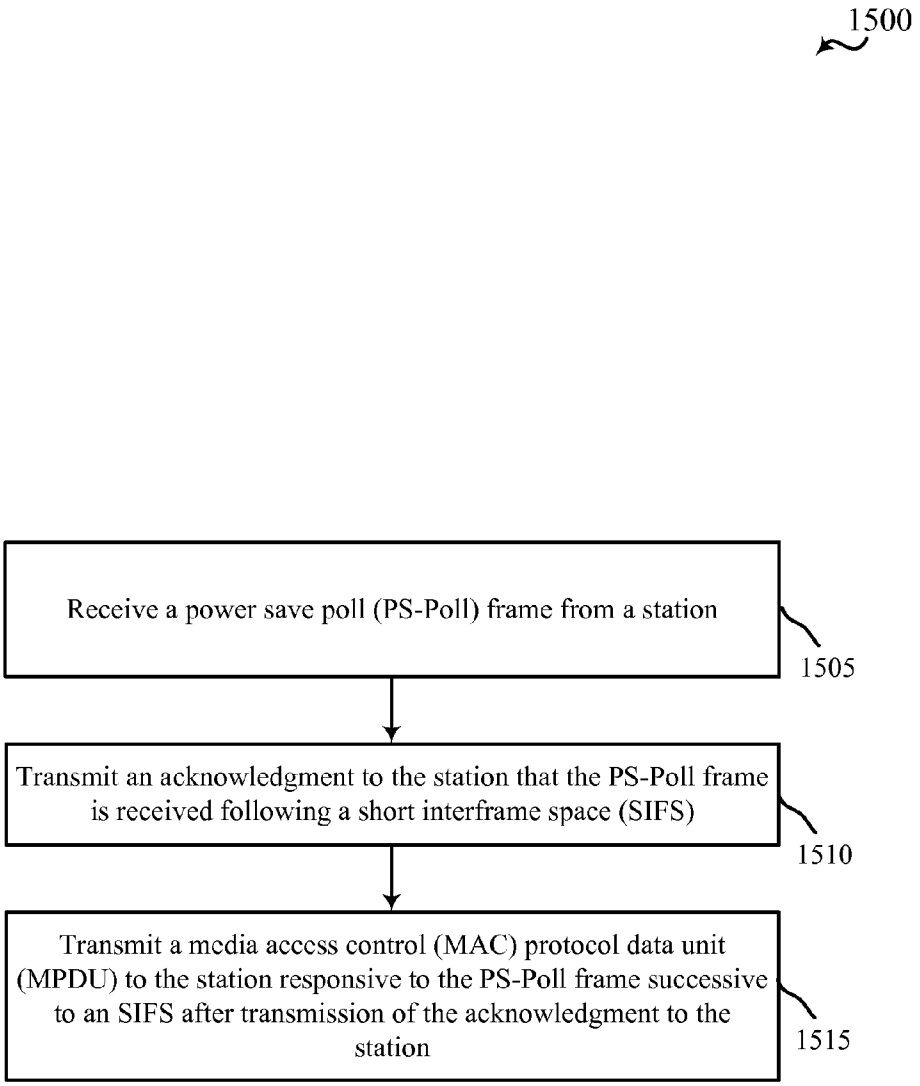

1500
Receive a power save poll (PS-Poll) frame from a station
1505
Transmit an acknowledgment to the station that the PS-Poll frame is received following a short interframe space (SIFS)
1510
Transmit a media access control (MAC) protocol data unit (MPDU) to the station responsive to the PS-Poll frame successive to an SIFS after transmission of the acknowledgment to the station
1515

FIG. 15

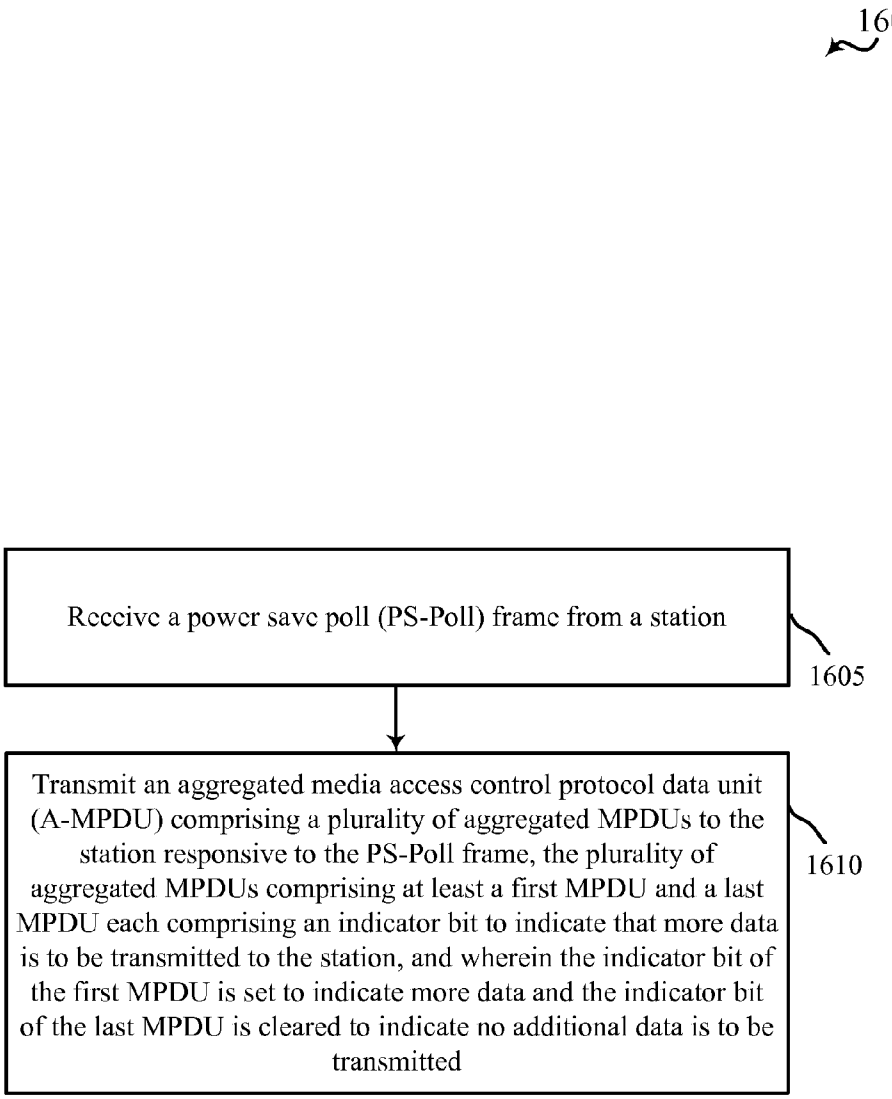

1600
Receive a power save poll (PS-Poll) frame from a station
1605
Transmit an aggregated media access control protocol data unit (A-MPDU) comprising a plurality of aggregated MPDUs to the station responsive to the PS-Poll frame, the plurality of aggregated MPDUs comprising at least a first MPDU and a last MPDU each comprising an indicator bit to indicate that more data is to be transmitted to the station, and wherein the indicator bit of the first MPDU is set to indicate more data and the indicator bit of the last MPDU is cleared to indicate no additional data is to be transmitted
1610

FIG. 16

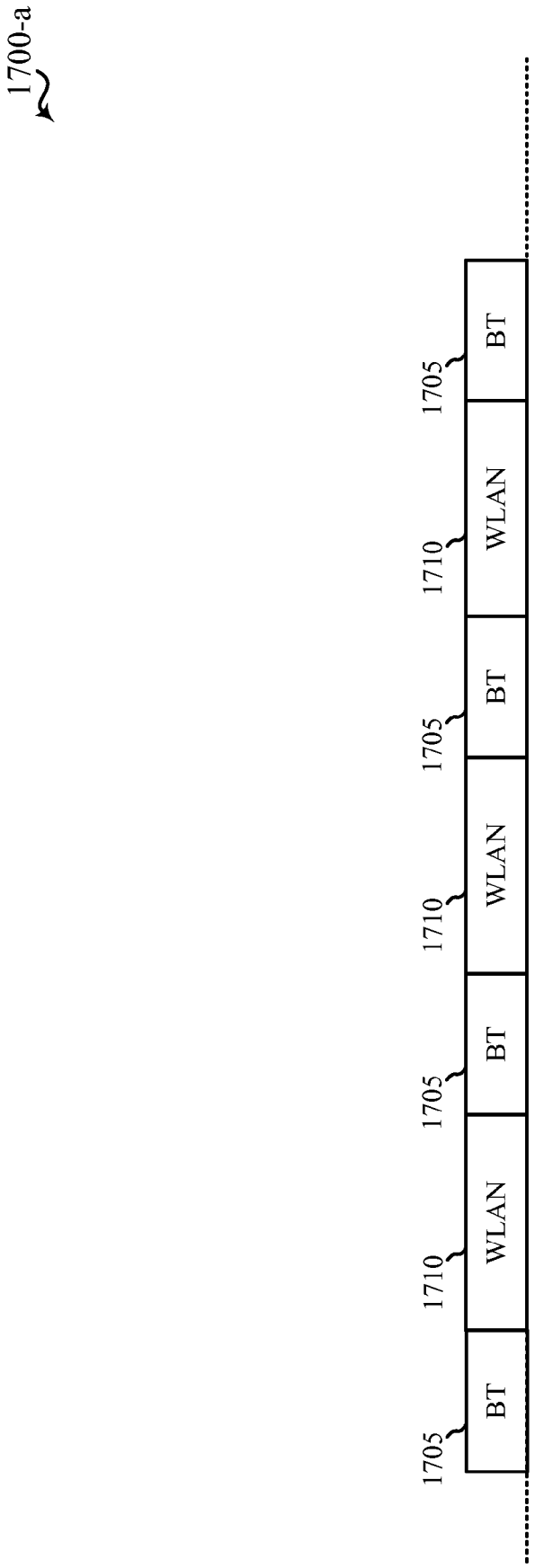

1700-a
1705
BT
1710
WLAN
1705
BT
1710
WLAN
1705
BT
1710
WLAN
1705
BT

FIG. 17A

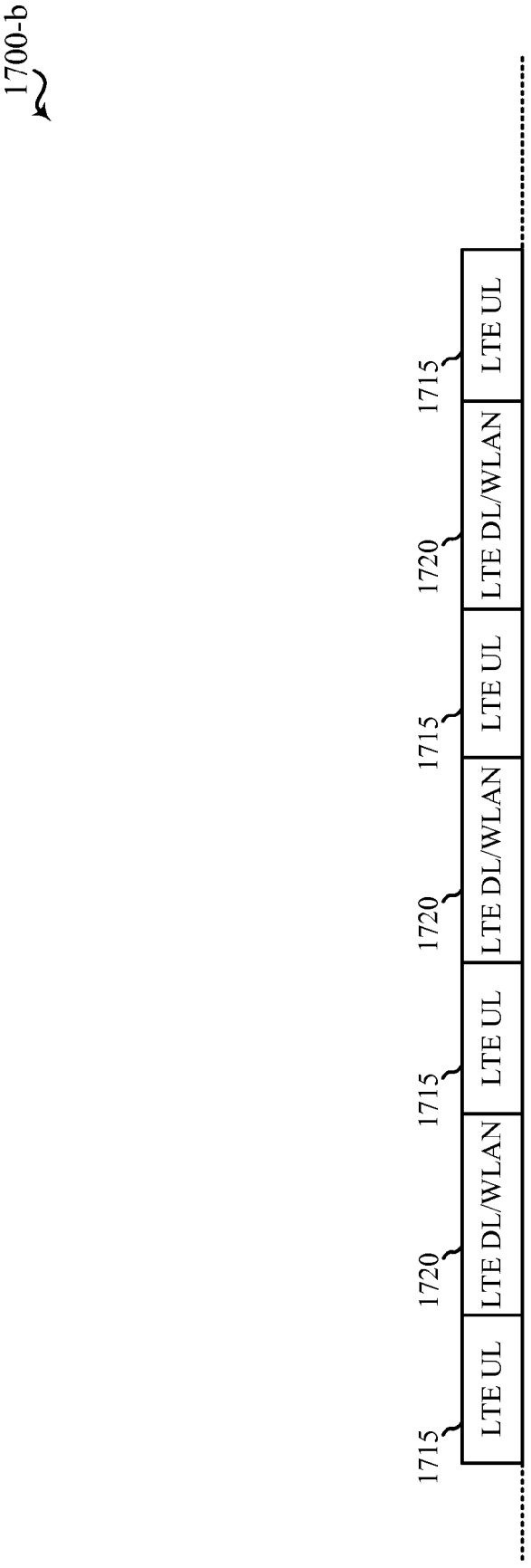

1700-b
1715
LTE UL
1720
LTE DL/WLAN
1715
LTE UL
1720
LTE DL/WLAN
1715
LTE UL
1720
LTE DL/WLAN
1715
LTE UL

FIG. 17B

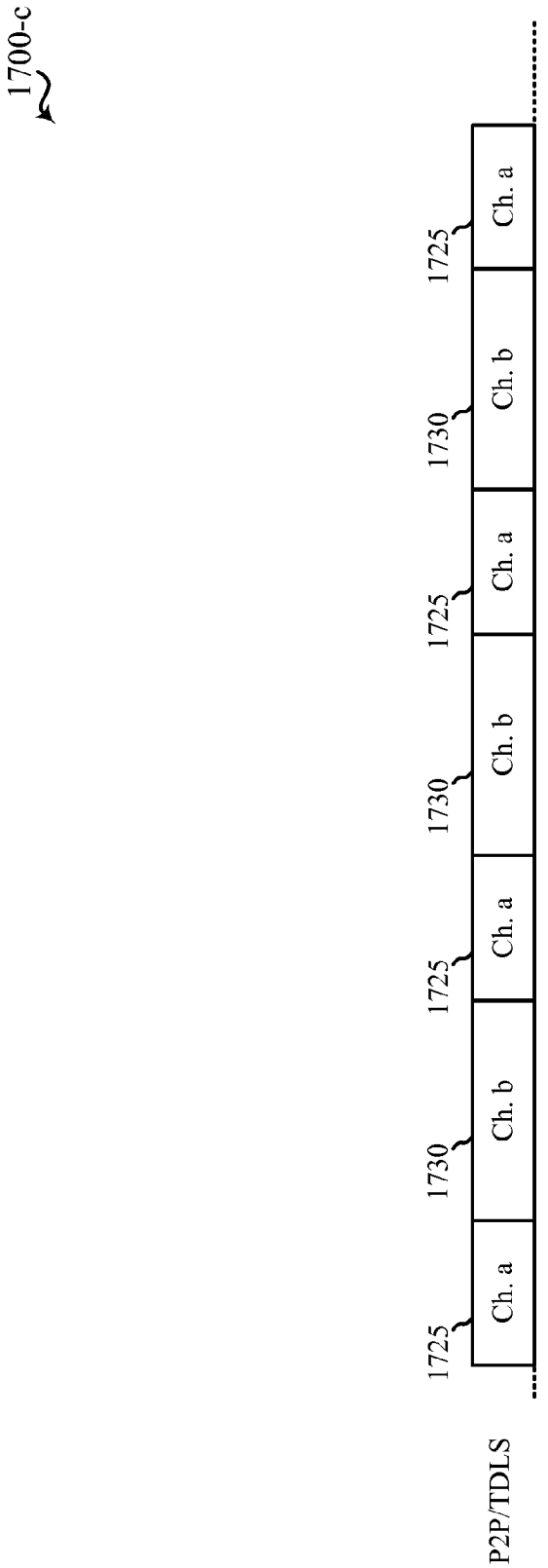

1700-c
P2P/TDLS
1725
Ch. a
1730
Ch. b
1725
Ch. a
1730
Ch. b
1725
Ch. a
1730
Ch. b
1725
Ch. a

FIG. 17C

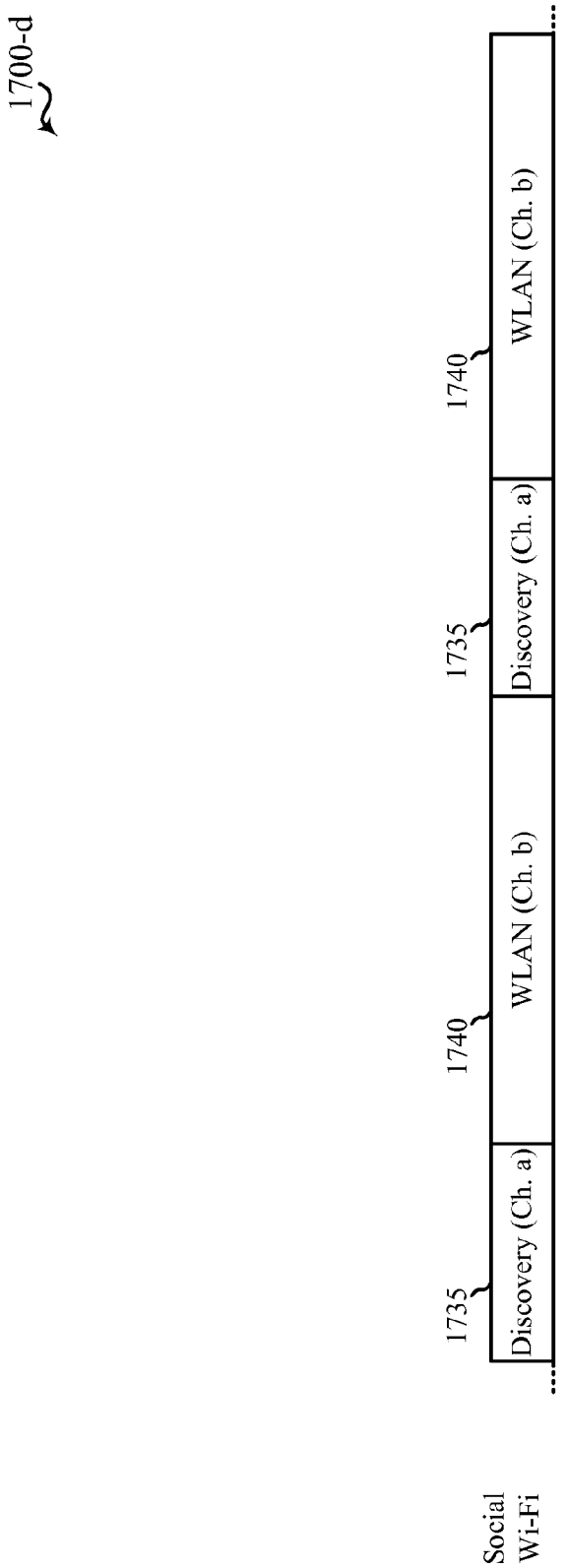

1700-d
Social Wi-Fi
1735
Discovery (Ch. a)
1740
WLAN (Ch. b)
1735
Discovery (Ch. a)
1740
WLAN (Ch. b)

FIG. 17D

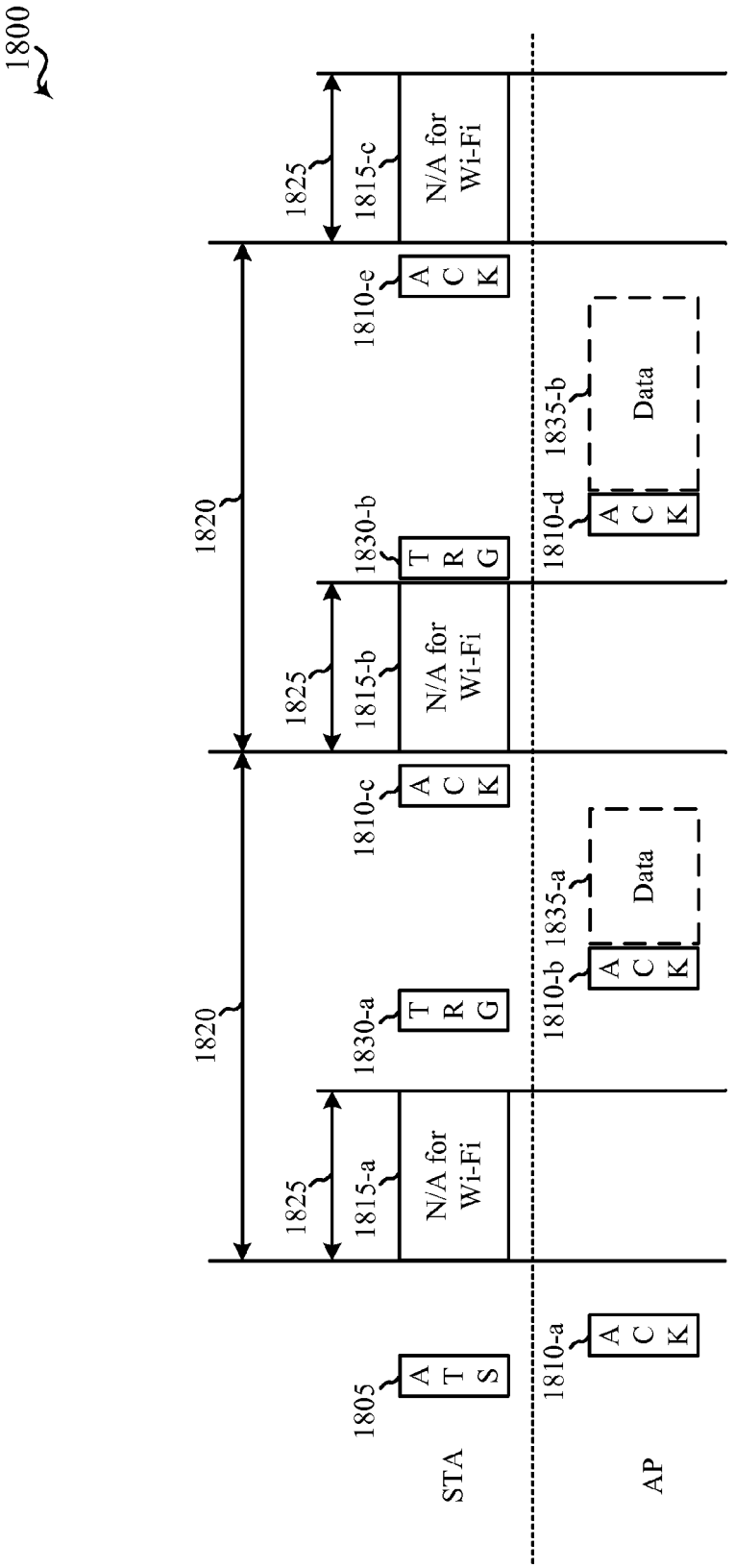

1800
STA
AP
1805
ATS
1810-a
ACK
1820
1825
1815-a
N/A for Wi-Fi
1830-a
TRG
1810-b
ACK
1835-a
Data
1810-c
ACK
1815-b
N/A for Wi-Fi
1830-b
TRG
1810-d
ACK
1835-b
Data
1820
1825
1815-c
N/A for Wi-Fi
1810-e
ACK

FIG. 18

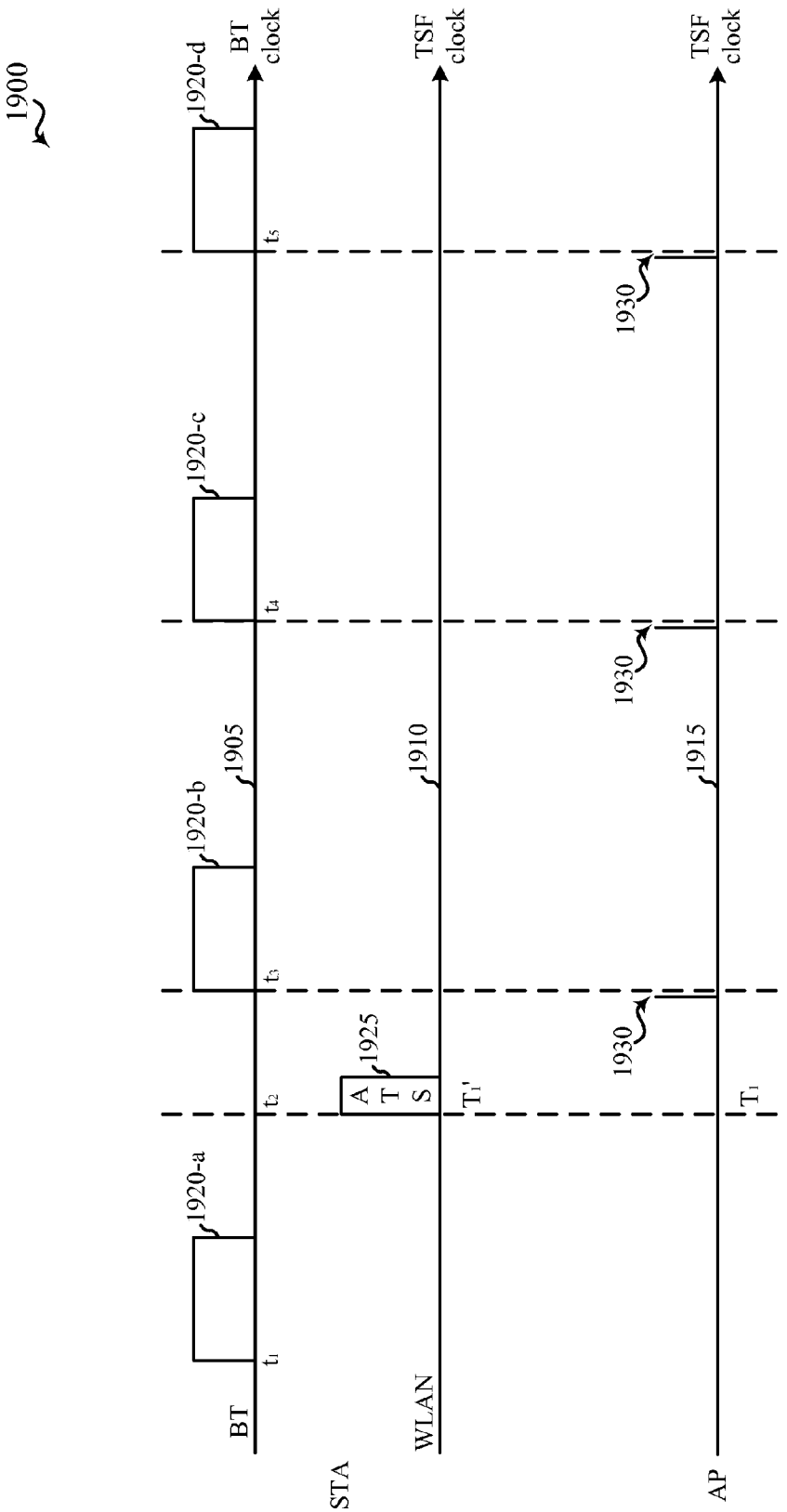

1900
BT clock
TSF clock
TSF clock
1920-d
1920-c
1920-b
1920-a
1905
1910
1915
1925
1930
1930
1930
t5
t4
t3
t2
t1
T1'
T1
A
T
S
BT
WLAN
STA
AP

FIG. 19

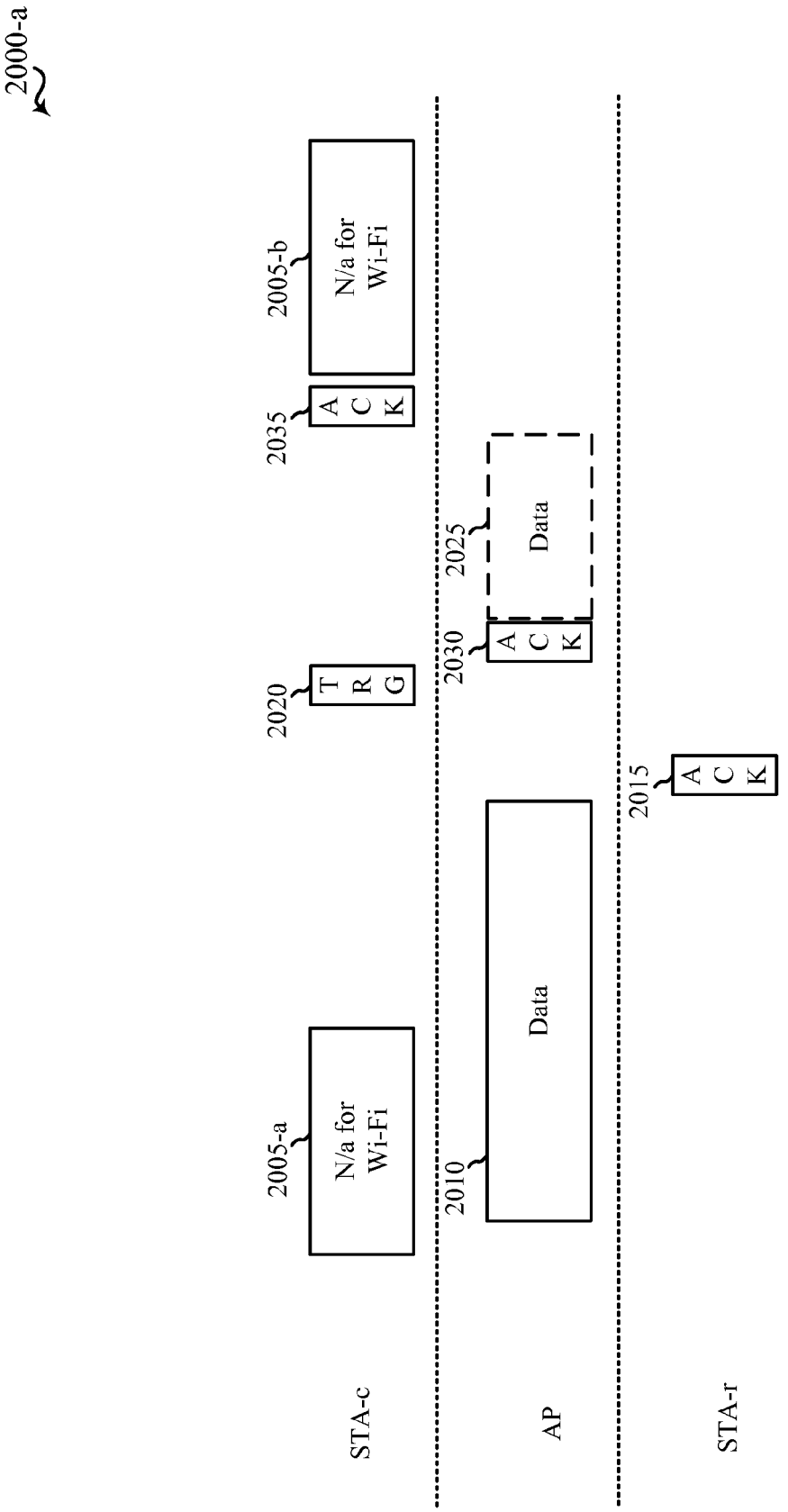

2000-a
STA-c
AP
STA-r
2005-a
N/a for Wi-Fi
2010
Data
2015
ACK
2020
TRG
2030
ACK
2025
Data
2035
ACK
2005-b
N/a for Wi-Fi

FIG. 20A

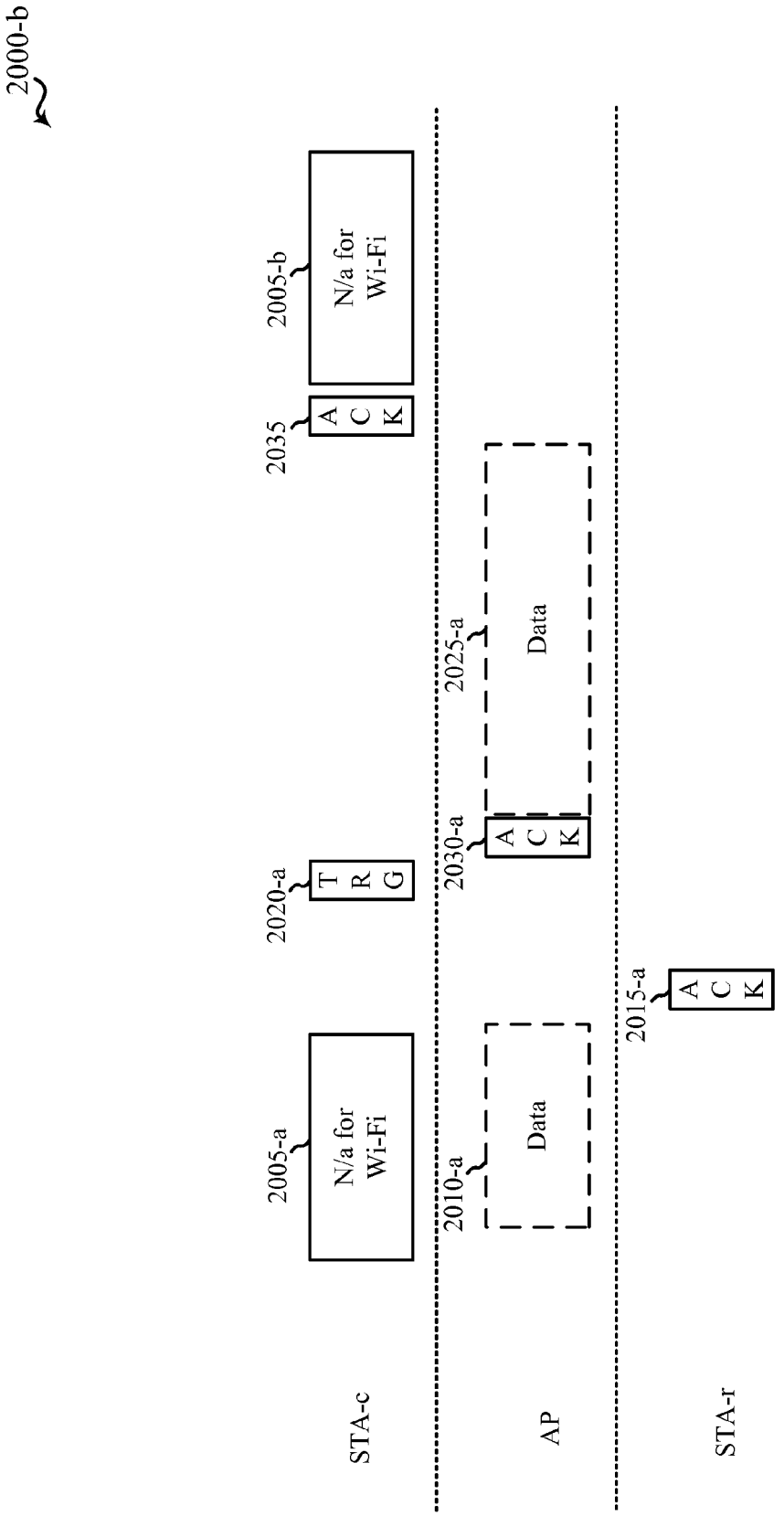

2000-b
STA-c
AP
STA-r
2005-a
N/a for Wi-Fi
2010-a
Data
2015-a
ACK
2020-a
TRG
2030-a
ACK
2025-a
Data
2035
ACK
2005-b
N/a for Wi-Fi

FIG. 20B

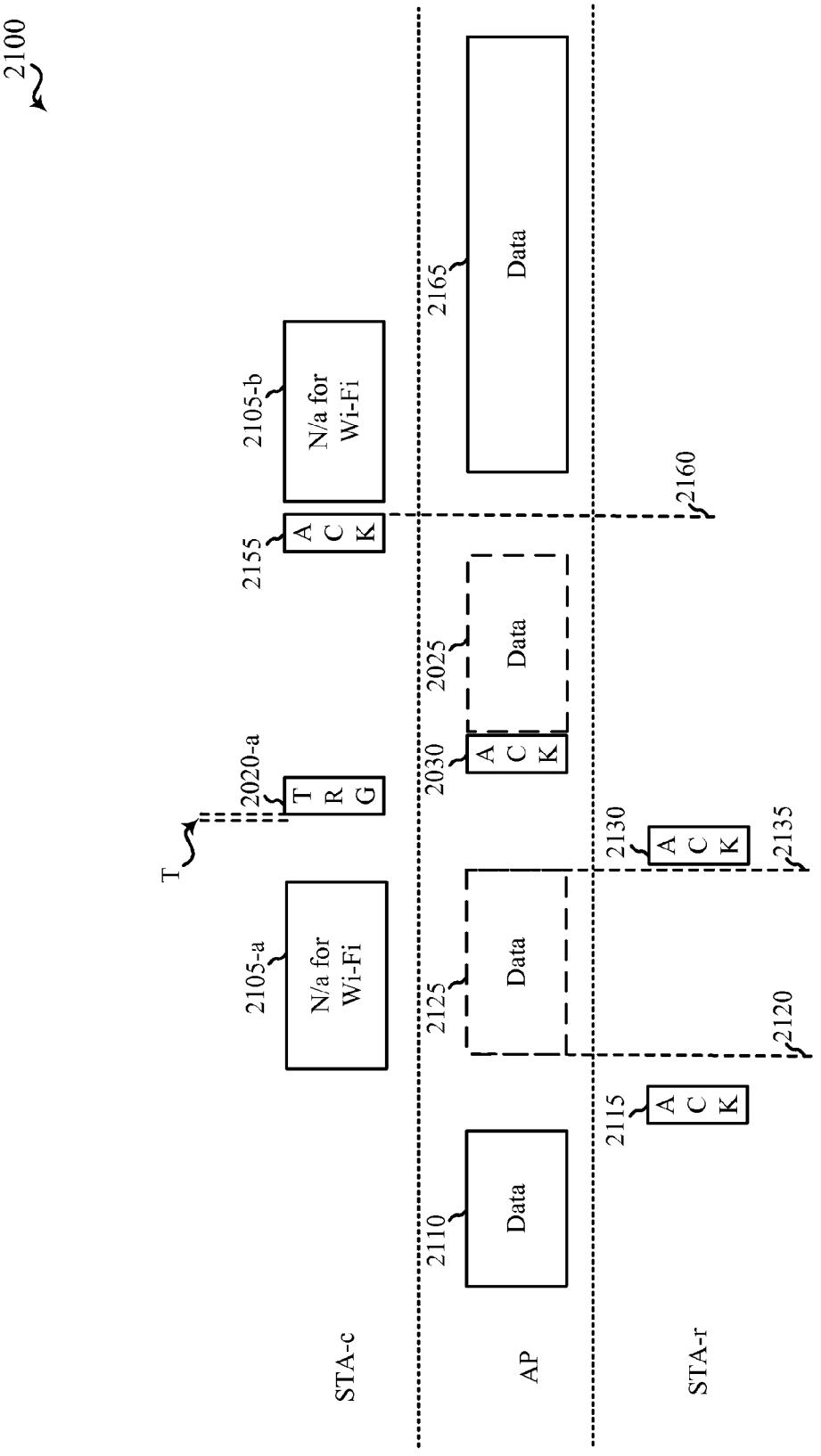

2100
STA-c
AP
STA-r
T
2105-a
N/a for Wi-Fi
2020-a
TRG
2110
Data
2115
ACK
2125
Data
2120
2130
ACK
2135
2030
ACK
2025
Data
2155
ACK
2105-b
N/a for Wi-Fi
2165
Data
2160

FIG. 21

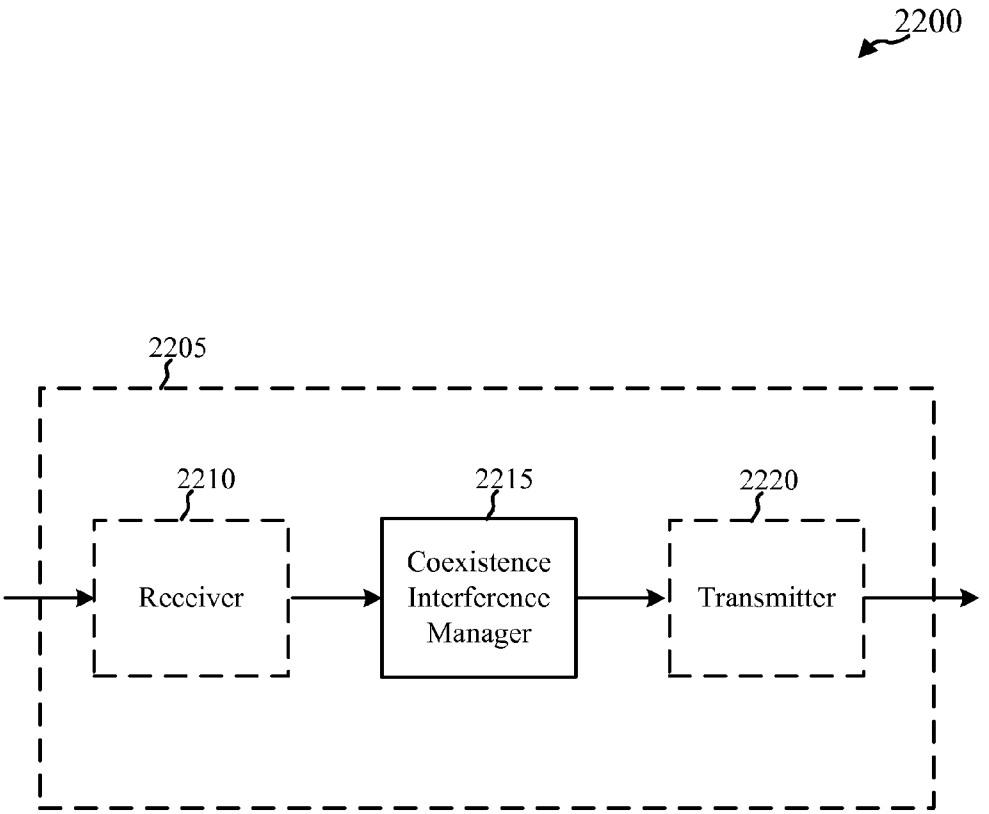

2200
2205
2210
2215
2220
Receiver
Coexistence Interference Manager
Transmitter

FIG. 22

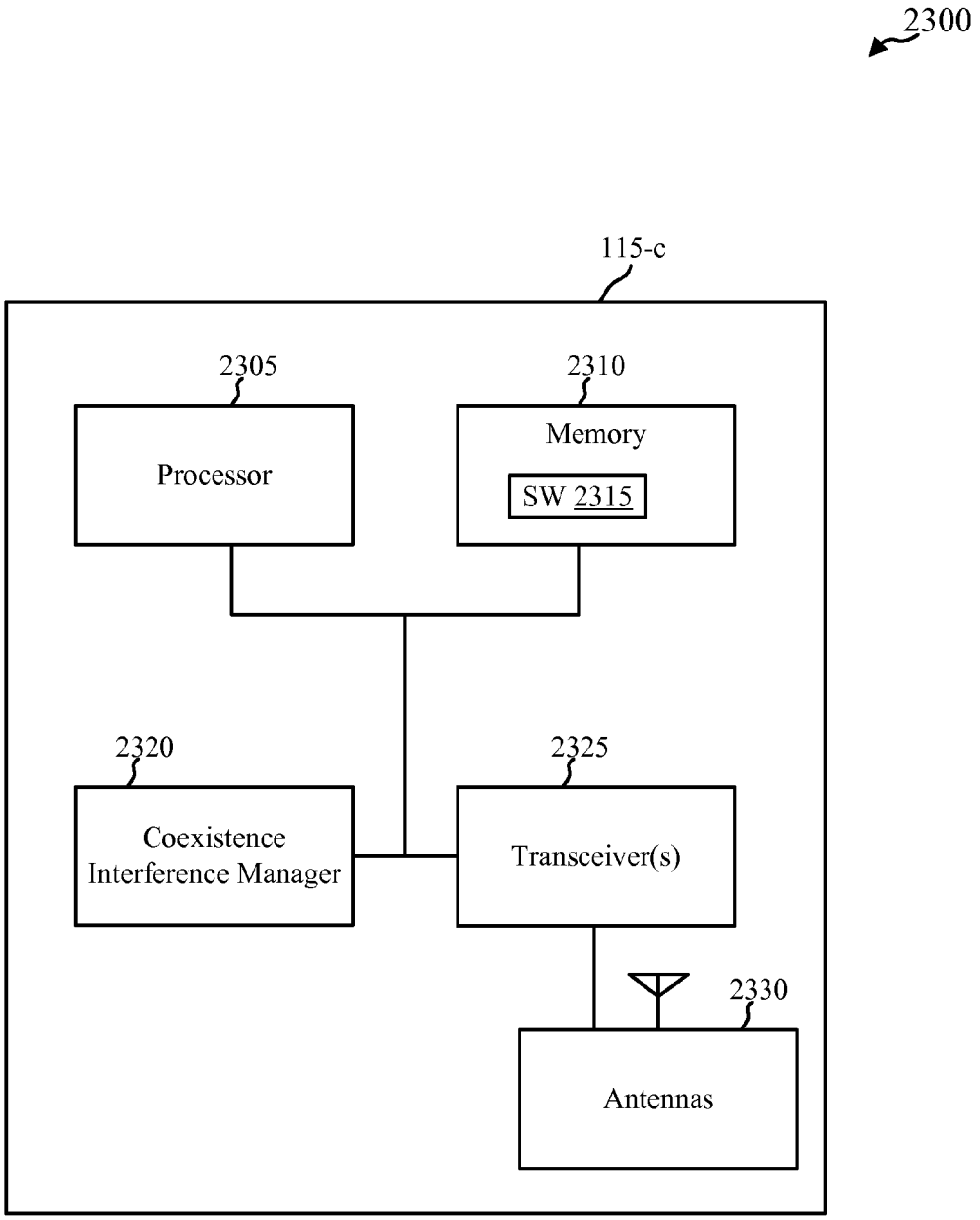

2300
115-c
2305
Processor
2310
Memory
SW 2315
2320
Coexistence Interference Manager
2325
Transceiver(s)
2330
Antennas

FIG. 23

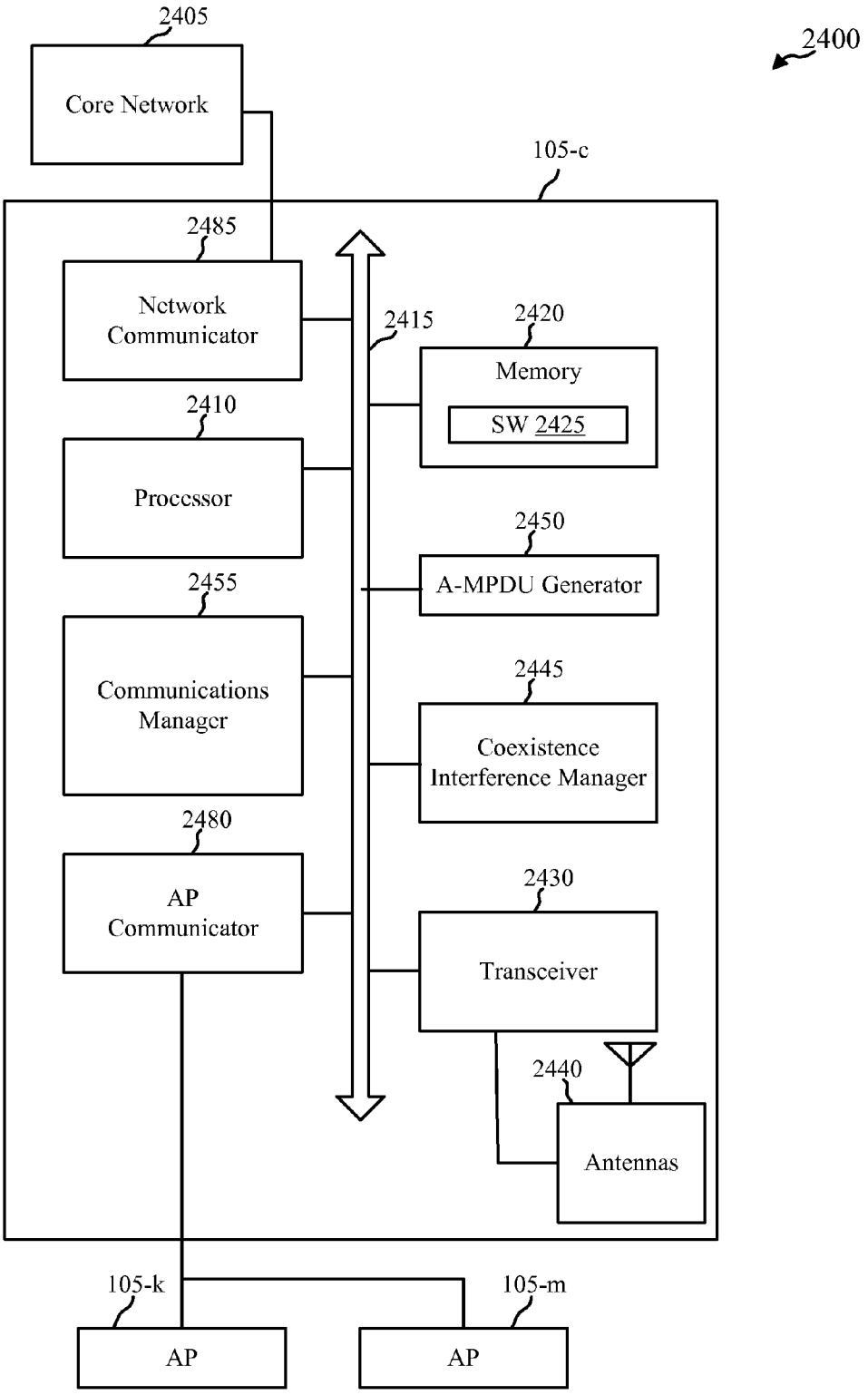

2405
2400
Core Network
105-c
2485
Network Communicator
2415
2420
Memory
SW 2425
2410
Processor
2450
A-MPDU Generator
2455
Communications Manager
2445
Coexistence Interference Manager
2480
AP Communicator
2430
Transceiver
2440
Antennas
105-k
105-m
AP
AP

FIG. 24

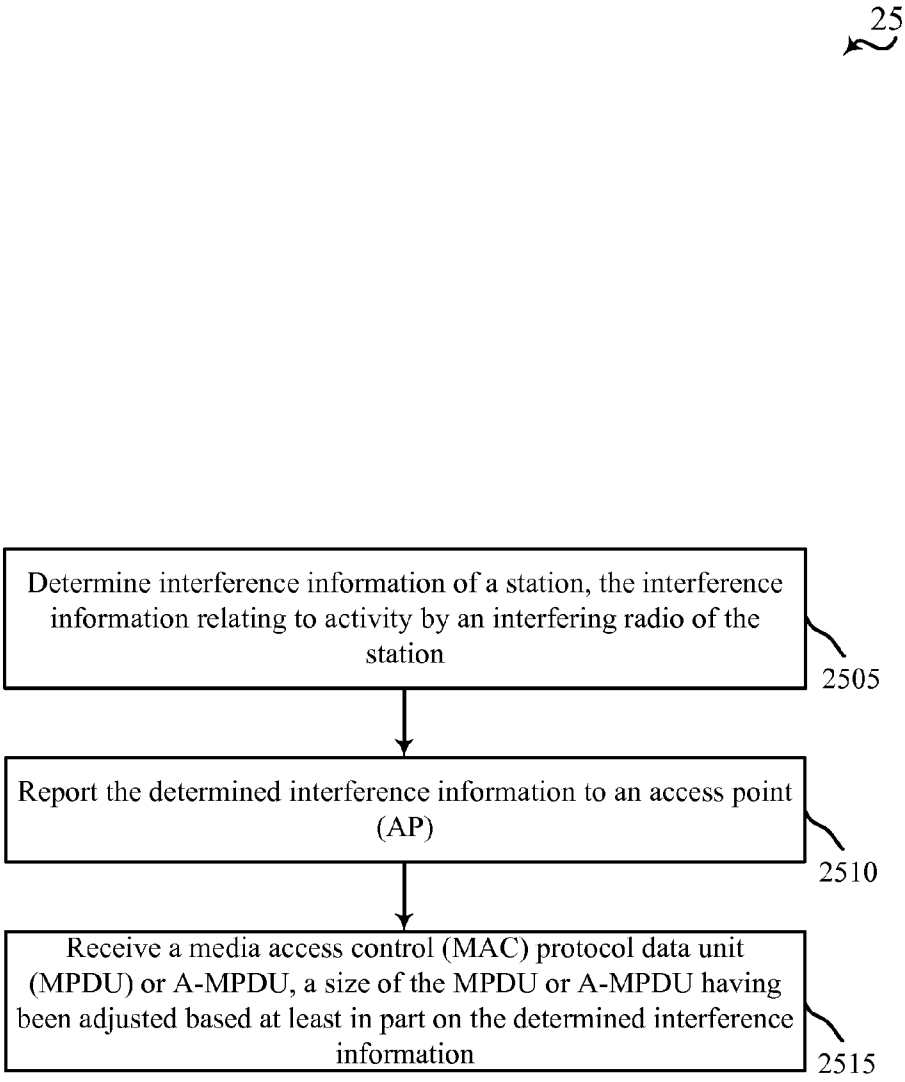

2500
Determine interference information of a station, the interference information relating to activity by an interfering radio of the station
2505
Report the determined interference information to an access point (AP)
2510
Receive a media access control (MAC) protocol data unit (MPDU) or A-MPDU, a size of the MPDU or A-MPDU having been adjusted based at least in part on the determined interference information
2515

FIG. 25

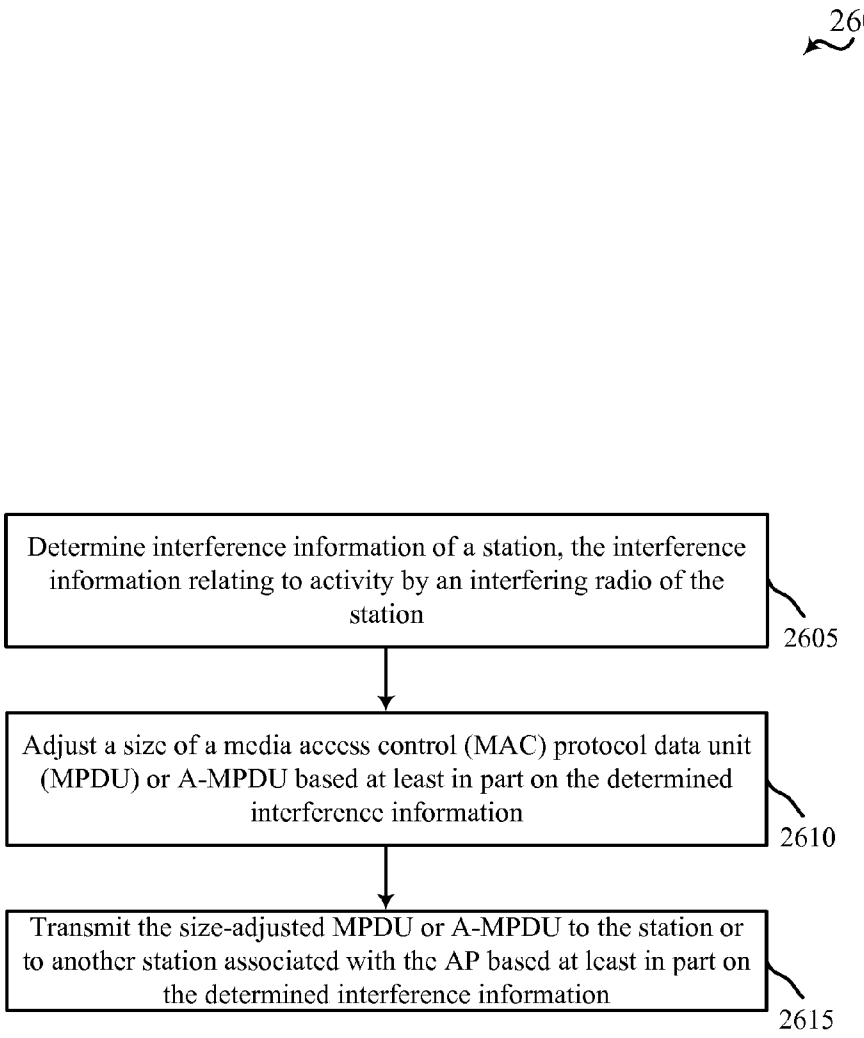

2600
Determine interference information of a station, the interference information relating to activity by an interfering radio of the station
2605
Adjust a size of a media access control (MAC) protocol data unit (MPDU) or A-MPDU based at least in part on the determined interference information
2610
Transmit the size-adjusted MPDU or A-MPDU to the station or to another station associated with the AP based at least in part on the determined interference information
2615

FIG. 26

ACCESS POINT-AIDED COEXISTENCE/CONCURRENCY AT MOBILE DEVICES

CROSS REFERENCES

[0001] The present application for patent claims priority to U.S. Provisional Patent Application No. 61/823,863 by Cho et al., entitled "SIFS RESPONSE TO PS-POLL," filed May 15, 2013, assigned to the assignee hereof, and expressly incorporated by reference herein. The present application is related to copending application Ser. No. 13/302,9U1 by Cho et al., entitled "ACCESS POINT RESPONSE TO PS-POLL," assigned to the assignee hereof, and expressly incorporated by reference herein. The present application is also related to copending application Ser. No. 13/302,9U2 by Cho et al., entitled "ACCESS POINT RESPONSE TO PS-POLL," assigned to the assignee hereof, and expressly incorporated by reference herein.

BACKGROUND

[0002] Wireless communications networks are widely deployed to provide various communication services such as voice, video, packet data, messaging, broadcast, and the like. These wireless networks may be multiple-access networks capable of supporting multiple users by sharing the available network resources.

[0003] A wireless communications network may include a number of network devices such as access points (APs) that can support communication for a number of wireless devices. A wireless device may communicate with a network device bi-directionally. For example, in a wireless local area network (WLAN), a station (STA) may communicate with an associated AP via downlink and uplink. The downlink (or forward link) refers to the communication link from the AP to the station, and the uplink (or reverse link) refers to the communication link from the station to the AP.

[0004] In WLANs, there may be cases in which a station may desire to enter a power saving mode in which transmissions between an AP and station are reduced, allowing the station to power off a component(s), such as radio components, and thereby reduce power consumption. Existing power saving techniques may, in some cases, result in relatively long periods of time between a determination by a station to enter a power saving mode and the powering off of related components, because of related network signaling to notify and confirm power saving mode with an AP. Therefore, power conservation techniques are desirable that are simple to implement and have relatively short time periods between a determination to enter a power save mode by a station and the station entering a power conservation mode.

SUMMARY

[0005] Various methods, systems, devices, and apparatuses are described for wireless communications that may enable a WLAN access point (AP) to schedule packet transmissions to (or from) a mobile device taking into consideration the schedule of various other coexisting transmission/reception (Tx/Rx) activities on the mobile device. Various embodiments may increase throughput at the mobile device. Various embodiments also may benefit other stations associated with the same AP.

[0006] A method for wireless communications is described. In one configuration, the method may involve determining interference information for a node having a WLAN radio. The interference information may relate to operations by an interfering radio of the node that interfere with WLAN communications of the node. The method also may involve scheduling a transmission to the node based at least in part on the interference information.

[0007] In some aspects, the method may involve adjusting a number of packets included in a physical layer convergence protocol (PLCP) protocol data unit (PPDU) of the transmission to the node based at least in part on the interference information. In some aspects, the PPDU may be an aggregated media access control (MAC) protocol data unit (A-MPDU). Alternatively or additionally, the method may involve fragmenting a media access control (MAC) protocol data unit (MPDU) of the transmission to the node based at least in part on the interference information.

[0008] In some aspects, the method may involve adjusting a number of packets included in a physical layer convergence protocol (PLCP) protocol data unit (PPDU) of a transmission to a different node based at least in part on the interference information. Alternatively or additionally, the method may involve fragmenting a media access control (MAC) protocol data unit (MPDU) of a transmission to a different node based at least in part on the interference information.

[0009] In some aspects, determining interference information for the node may involve receiving at least part of the interference information from the node. Alternatively or additionally, determining interference information for the node may involve estimating at least part of the interference information using transmissions received from the node.

[0010] In some aspects, the method may involve: determining that a transmission to the node is delayed due to interference; transmitting a PPDU over a transmission medium to a different node during the interference; and, providing a priority to the node for accessing the transmission medium after the interference ends. In some aspects, providing a priority to the node may involve adjusting a size of the PPDU to the different node so that transmission of the PPDU to the different node ends about a same time as the interference ends.

[0011] In some aspects, the method may involve: receiving a trigger frame from the node after the interference ends; and, transmitting data to the node in response to the trigger frame. The received trigger frame may have been sent following a space after the interference ended, wherein the space is selected from the group consisting of: a short interframe space (SIFS), a point coordination function (PCF) interframe space (PIFS), a distributed coordination function (DCF) interframe space (DIFS), or a reduced interframe space (RIFS). In other aspects, the method may involve: determining when the interference ends based at least in part on the interference information; and, transmitting data to the node once the interference ends.

[0012] In some aspects, the method may involve: setting a flag that indicates that the node has been bypassed for transmission; and, when the flag is set, adjusting a size of the PPDU to the different node so that transmission of the PPDU to the different node ends about a same time as the interference ends. In some aspects, the method also may involve clearing the flag upon successfully transmitting data to the node. Alternatively or additionally, the method may involve clearing the flag upon a certain number of unsuccessful transmissions of data to the node.

[0013] In some aspects, the transmissions of the interfering radio use a different radio access technology than WLAN.

Alternatively or additionally, the interfering radio may be the WLAN radio. In such case, the interference information may be based at least in part on a schedule of the WLAN radio for accessing a channel other than a channel for communicating a node performing scheduling of the transmission, e.g., an access point of the node.

[0014] In some aspects, the method may involve: identifying a sub-frame error based at least in part on the interference information; and, handling the identified sub-frame error in rate control.

[0015] An apparatus for wireless communications is described. In one configuration, the apparatus may include a coexistence interference manager configured to determining interference information for a node having a WLAN radio. The interference information may relate to operations by an interfering radio of the node that interfere with WLAN communications of the node. The apparatus also may include a communications manager configured to schedule a transmission to the node based at least in part on the interference information. The coexistence interference manager and/or the communications manager may be configured to perform various additional functions of the methods described above and as described further herein. Alternatively or additionally, the apparatus may include additional components that are configured to perform various additional functions of the methods described above and as described further herein.

[0016] Another apparatus for wireless communications is described. In one configuration, the apparatus may include means for determining interference information for a node having a WLAN radio. The interference information may relate to operations by an interfering radio of the node that interfere with WLAN communications of the node. The apparatus also may include means for scheduling a transmission to the node based at least in part on the interference information. Further, the apparatus may include means configured to perform various additional functions of the methods described above and as described further herein.

[0017] A computer program product is described. In one configuration, the computer program product may be a non-transitory computer-readable medium including instructions stored thereon. The instructions may be executable by a computer to: determine interference information for a node having a WLAN radio, the interference information relating to operations by an interfering radio of the node that interfere with WLAN communications of the node; and, schedule a transmission to the node based at least in part on the interference information. Further, the stored instructions may be executable by the computer to perform various additional functions of the methods described above and as described further herein.

[0018] The foregoing has outlined rather broadly the features and technical advantages of examples according to the disclosure in order that the detailed description that follows may be better understood. Additional features and advantages will be described hereinafter. The conception and specific examples disclosed may be readily utilized as a basis for modifying or designing other structures for carrying out the same purposes of the present disclosure. Such equivalent constructions do not depart from the spirit and scope of the appended claims. Features which are believed to be characteristic of the concepts disclosed herein, both as to their organization and method of operation, together with associated advantages will be better understood from the following description when considered in connection with the accompanying figures. Each of the figures is provided for the purpose of illustration and description only, and not as a definition of the limits of the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] A further understanding of the nature and advantages of the present disclosure may be realized by reference to the following drawings. In the appended figures, similar components or features may have the same reference label. Further, various components of the same type may be distinguished by following the reference label by a dash and a second label that distinguishes among the similar components. If only the first reference label is used in the specification, the description is applicable to any one of the similar components having the same first reference label irrespective of the second reference label.

[0020] FIG. **1** shows a diagram that illustrates an example of a wireless local area network (WLAN) that supports power conservation modes according to various embodiments;

[0021] FIG. **2** shows a diagram that illustrates an example of a frame exchange between an AP and a station entering a power save mode according to various embodiments;

[0022] FIG. **3** shows a diagram that illustrates another example of an exchange between an AP and a station entering a power save mode according to various embodiments;

[0023] FIG. **4** shows a diagram that illustrates an example of transmissions between an AP and a station entering a power save mode according to various embodiments;

[0024] FIG. **5** shows a diagram that illustrates another example of transmissions between an AP and a station entering a power save mode according to various embodiments;

[0025] FIG. **6** shows a diagram that illustrates another example of transmissions between an AP and a station entering a power save mode according to various embodiments;

[0026] FIG. **7** shows a diagram that illustrates another example of transmissions between an AP and a station entering a power save mode according to various embodiments;

[0027] FIG. **8** shows a diagram that illustrates another example of transmissions between an AP and a station entering a power save mode according to various embodiments;

[0028] FIG. **9** is a flowchart of an example of operations related to entering power save mode for a station according to various embodiments;

[0029] FIG. **10** is a flowchart of an example of operations related to entering power save mode for an AP according to various embodiments;

[0030] FIG. **11** shows a block diagram that illustrates an example of a power saving mode architecture according to various embodiments;

[0031] FIG. **12** shows a block diagram that illustrates an example of a station architecture according to various embodiments;

[0032] FIG. **13** shows a block diagram that illustrates an example of an AP architecture according to various embodiments;

[0033] FIG. **14** is a flowchart of an example of a method for power conservation in a wireless communication system according to various embodiments;

[0034] FIG. **15** is a flowchart of an example of another method for power conservation in a wireless communication system according to various embodiments;

[0035] FIG. **16** is a flowchart of an example of yet another method for power conservation in a wireless communication system according to various embodiments;

[0036] FIGS. **17**A-D show diagrams that illustrate examples of coexisting communications at a mobile device;

[0037] FIG. **18** shows a diagram that illustrates an example of transmissions between a station and an AP for taking into consideration scheduling information of other coexisting Tx/Rx activities on the station;

[0038] FIG. **19** shows a timing diagram that illustrates an approach for deriving timing information related to coexisting/interfering Tx/Rx activities on a station;

[0039] FIG. **20**A shows a diagram that illustrates how a coexistence station may be at a disadvantage when competing for WLAN medium with a non-coexistence or regular station in the same BSS;

[0040] FIG. **20**B shows a diagram that illustrates how adjusting the size of an A-MPDU to the non-coexistence station(s) may improve throughput for the coexistence station and fairness to the coexistence station;

[0041] FIG. **21** shows a diagram that illustrates an example of transmissions between a coexistence station and an AP and transmissions between a non-coexistence or regular station and the AP;

[0042] FIG. **22** shows a block diagram that illustrates an example of a device that may be used to implement various embodiments for dealing with coexistence interference;

[0043] FIG. **23** shows a diagram that illustrates a station that may be used to implement various embodiments for dealing with coexistence interference;

[0044] FIG. **24** shows a diagram that illustrates AP that may be used to implement various embodiments for dealing with coexistence interference;

[0045] FIG. **25** is a flowchart of an example of a method for dealing with coexistence interference; and

[0046] FIG. **26** is a flowchart of an example of another method for dealing with coexistence interference.

DETAILED DESCRIPTION

[0047] Described examples are directed to methods, systems, devices, and apparatuses for power conservation in a wireless communications system that may enhance power conservation through efficient transmissions and acknowledgements of information between an AP and a station. The time between a determination by a station to enter a power saving mode and entering network sleep mode by the station may be reduced through a transmission, by an AP, of a media access control (MAC) protocol data unit (MPDU) to the station successive to a short interframe space (SIFS) after transmission of an acknowledgement to the station of a PS-Poll frame from the station. Transmission of the MPDU after the SIFS following the acknowledgement may reduce the time associated with random backoffs following an acknowledgement of the AP, and may reduce or eliminate the time associated with queue delay, other traffic, or collisions of traffic with another station(s). The time to enter a power saving mode by a station may also be reduced through transmission of aggregated MPDUs (A-MPDUs), with initial MPDUs of an A-MPDU having an indicator bit set to indicate more data and a last MPDU of the A-MPDU having its indicator bit cleared to indicate no additional data is to be transmitted. Efficiencies may further be enhanced through an AP preventing a retransmission of an MPDU to the station in the absence of an acknowledgement from the station that the MPDU is received. In addition to power savings, examples described may also provide, for example, a more efficient usage of the overall wireless medium, thus enhancing medium resources available for other devices, providing a higher throughput, lower wait times for devices to access the medium, and may reduce the amount of collisions in the medium.

[0048] Throughout this description, the terms MPDU and A-MPDU are used. It should be understood, however, that other types of data units may be employed. In terms of MPDUs and A-MPDUs, the term physical layer convergence protocol (PLCP) data unit (PPDU) may be used.

[0049] The power conservation techniques presented herein are generally described in connection with WLANs for simplicity. A WLAN (or Wi-Fi network) may refer to a network that is based on the protocols described in the various IEEE 802.11 standards (e.g., 802.11a/g, 802.11n, 802.11ac, 802.11ah, etc.). The same or similar techniques, however, may be used for various other wireless communications systems such as cellular wireless systems, peer-to-peer wireless communications, ad hoc networks, satellite communications systems, and other systems. The terms "system" and "network" may be used interchangeably.

[0050] Thus, the following description provides examples, and is not limiting of the scope, applicability, or configuration set forth in the claims. Changes may be made in the function and arrangement of elements discussed without departing from the spirit and scope of the disclosure. Various examples may omit, substitute, or add various procedures or components as appropriate. For instance, the methods described may be performed in an order different from that described, and various steps may be added, omitted, or combined. Also, features described with respect to certain examples may be combined in other examples.

[0051] As used herein, the term "successive to" refers to a second transmission that immediately follows a first transmission. For example, an MPDU that is transmitted "successive to an SIFS after transmission of an acknowledgement" means that the MPDU is transmitted immediately following an SIFS period that immediately follows the termination of the acknowledgement.

[0052] Referring first to FIG. **1**, a WLAN **100** or Wi-Fi network is shown that is configured to provide enhanced power conservation. The WLAN **100** includes an AP **105** and multiple associated stations **115**. In this example, there are shown seven (7) stations or STAs **115**, which are identified as STA_1, STA_2, STA_3, STA_4, STA_5, STA_6, and STA_7. The WLAN **100**, however, may have more or fewer stations **115** than those shown in FIG. **1** since the number shown is simply for illustrative purposes. The AP **105** and the associated stations **115** may represent a basic service set (BSS). The various stations **115** in the BSS are able to communicate with one another through the AP **105**. Also shown is a coverage area **120** of the AP **105**, which may represent a basic service area (BSA) of the WLAN **100**. Although not shown in FIG. **1**, the BSS associated with the WLAN **100** is typically connected to a wired or wireless distribution system (DS) that allows multiple APs to be connected in an extended service set.

[0053] The AP **105** is configured to communicate bi-directionally with each of the stations **115** using transmissions **130**. The transmissions **130** may include downlink transmissions (e.g., beacon frames) that are sent from the AP **105** to a station **115** as well as uplink transmissions (e.g., acknowledgements or ACK frames) that are sent from a station **115** to the AP **105**. Typically, the AP **105** is configured to broadcast its downlink transmissions to the stations **115** that are within the coverage area **120**. In situations where a station **115** does not expect to

actively transmit or receive data, it may be beneficial for the station **115** to power down certain of its components, such as radio components, in order to reduce power consumption of the station. Various wireless standards, such as the 802.11 standards, define a power-save mode for stations **115**. In power-save mode, a station **115** may choose to enter a network sleep mode for a beacon interval(s)s, waking periodically to receive beacon frames that include a delivery traffic indication message (DTIM). In some implementations, a DTIM may be transmitted periodically in beacon frames, such as, for example, every other beacon frame, and a station **115** in network sleep mode may awaken to receive every other beacon frame but otherwise remain asleep and may thereby reduce power consumption. To initiate a power-save mode, a station **115** may transmit a notification to the AP **105**, so that the AP **105** will know how to handle data traffic destined for the station **115**. In some examples, the AP **105** and a station of the stations **115** may be configured to implement communications related to entry of a power save mode by the station.

[0054] With reference now to FIG. **2**, an example **200** of transmissions between a station and an AP, such as between a station **115** and AP **105** of FIG. **1**, according to traditional power saving mode techniques is described. In this example, a station at some point determines that it should enter into a power save mode. Such a determination may be made, for example, based on a state of a transmit data queue of the station, recent activity of the station, or power saving preferences set for the station, to name but a few examples. After the station has entered power save mode, it may determine that there is data pending for it at the AP. Such a determination may be based on, for example, a "TIM bit" which may be set in the beacon sent out by the AP. In order to retrieve that data, but still remaining in a Wi-Fi protocol based power save state, the station may transmit a power-save polling (PS-Poll) frame **205** to the AP. The AP, following a short interframe space (SIFS) **210** may transmit an acknowledgement **215** that acknowledges the receipt of the PS-Poll frame. Following a DCF interframe space (DIFS) and a random backoff (RBO) **220**, the AP may transmit a single MPDU **225** in response to the PS-Poll frame **205**. Following an SIFS **230**, the station may transmit an acknowledgement **235** that the MPDU **225** was received.

[0055] At this point, the AP assumes that the station has gone back into a network sleep mode, and the station may go into network sleep mode. According to various implementations, the duration of the DIFS and RBO on average is approximately 110 μsec. Additionally, other factors may also cause delays in a station entering network sleep mode. For example, queue delays within the AP may result in a delay of the transmission of MPDU **225** by the AP, and reception of MPDU **225** by the STA. Such a queue delay may occur, for example, when another station receives an MPDU or an aggregated MPDU (A-MPDU) from the AP, which was queued to be transmitted before the MPDU **225**. Such a queue delay may result in a delayed entry by the station into network sleep mode, and thus result in increased power consumption relative to a case that experiences no queue delay. Another factor that may delay a station from entering network sleep mode is traffic from another station that may be transmitted following lower RBO. The AP would then be delayed in transmitting MPDU **225**, which would in turn delay the station from entering network sleep mode. A further factor that may delay a station from entering network sleep mode is a collision between the AP transmitted MPDU **225** and a transmission of another station. Such a situation results in a retransmission of the MPDU **225** following an increased RBO, potentially with a reduced data rate. Thus, such a situation may also delay the station from entering network sleep mode.

[0056] With reference now to FIG. **3**, an example **300** of transmissions between a station and an AP, such as between a station **115** and AP **105** of FIG. **1**, according to various examples is described. In this example, a station makes a determination to enter into a power save mode. As mentioned above, such a determination may be made based on a number of factors at the station. After the station has entered power save mode, it may determine that there is data pending for it at the AP, similarly as described above with respect to FIG. **2**. In order to retrieve that data while maintaining a power save state, the station may transmit a PS-Poll frame **205**-*a* to the AP. The AP, following SIFS **210**-*a* may transmit an acknowledgement **215**-*a* that acknowledges the receipt of the PS-Poll frame, also similarly as described with respect to FIG. **2**. Following a DIFS and RBO **220**-*a*, the AP may transmit a single MPDU **225**-*a* in response to the PS-Poll frame **205**-*a*. Following an SIFS **230**-*a*, the station may transmit an acknowledgement **305** that the MPDU **225**-*a* was received.

[0057] Circumstances may arise, however, which may prevent the acknowledgement **305** from being received at the AP. For example, interference may result in the AP being unable to properly receive the acknowledgement **305**. The station, however, having sent the acknowledgement **305** may enter into network sleep mode. The AP, following a timeout period **315**, may retransmit MPDU **225**-*a*. The station, having entered network sleep mode, does not receive the retransmitted MPDU **225**-*a*, and the AP thus does not receive an acknowledgement again. The AP, in this example, retransmits MPDU **225**-*a* after period **310**, which is an increased backoff period with respect to period **310**. According to the example of FIG. **3**, the station again would not transmit an acknowledgement, resulting in the AP again retransmitting the MPDU **225**-*a* following period **320** which has an increased backoff period as compared to period **315**.

[0058] According to some examples, the AP may discontinue sending retransmissions of the MPDU following a limited number of MPDUs after the PS-Poll frame. Such a limit on retransmissions may save some network and AP resources, as compared to implementations where retransmissions are attempted until an acknowledgement is received. Additionally, according to some examples, a data transmission rate for the station may remain unadjusted in the absence of the acknowledgement from the station that the MPDU is received, based on the assumption that the station may be in sleep mode. In some other cases, the AP may transmit at unadjusted data rate for a limited number of attempts, and then adjust the data rate for a subsequent transmission(s) of an MPDU. In some examples, the AP and station may communicate on a busy or noisy channel, which may result in the station being unable to receive transmissions at the unchanged rate, and it may be determined that the lack of an acknowledgement is a result of the channel conditions or is a result of a collision with another station(s) communicating with the AP. In such cases, the retransmission of MPDU **225**-*a* may be performed using an adjusted data rate or with a different backoff period applied. Adjusting the data transmission rate may be accomplished, for example, through an update to a rate adaptation table at the AP.

[0059] With reference now to FIG. **4**, an example **400** of transmissions between a station and an AP, such as between a station **115** and AP **105** of FIG. **1**, according to power saving techniques of various examples is described. In this example, a station determines that it should enter into a power save mode. Such a determination may be made as discussed above, according to factor(s) at the station. After the station has entered power save mode, it may determine that there is data pending for it at the AP, similarly as described above with respect to FIG. **2**. In order to retrieve that data while maintaining a power save state, the station may transmit a PS-Poll frame **405** to the AP. The AP, following SIFS **410** may transmit an acknowledgement **415** that acknowledges the receipt of the PS-Poll frame. In the example of FIG. **4**, instead of waiting for a DCF interframe space (DIFS) and a random backoff (RBO) periods, the AP waits only for an SIFS **420**, and transmits MPDU **425**. That is, the AP transmits MPDU **425** successive to SIFS **420** without waiting for the DIFS and RBO times after the transmission of the acknowledgement **415** to the station. Following another SIFS **430**, the station may transmit an acknowledgement **435** that the MPDU **425** was received. At this point, the AP assumes that the station has gone to network sleep mode, and the station may go into network sleep mode. During the time that the AP is transmitting acknowledgement **415**, a module of the AP may prepare the MPDU **425** for transmission such that the MPDU **425** is set to be transmitted successive to SIFS **420**. In such a manner, the time for the station to enter network sleep is reduced, thus enhancing power savings at the station. In cases where the DIFS and RBO times are reduced, the station may enter network sleep mode, according to some examples, approximately 100 μs sooner. However, in cases where additional delay may be present, such as queue delays, other traffic delays, and/or collision delays, the time for the station to enter network sleep may be more significantly reduced, thus further enhancing power savings.

[0060] In some examples, an AP may have additional data in its buffered data queue to be transmitted to the station than may be transmitted in a single MPDU. With reference now to FIG. **5**, another example **500** of transmissions between a station and an AP, such as between a station **115** and AP **105** of FIG. **1**, according to power saving techniques of various examples is described. In this example, a station determines that it should enter into a power save mode. Such a determination may be made as discussed above, according to factor (s) at the station. After the station has entered power save mode, it may determine that there is data pending for it at the AP, similarly as described above with respect to FIG. **2**. In order to retrieve that data while maintaining a power save state, the station may transmit a PS-Poll frame **505** to the AP. The AP, following SIFS **510** may transmit an acknowledgement **515** that acknowledges the receipt of the PS-Poll frame. In the example of FIG. **5**, the AP waits only for the SIFS **520**, and transmits MPDU **525**. The MPDU **525** may include an indicator bit to indicate that more data is to be transmitted to the station following the transmission of the MPDU **525**. Such an indicator bit may be referred to as a "more bit" and may be set or cleared based on the status of the buffered data queue at the AP.

[0061] Following an SIFS **530**, the station may transmit an acknowledgement **535** that the MPDU **525** was received. At this point, the AP assumes that the station has gone to network sleep mode, although the station, based on the more bit of the MPDU **525**, may not enter into sleep mode. In the example of FIG. **5**, the station, following period **540**, transmits a second PS-Poll frame **545**. The AP, following SIFS **550** may transmit an acknowledgement **555** that acknowledges the receipt of the second PS-Poll frame **545**. The AP again waits only for the SIFS **560**, and transmits MPDU **565**. If the buffered data queue at the AP does not include any additional data for the station, the more bit of MPDU **565** may be cleared. Following an SIFS **570**, the station may transmit an acknowledgement **575** that the MPDU **565** was received. At this point, the AP assumes that the station has gone to network sleep mode, and the station may go into network sleep mode.

[0062] In some examples, rather than transmitting a single MPDU, an AP may transmit an aggregated MPDU (A-MPDU). Such an A-MPDU may include multiple MPDUs transmitted sequentially by the AP. With reference now to FIG. **6**, another example **600** of transmissions between a station and an AP, such as between a station **115** and AP **105** of FIG. **1**, according to power saving techniques of various examples is described. In this example, a station determines that it should enter into a power save mode. Such a determination may be made as discussed above, according to factor (s) at the station. After the station has entered power save mode, it may determine that there is data pending for it at the AP, similarly as described above with respect to FIG. **2**. In order to retrieve that data while maintaining a power save state, the station may transmit a PS-Poll frame **605** to the AP. The AP, following an SIFS **610** may transmit an acknowledgement **615** that acknowledges the receipt of the PS-Poll frame. In the example of FIG. **6**, the AP waits only for the SIFS **620**, and transmits an A-MPDU **625**. The A-MPDU **625** may include a number of MPDUs **630**, **635**, **640** transmitted sequentially from the AP. In the example of FIG. **6**, the first two MPDUs **630**, **635** of A-MPDU **625** have a more bit that is set, and the last MPDU **640** has a more bit which is cleared to indicate that no more data is to be transmitted by the AP to the station following the transmission of the A-MPDU **625**. In other examples, all of the more bits of A-MPDU **625** may be set to indicate that the buffered data queue at the AP still contains additional data, which the AP could send to the STA when the STA request it to do so, with, for example, a PS-POLL frame.

[0063] Following an SIFS **645**, the station may transmit a block acknowledgement (BA) **650** indicating which MPDUs **630**, **635**, **640** of A-MPDU **625** are properly received. Such a BA **650** may include, according to some implementations, a starting MPDU sequence number and a bitmap of a predefined number of prior sequence numbers, with bits of the bitmap set or cleared to indicate which sequence numbers have been properly received at the station. In the example of FIG. **6**, the BA **650** may indicate that MPDU **635** was not received. At this point, the AP assumes that the station has gone to network sleep mode, although the station, based on a status of its receive queue indicating that MPDU **635** was not properly received, may not enter into sleep mode. In the example of FIG. **6**, the station, following period **655**, transmits a second PS-Poll frame **660**. The AP, following SIFS **665** may transmit an acknowledgement **670** that acknowledges the receipt of the second PS-Poll frame **660**. The AP again waits only for the SIFS **675**, and transmits MPDU **680**. MPDU **680** may contain data initially attempted to be transmitted in MPDU **635**. If the buffered data queue at the AP does not include any additional data for the station, the more bit of MPDU **680** may not be set. Following an SIFS **685**, the station may transmit an acknowledgement **690** that the

MPDU **680** was received. At this point, the AP assumes that the station has gone to network sleep mode, and the station may go into network sleep mode knowing that there is no more data pending at the AP.

[0064] In some cases, the AP may not properly receive a BA from a station, and may retransmit an A-MPDU following a random backoff period. Similarly as discussed above with respect to FIG. **3**, if, after a limited number of re-transmits, no BA is received the AP may in some examples assume that the station was asleep and makes no change to the rate table. In some examples, however, additional data may be received at the AP for transmission to the station. According to some examples, additional MPDUs may be added to a re-transmitted A-MPDU. With reference now to FIG. **7**, an example **700** of retransmissions between a station and an AP that may include additional MPDUs is described. Such transmissions may be between, for example, a station **115** and AP **105** of FIG. **1**. In this example, a station initially determines that it should enter into a power save mode. After the station has entered power save mode, it may determine that there is data pending for it at the AP, similarly as described above with respect to FIG. **2**. In order to retrieve that data while maintaining a power save state, the station may transmit a PS-Poll frame **705** to the AP. The AP, following an SIFS **710** may transmit an acknowledgement **715** that acknowledges the receipt of the PS-Poll frame. In the example of FIG. **7**, the AP waits only for the SIFS **720**, and transmits an A-MPDU **725**. The A-MPDU **725** may include a number of MPDUs **730**, **735**, **740** transmitted sequentially from the AP. In the example of FIG. **7**, the first two MPDUs **730**, **735** of A-MPDU **725** have a more bit that is set, and the last MPDU **740** has a more bit this is cleared, to indicate that no more data is to be transmitted to the station following the transmission of the A-MPDU **725**.

[0065] Following an SIFS **745**, the station may transmit a BA **750** indicating which MPDUs **730**, **735**, **740** of A-MPDU **725** are properly received. In the example of FIG. **7**, the BA **750** may indicate that MPDU **735** was not received. Circumstances may arise, however, which may prevent the BA **750** from being received at the AP. For example, interference may result in the AP being unable to properly receive the BA **750**. The AP, in the example of FIG. **7**, may have received additional data for the station. In such a case, the AP, following a timeout period **755**, may transmit A-MPDU **760**. The A-MPDU **760** may include retransmissions of MPDUs **730**, **735**, and **740** transmitted sequentially from the AP, as well as MPDU **765**, which includes the additional data received at the AP. In other examples, BA **750** may be properly received by the AP, but the station may send another PS-Poll frame to the AP in order to retrieve the missing frame as indicated by the BA, at which point the AP may add MPDU **765** in the subsequent A-MPDU. In the example of FIG. **7**, the first three MPDUs **730**, **735**, and **740** of A-MPDU **760** have a more bit that is set, and the last MPDU **765** has a more bit this is cleared, indicate that more data is to be transmitted to the station following the transmission of the A-MPDU **760**. Following an SIFS **770**, the station may transmit a BA **775** that the A-MPDU **760** was received. At this point, the AP assumes that the station has gone to network sleep mode, and the station may go into network sleep mode. In some cases, the BA **775** may indicate that one of MPDUs **730**, **735**, **740**, and **765** were not properly received, at which point the station may transmit another PS-Poll frame in a similar manner as discussed above with respect to FIG. **6**.

[0066] In some implementations, a station may not be configured to recognize that different MPDUs in an A-MPDU may contain different values for more bits. In some examples, an AP may recognize that the station does not have such capability, and may always set the more bits in an A-MPDU to the same value. With reference now to FIG. **8**, another example **800** of A-MPDU transmissions between a station and an AP, such as between a station **115** and AP **105** of FIG. **1**, according to power saving techniques of various examples is described. In this example, a station determines that it should enter into a power save mode. After the station has entered power save mode, it may determine that there is data pending for it at the AP, similarly as described above with respect to FIG. **2**. In order to retrieve that data while maintaining a power save state, the station may transmit a PS-Poll frame **805** to the AP. The AP, following an SIFS **810** may transmit an acknowledgement **815** that acknowledges the receipt of the PS-Poll frame. In the example of FIG. **8**, the AP waits only for the SIFS **820**, and transmits an A-MPDU **825**. The A-MPDU **825** may include a number of MPDUs **830**, **835**, **840** transmitted sequentially from the AP. In the example of FIG. **8**, the buffered data queue of AP may be empty following the transmission of MPDU **840**, but the AP may recognize that the station is not configured to recognize different values of more bits in A-MPDU **825**. Thus, each of the MPDUs **830**, **835** and **840** of A-MPDU **825** has a more bit that is set. Following an SIFS **845**, the station may transmit a BA **850** indicating that all MPDUs **830**, **835**, **840** of A-MPDU **825** are properly received. At this point, the AP assumes that the station has gone to network sleep mode, although the station, based on the value of the more bits of A-MPDU **825**, may not enter into sleep mode. In the example of FIG. **8**, the station, following period **855**, transmits a second PS-Poll frame **860**. The AP, following SIFS **865** may transmit an acknowledgement **870** that acknowledges the receipt of the second PS-Poll frame **860**. The AP again waits only for the SIFS **875**, and transmits a null data frame **880** having a more bit that is not set. Following an SIFS **885**, the station may transmit an acknowledgement **890** that the null data frame **880** was received. At this point, the AP assumes that the station has gone to network sleep mode, and the station may go into network sleep mode.

[0067] With reference now to FIG. **9**, a flow diagram of a method **900** for power conservation at a station is discussed in accordance with various examples. The method **900** may be implemented using, for example, the stations **115** of FIG. **1**. At block **905**, the station transmits a PS-Poll frame. At block **910**, the station determines if an acknowledgement of the PS-Poll frame is received. If an acknowledgement is not received, the station may transmit the PS-Poll frame again, as indicated at block **905**. If the station does receive an acknowledgement, the station then determines if an MPDU or A-MPDU is received. If an MPDU or A-MPDU is not received within a timeout period, the station may transmit another PS-Poll frame, as indicated at block **905**, or in some examples may simply enter network sleep mode. If an MPDU or A-MPDU is received at block **915**, the station determines an ACK policy, which can be ACK or BA, according to block **920**. For a single MPDU, this is typically ACK, and for A-MPDU this is typically BA, but not always. In the case of the acknowledgement policy being an ACK policy, an acknowledgement may be transmitted, according to block **925**. In the case of a BA policy, the station may transmit a BA, according to block **930**. At block **935**, the station determines

if the re-order queue at the station is empty. If the re-order queue is not empty, operations continue at block **905**. If the re-order queue is empty, the station determines if an MPDU more bit was set in the received MPDU or more bit was set in the last received MPDU of the A-MPDU, as indicated at block **940**. If the more bit was set, operations may continue at block **905**. Similarly, as discussed above, in some configurations, a station may be able to identify if a more bit is set or cleared in different MPDUs of an A-MPDU. If it is determined that the more bit is not set, the station enters network sleep mode, as indicated at block **945**.

[0068] Turning now to FIG. **10**, a flow diagram of a method **1000** for power conservation at an AP is discussed in accordance with various examples. The method **1000** may be implemented using, for example, the APs **105** of FIG. **1**. At block **1005**, the AP receives a PS-Poll frame. At block **1010**, the AP transmits an acknowledgement of the PS-Poll frame. The AP then determines, at block **1015**, whether the buffered data queue for the station is empty. If the buffered data queue is empty, the AP transmits a null frame with the more bit cleared following an SIFS period after transmission of the acknowledgement, as indicated at block **1020**. At block **1025**, the AP determines if an acknowledgement is received. If an acknowledgement is not received, the AP station may retransmit, at block **1030**, the null frame a limited number of times, similarly as discussed above. If an acknowledgement is received at block **1025**, the AP may assume that the station is asleep, as indicated at block **1035**. If, at block **1015**, the buffered data queue is not empty, the AP, at block **1040**, determines if more data is present after an A-MPDU is transmitted to the station. If more data is present, the AP may transmit an A-MPDU with more bits set for each MPDU of the A-MPDU, as indicated at block **1045**. In some examples, the AP may also determine that the station may not be configured to distinguish that different MPDUs of an A-MPDU may have different values for a more bit, and may set all of the more bits of the MPDUs of the A-MPDU. If it is determined that the buffered data queue will be empty following transmission of an A-MPDU, the AP may transmit an A-MPDU with the more bit of the last MPDU cleared, as indicated at block **1050**. As noted above, in cases where a station may not recognize different more bit values in an A-MPDU, block **1055** may be skipped. At block **1055**, it is determined whether a BA is received for all of the MPDUs. If a BA is received, the AP may assume that the station is asleep, according to block **1035**. If the BA is not received, the AP may retransmit the A-MPDU a limited number of times, as indicated at block **1060**. Retransmissions may be performed in a similar manner as discussed above, for example.

[0069] With reference now to FIG. **11**, a block diagram illustrates a device **1100** that may be used in power conservation of various examples. The device **1100** may be an example of various aspects of the APs **105** or stations **115** described with reference to FIG. **1**. The device **1100**, or portions of it, may also be a processor. The device **1100** may include a receiver **1110**, a power save mode module **1115**, and/or a transmitter **1120**. Each of these components may be in communication with each other. The device **1100**, through the receiver **1110**, the power save mode module **1115**, and/or the transmitter **1120**, may be configured to transmit and receive transmissions for entering a power save mode, similarly as discussed above with respect to FIGS. **2-10**.

[0070] Turning to FIG. **12**, a diagram **1200** is shown that illustrates a station **115-*b*** configured for power conservation according to various examples. The station **115-*b*** may have various other configurations and may be included or be part of a personal computer (e.g., laptop computer, netbook computer, tablet computer, etc.), a cellular telephone, a PDA, a digital video recorder (DVR), an internet appliance, a gaming console, an e-readers, etc. The station **115-*b*** may have an internal power supply (not shown), such as a small battery, to facilitate mobile operation. The station **115-*b*** may be an example of the stations **115** of FIG. **1**.

[0071] The station **115-*b*** may include a processor **1205**, a memory **1210**, a transceiver **1225**, antennas **1230**, and a power manager **1220**. The power manager **1220** may be an example of the power save mode module **1115** of FIG. **11**. Each of these components may be in communication with each other, directly or indirectly, over a bus(es) for example.

[0072] The memory **1210** may include random access memory (RAM) and read-only memory (ROM). The memory **1210** may store computer-readable, computer-executable software (SW) code **1215** containing instructions that are configured to, when executed, cause the processor **1205** to perform various functions described herein for power conservation. Alternatively, the software code **1215** may not be directly executable by the processor **1205** but be configured to cause the computer (e.g., when compiled and executed) to perform functions described herein.

[0073] The processor **1205** may include an intelligent hardware device, e.g., a central processing unit (CPU), a microcontroller, an application-specific integrated circuit (ASIC), etc. The processor **1205** may process information received through the transceiver **1225** and/or to be sent to the transceiver **1225** for transmission through the antennas **1230**. The processor **1205** may handle, alone or in connection with the power manager **1220**, various aspects for entering into a network sleep mode.

[0074] The transceiver **1225** may be configured to communicate bi-directionally with APs **105** in FIG. **1**. The transceiver **1225** may be implemented as a transmitter(s) and a separate receiver(s). The transceiver **1225** may include a modem configured to modulate packets and provide the modulated packets to the antennas **1230** for transmission, and to demodulate packets received from the antennas **1230**. While the station **115-*b*** may include a single antenna, there may be examples in which the station **115-*b*** may include multiple antennas **1230**.

[0075] The components of the station **115-*b*** may be configured to implement aspects discussed above with respect to FIGS. **2-10**, and those aspects may not be repeated here for the sake of brevity. Moreover, the components of the station **115-*b*** may be configured to implement aspects discussed below with respect to FIGS. **14-16**, and those aspects may not be repeated here also for the sake of brevity.

[0076] Turning to FIG. **13**, a diagram **1300** is shown that illustrates an access point or AP **105-*b*** configured for power conservation according to various examples. In some examples, the AP **105-*b*** may be an example of the APs **105** of FIG. **1**. The AP **105-*b*** may include a processor **1310**, a memory **1320**, a transceiver **1330**, antennas **1340**, and a power save communicator **1345**. The power save communicator **1345** may be an example of the power save mode module **1115** of FIG. **11**. In some examples, the AP **105-*b*** may also include one or both of an AP communicator **1380** and a network communicator **1385**. Each of these components may be in communication with each other, directly or indirectly, over a bus(es) **1315**.

[0077] The memory **1320** may include RAM and ROM. The memory **1320** may also store computer-readable, computer-executable software (SW) code **1325** containing instructions that are configured to, when executed, cause the processor **1310** to perform various functions described herein for entry of a power save mode by a station, for example. Alternatively, the software code **1325** may not be directly executable by the processor **1310** but be configured to cause the computer, e.g., when compiled and executed, to perform functions described herein.

[0078] The processor **1310** may include an intelligent hardware device, e.g., a CPU, a microcontroller, an ASIC, etc. The processor **1310** may process information received through the transceiver **1330**, the AP communicator **1380**, and/or the network communicator **1385**. The processor **1310** may also process information to be sent to the transceiver **1330** for transmission through the antennas **1340**, to the AP communicator **1380**, and/or to the network communicator **1385**. The processor **1310** may handle, alone or in connection with power save communicator **1345**, various aspects related to power save mode communications as discussed above.

[0079] The transceiver **1330** may include a modem configured to modulate packets and provide the modulated packets to the antennas **1340** for transmission, and to demodulate packets received from the antennas **1340**. The transceiver **1330** may be implemented as a transmitter(s) and a separate receiver(s). The transceiver **1330** may be configured to communicate bi-directionally, via the antennas **1340**, with a station(s) **115** as illustrated in FIG. **1** or FIG. **12**, for example. The AP **105**-*b* may typically include multiple antennas **1340** (e.g., an antenna array). The AP **105**-*b* may communicate with a core network **1305** through the network communicator **1385**. The AP **105**-*b* may communicate with other APs, such as the access point **105**-*i* and the access point **105**-*j*, using an AP communicator **1380**.

[0080] According to the architecture of FIG. **13**, the AP **105**-*b* may further include a communications manager **1350**. The communications manager **1350** may manage communications with stations and/or other devices as illustrated in the WLAN **100** of FIG. **1**, for example. The communications manager **1350** may be in communication with some or all of the other components of the AP **105**-*b* via the bus or buses **1315**. Alternatively, functionality of the communications manager **1350** may be implemented as a component of the transceiver **1330**, as a computer program product, and/or as a controller element(s) of the processor **1310**.

[0081] The components of the AP **105**-*b* may be configured to implement aspects discussed above with respect to FIGS. **2**-**10**, and those aspects may not be repeated here for the sake of brevity. Moreover, the components of the AP **105**-*b* may be configured to implement aspects discussed below with respect to FIGS. **14**-**16** and those aspects may not be repeated here also for the sake of brevity.

[0082] Turning next to FIG. **14**, a flow diagram is described for a method **1400** for power conservation in accordance with various examples. The method **1400** may be implemented using, for example, the APs **105** of FIG. **1** or **13**; or the device **1100** of FIG. **11**, for example. At block **1405**, the AP may receive a power save poll (PS-Poll) frame from a station. At block **1410**, the AP may transmit a MPDU to the station responsive to the PS-Poll frame. At block **1415**, the AP determines if an acknowledgement of the MPDU is received from the station. Finally, the AP may prevent a retransmission of the MPDU to the station in the absence of the acknowledgement from the station that the MPDU is received.

[0083] Turning next to FIG. **15**, a flow diagram is described for a method **1500** for power conservation in accordance with various examples. The method **1500** may be implemented using, for example, the APs **105** of FIG. **1** or **13**; or the device **1100** of FIG. **11**, for example. At block **1505**, the AP receives a power save poll (PS-Poll) frame from a station. The AP then may transmit an acknowledgement to the station that the PS-Poll frame is received following a short interframe space (SIFS), according to block **1510**. At block **1515**, the AP transmits an MPDU to the station responsive to the PS-Poll frame successive to an SIFS after transmission of the acknowledgement to the station.

[0084] Turning next to FIG. **16**, a flow diagram is described for a method **1600** for power conservation in accordance with various examples. The method **1600** may be implemented using, for example, the APs **105** of FIG. **1** or **13**; or the device **1100** of FIG. **11**, for example. At block **1605**, the AP receives a power save poll (PS-Poll) frame from a station. In response to the PS-Poll frame, the AP, at block **1610**, transmits an A-MPDU comprising a plurality of aggregated MPDUs to the station, the plurality of aggregated MPDUs comprising a first MPDU and a last MPDU each comprising an indicator bit to indicate that more data is to be transmitted to the station, and wherein the indicator bit of the first MPDU is set to indicate more data and the indicator bit of the last MPDU is cleared to indicate no additional data is to be transmitted.

[0085] According to another aspect of this disclosure, described examples are directed to methods, systems, devices, and apparatuses to enable a WLAN access point (AP) to schedule packet transmissions to (or from) a mobile device taking into consideration the schedule of various other coexisting transmission/reception (Tx/Rx) activities on the mobile device. Various embodiments may increase throughput at the mobile device. Various embodiments also may benefit other stations associated with the same AP.

[0086] Tx/Rx activities coexisting with WLAN communications on the mobile device may include, for example, Long Term Evolution (LTE) and Bluetooth (BT). Additionally or alternatively, the coexisting Tx/Rx activities may include WLAN communications (e.g., Wi-Fi concurrency), such as when the mobile device accesses the Internet via the AP and concurrently communicates with another device, for example, in a peer-to-peer (P2P) network.

[0087] In one example, a WLAN AP may learn interference information (e.g., schedule, timing, etc.) from a coexisting radio at the mobile device (e.g., station). The AP may learn the interference information from the mobile device explicitly reporting to the AP. The device may report time windows with interference and a pattern of the windows, for example, using a proprietary signaling frame or an existing unscheduled automatic power save delivery (U-APSD) action frame (e.g., add traffic stream (ATS) frame). The device may notify the AP of the time windows during which the station is not available for receiving packets. The AP and mobile device may set up a BlockACK session to enable aggregated media access control (MAC) protocol data unit (A-MPDU) transmissions from the AP to the device. The device may send a trigger frame (e.g., PS-Poll) after the channel becomes available. In response, the AP may send an acknowledgment (ACK) followed by an A-MPDU with a size (e.g., # of sub-frames) adjusted according to the interference information. Thus, the size of the A-MPDU may be adjusted dynamically to fit the Wi-Fi time

window that exists before the next interference window. The AP also may adjust the A-MPDU sizes to other non-coexistence stations using the interference information. Further, the AP may fragment the A-MPDU (or MPDU) using the interference information.

[0088] The scheduling techniques presented herein are generally described in connection with WLANs for simplicity. The same or similar techniques, however, may be used for various other wireless communications systems such as cellular wireless systems, peer-to-peer wireless communications, ad hoc networks, satellite communications systems, and other systems. The terms "system" and "network" may be used interchangeably.

[0089] Referring to FIG. **17**A, an example **1700**-*a* of coexisting communications at a mobile device is depicted. In this example, the mobile device may be a station **115** and may communicate with a WLAN AP **105**, such as described above with respect to FIG. **1**. As shown, the mobile device may communicate concurrently with the AP and another device via Wi-Fi (WLAN) and BT, respectively. BT communications **1705** and WLAN communications **1710** are illustrated in FIG. **17**A as employing time division duplexing (TDD) on the mobile device. Alternatively or additionally, frequency division duplexing (FDD) may be employed to avoid mutual interference between WLAN and BT.

[0090] FIG. **17**B illustrates an example **1700**-*b* of coexisting communications at a mobile device. As above, the mobile device may be a station **115** and may communicate with a WLAN AP **105**, such as described above with respect to FIG. **1**. In this example, the mobile device may communicate concurrently with the AP and another device via Wi-Fi (WLAN) and LTE, respectively. LTE uplink (UL) communications **1715** and LTE downlink (DL)/WLAN communications **1720** are illustrated in FIG. **17**B as employing TDD on the mobile device to avoid mutual interference between WLAN and LTE.

[0091] FIG. **17**C illustrates an example **1700**-*c* of coexisting communications at a mobile device. As above, the mobile device may be a station **115** and may communicate with a WLAN AP **105**, such as described above with respect to FIG. **1**. In this example, the mobile device may communicate concurrently with the AP via Wi-Fi (WLAN) to access the Internet and with another device via Wi-Fi over a P2P network or tunneled direct link setup (TDLS). WLAN communications **1725** on channel a may retrieve video and/or audio data from the Internet and P2P/TDLS communications **1730** on channel b may send the data to a displaying television. The WLAN communications **1725** and the P2P/TDLS communications **1730** are illustrated in FIG. **17**C as employing TDD on the mobile device because the Wi-Fi cannot be active on both channels a and b at the same time.

[0092] FIG. **17**D illustrates an example **1700**-*d* of coexisting communications at a mobile device. As above, the mobile device may be a station **115** and may communicate with a WLAN AP **105**, such as described above with respect to FIG. **1**. In this example, the mobile device may communicate using social Wi-Fi. The mobile device may have to tune to a discovery channel, e.g., channel a, periodically to perform communications **1735** for discovering other devices or to be discovered by other devices. When not in a discovery mode, the mobile device may perform social Wi-Fi (WLAN) communications **1740** on channel b. The discovery communications **1735** and the social Wi-Fi communications **1740** are illustrated in FIG. **17**D as employing TDD on the mobile device because the Wi-Fi cannot be active on both channels a and b at the same time. Thus, the discovery time intervals (e.g., discovery windows) may be considered to be time windows during which the mobile device is not available for social Wi-Fi communications.

[0093] Existing solutions for coexisting communications at a mobile device, such as the coexisting communications depicted in FIGS. **17**A-D, may not fully utilize the capacity of the WLAN radio of the mobile device. For example, a coexistence solution may involve a power save poll (PS-POLL) being sent from the mobile device to the AP when the mobile device is available to receive data via WLAN. The AP may respond to the PS-POLL by sending data to the mobile device. However, the AP may be able to deliver only one packet upon each PS-POLL. Overhead associated with the PS-POLL and potential processing delay at the AP may significantly limit WLAN throughput.

[0094] Another coexistence solution may involve a clear-to-send (CTS) signal, such as CTS-to-self. The CTS signal may block the entire basic service set (BSS), blocking transmissions from all other devices (e.g., stations) in the BSS. Such blocking may degrade the overall performance of the BSS.

[0095] When the CTS-based solution is used, the mobile device may explicitly disable A-MPDU to conservatively avoid collisions between AP's A-MPDU transmissions and BT activities on the mobile device, for example. As A-MPDU transmissions are employed to increase throughput, the foregoing existing solutions may be unsatisfactory or unsuitable.

[0096] With reference now to FIG. **18**, an example **1800** of transmissions between a station (STA) and an AP, such as between a station **115** and AP **105** of FIG. **1**, according to one approach for taking into consideration scheduling information of other coexisting Tx/Rx activities on the STA is illustrated. In this example, the STA at some point determines interference information (e.g., schedule, timing, etc.) regarding the coexisting Tx/Rx activities on the STA. The interference information may include information on time windows with interference from the coexisting Tx/Rx activities, pattern(s) of the interference time windows, etc. The STA may be considered to not be available for Wi-Fi during interference time windows.

[0097] The interference information may be provided to the AP by the STA using propriety signaling frames or leveraging unscheduled automatic power save delivery (U-APSD). For example, the STA may use an add traffic stream (ATS) frame **1805** to notify the AP of the time windows during which the STA is not available for receiving packets. The ATS frame **1805** may be referred to as a coexistence action frame in the context of this disclosure. In response to the ATS frame, the AP may transmit an acknowledgment (ACK) frame **1810**-*a* to the STA. The STA and the AP may set up a BlockACK session to enable data transmissions, such as MPDU or A-MPDU transmissions, from the AP to the STA.

[0098] As noted above, the interference information provided to the AP via the ATS frame **1805** may indicate time windows **1815** with interference and a pattern of the windows, for example. The predefined field of the ATS frame **1805** are capable of providing limited information to the AP. However, the ATS frame includes an additional field for providing vendor-specific information. This additional field may be used to provide additional interference information to the AP. Examples of additional interference information may include an estimated duration and/or interference level of

each time window (e.g., interference time window) during which Wi-Fi at the STA is not available, and/or clock drift between the coexisting radios (e.g., WLAN and BT or LTE).

[0099] A simple periodic pattern of interference time windows **1815** is illustrated in FIG. **18** for clarity, with a period **1820**. Also for simplicity, the interference time windows **1815** are illustrated as having a same duration **1825**.

[0100] After the ATS frame **1805** has been transmitted by the STA and acknowledged by the AP, a first interference time window **1815**-*a* may occur, during which the STA may be considered to be unavailable for Wi-Fi communications. After the first interference time window **1815**-*a*, the STA may transmit a first trigger frame (e.g., a PS-Poll) **1830**-*a* to the AP to indicate that the STA is ready to receive data from the AP. The AP may send an ACK frame **1810**-*b* in response, and then transmit data **1835**-*a* as a first A-MPDU, for example. Using the interference information received via the ATS frame **1805** from the STA, the AP may adjust a size (e.g., number of sub-frames) of the outgoing A-MPDU **1835**-*a* so that the A-MPDU **1835**-*a* may be successfully delivered within an available time window before a subsequent interference time window **1815**-*b* occurs. The STA may transmit an ACK frame **1810**-*c* in response upon successfully receiving the first A-MPDU **1835**-*a*.

[0101] Additionally or alternatively, the AP may fragment the A-MPDU **1835** (or an MPDU) using the interference information if the available time window is not long enough to fit the entire A-MPDU. Such interference-information aware fragmentation may enable the STA to operate robustly (e.g., good Wi-Fi throughput) even when channel conditions are poor (e.g., such that not even a single packet may be transmitted successfully). For example, poor conditions may cause the AP to drop its physical layer (PHY) data rate due to WLAN transmission failures (e.g., caused by coexistence interference), which may lower overall network performance. Adjusting the number of sub-frames in an A-MPDU and/or fragmenting an A-MPDU as described herein may increase successful WLAN transmissions by avoiding interference time windows and potential collisions that would otherwise result. In particular, adjusting the fragmentation size may help at least some data to be transmitted successfully. Thus, the approaches described herein may help to avoid the AP dropping its PHY rate, the potential increase in collisions/transmission failures resulting from the AP dropping its PHY rate, the potential further lowering of the APs PHY rate in response to the increase in collisions/transmission failures, and so on, which eventually may render the Wi-Fi link of the AP unusable.

[0102] The AP may not be able to completely avoid overlapping between A-MPDU transmissions and interference time windows using the interference information, for example, due to a lack of fine-grained timing control of outgoing frames by the AP. In such case, the AP may calculate which part(s) of the A-MPDU may get corrupted by the overlapping interference and may ignore the part(s) in PHY rate control/adaptation. Such calculation may be using the actual transmission time of the A-MPDU and the actual start of the overlapping interference time window.

[0103] As illustrated in FIG. **18**, the STA may send a second trigger frame **1830**-*b* to the AP after the second interference time window **1815**-*b* to indicate that the STA is ready to receive further data from the AP. The AP may send an ACK frame **1810**-*d* in response, and then transmit data **1835**-*b* as a second A-MPDU, for example. Using the interference information received via the ATS frame **1805** from the STA, the AP may adjust a size of the outgoing A-MPDU **1835**-*b* so that the A-MPDU **1835**-*b* may be successfully delivered within an available time window before a subsequent interference time window **1815**-*c* occurs.

[0104] As shown, the adjusted size of the second A-MPDU **1835**-*b* may differ from the adjusted size of the first A-MPDU **1835**-*a*. In this example, the second A-MPDU **1835**-*b* may be larger because the available time window before the subsequent interference time window **1815**-*c* occurs is longer due to the second trigger frame **1830**-*b* being sent sooner after the second interference time window **1815**-*b*, as compared to the timing of the first trigger frame **1830**-*a* after the first interference time window **1815**-*a*. This is only one example of dynamically adjusting the size of an A-MPDU to fit the available non-interference time window. In practice, lengths of the available non-interference time windows may vary, for example, based on the duration **1825** of the preceding interference time window **1815** and the timing of the next interference time window **1815**.

[0105] Special handling may be needed for retransmissions. If a retransmission of a packet to the STA cannot be performed in time because Wi-Fi will become unavailable, it may be desirable to avoid having the packet cause head-of-the-line blocking. When packets to other STAs can be transmitted, the packet to the STA may be buffered and the retry count of the packet for any later transmission may be remembered.

[0106] The approach described above with respect to FIG. **18** involves the STA determining interference information regarding the coexisting Tx/Rx activities on the STA and the STA transmitting the determined interference information to the AP. Additionally or alternatively, the AP may determine interference information of the STA by estimating the interference information implicitly, such as described below.

[0107] In some embodiments, the STA may be configured to attempt to stop the AP from transmitting packets to the STA when Wi-Fi is not available at the STA for receiving packets. The STA may transmit CTS frames and/or power save control frames (e.g., PS-Poll frames, QoS-Null frames, etc.) to attempt to stop the AP from transmitting packets to the STA. A pattern of such frames may be used by the AP to estimate whether the STA has an active coexistence radio, as well as to estimate information regarding the time windows during which Wi-Fi is unavailable for the STA. Using such estimated interference information, the AP may attempt to deliver data (e.g., MPDUs and/or A-MPDUs) to the STA. Such an approach may be employed, for example, when the AP has a relatively high confidence level regarding the estimated interference information or as long as the transmitted data is acknowledged by the STA as having been received successfully.

[0108] FIG. **19** shows a timing diagram **1900** that illustrates an approach for deriving timing information to be included, for example, in the ATS frame **1805** discussed above with respect to FIG. **18**. Timing information in the notification from the STA to the AP may be derived from the timing synchronization function (TSF) clock for WLAN and the clock for the coexisting radio at the STA. On the STA, the WLAN radio and the BT (or LTE) radio typically run on different clocks. The BT clock may run independently from the STA TSF clock and timing of BT activities are derived from the BT clock. In order to derive the timing information

to be reported to the AP, the timing of BT activities based on the STA TSF clock may be determined.

[0109] The timing diagram **1900** includes a timeline **1905** for the BT clock of the STA, a timeline **1910** for the TSF clock of the STA, and a timeline **1915** for the TSF clock of the AP. BT time windows (representing BT activities) **1920**-*a*, **1920**-*b*, **1920**-*c* and **1920**-*d* are shown as occurring at times t_1, t_3, t_4 and t_5, respectively, based on the BT clock. When an ATS frame **1925** is prepared at time t_2 on the BT clock (time T_1' on the TSF clock of the STA), a time offset to the next BT time window is set according to the BT clock as t_3-t_2, where t_3 is the start of next BT time window **1920**-*b* based on the BT clock. Accordingly, the start time of the BT window **1920**-*b* based on the TSF clock will be $T_1'+t_3-t_2$. The interval between BT time windows **1920** may be calculated based on BT clock only. As noted above, the STA TSF clock (for WLAN) may be synchronized with the AP TSF clock, for example, using AP beacons. The difference between the STA TSF clock and the AP TSF clock is typically very small (e.g., less than 25 μs). A guard time may be set that is greater than or equal to the absolute value of $T_1'-T_1$, for example, to account for this difference.

[0110] In addition to dynamically adjusting the size of A-MPDUs sent to the mobile device/station having coexisting/concurrent communications as described above, various embodiments may have the AP adjust the size of A-MPDUs sent to another mobile device/STA that does not have coexisting/concurrent communications. The AP may use the interference information provided to the AP from the coexistence station and/or implicitly determine by the AP, such as described above, to guide the adjustment of the size of A-MPDUs sent to the non-coexistence station.

[0111] Adjusting the size of A-MPDUs sent to the non-coexistence station(s) may improve overall throughput, and also may improve fairness with respect to the coexistence station. As illustrated in the diagram **2000**-*a* of FIG. **20**A, the coexistence station (STA-c) may be at a disadvantage when competing for the WLAN medium with a non-coexistence or regular station (STA-r) in the same BSS.

[0112] The STA-c may have interference time windows **2005**-*a*, **2005**-*b*, etc., for example, due to concurrently active radios. When the Wi-Fi radio of the STA-c becomes available at the end of the first interference time window **2005**-*a*, there may be an ongoing transmission **2010** of data to the STA-r. At the end of the ongoing transmission **2010**, the STA-r may send an ACK frame **2015** to the AP. The AP may recognize and respond to a trigger frame (e.g., PS-Poll) **2020** only after the ACK frame **2015** is received by the AP. Thus, the ongoing transmission **2010** postpones a transmission **2025** of data (e.g., following an ACK frame **2030** from the AP to the STA-c) from the AP to the STA-c and thus limits throughput for the STA-c, for example, by allowing for a relatively small adjusted-sized A-MPDU for the transmission **2025** (e.g., with time for an ACK frame **2035** from the STA-c to the AP) before the next interference time window **2005**-*b* occurs. It should be understood that this problem may be exacerbated by the ever increasing WLAN devices and traffic in a network, which often may be the case in places such as airports, coffee shops, bookstores, libraries, etc.

[0113] Having the AP adjust the A-MPDU size to the non-coexistence station(s) may improve throughput for the coexistence station and fairness to the coexistence station. An example of this approach is illustrated in the diagram **2000**-*b* of FIG. **20**B. As in FIG. **20**A, the coexistence station STA-c may have interference time windows **2005**-*a*, **2005**-*b*, etc. In this example, however, when the AP sends a transmission **2010**-*a* to the STA-r, the AP may adjust the size of the A-MPDU (e.g., shortened as compared to the A-MPDU size of the transmission **2010** in FIG. **20**A) so that the transmission **2010**-*a* stops around the time when the Wi-Fi radio of the STA-c is going to become available.

[0114] Accordingly, an ACK frame **2015**-*a* at the end of the transmission **2010**-*a* may be sent by the STA-r to the AP sooner than in the example of FIG. **20**A. Thus, the AP may recognize and respond to a trigger frame **2020**-*a* sooner than in the example of FIG. **20**A, and sends a transmission **2025**-*a* of data (e.g., following an ACK frame **2030**-*a* from the AP to the STA-c) to the STA-c. As shown, the available time window for the transmission **2025**-*a* before the next interference time window **2005**-*b* occurs may allow for a larger adjusted-sized A-MPDU for the transmission **2025**-*a* (as compared to the available time window for the transmission **2025** in FIG. **20**A). The shortened A-MPDU size may give the STA-c a better opportunity to gain access to the medium.

[0115] The foregoing examples illustrate how the AP may manage downlink traffic, which may be the most common scenario. However, the AP may control the parameters of a BlockACK session even for uplink traffic to help a coexistence station gain its share of the medium. If a non-coexistence station blocks transmissions from/to a coexistence station more often that is acceptable (e.g., greater than a threshold number of times and/or number of times within a certain time interval), the AP may reduce the size of the A-MPDU or may even disable the BlockACK for the transmissions from the non-coexistence station to the AP.

[0116] With reference now to FIG. **21**, an example **2100** of transmissions between a coexistence station STA-c and an AP and transmissions between a non-coexistence or regular station STA-r and the AP according to one embodiment is illustrated. This embodiment may implement an algorithm that employs the following information: interference information (e.g., schedule of interfering Tx and/or Rx activities at the coexistence station); whether there is any pending data for the coexistence station at the AP; whether the coexistence station has been bypassed for its turn based on the scheduling policy of the AP; and, a list of non-coexistence stations. Thus, according to the embodiment illustrated in FIG. **21**, the AP may determine whether a transmission to the STA-c has been delayed due to interference. If so, the AP may transmit to some other STA, such as the STA-r during the interference and may give a priority for the medium to the STA-c right after the interference has ended.

[0117] The STA-c may have interference time windows **2105**-*a*, **2105**-*b*, etc., for example, due to concurrently active radios. Although not shown, interference information for the STA-c may be provided to the AP by the STA and/or may be derived implicitly by the AP, such as described above. After a first transmission **2110** of data to the STA-r and a corresponding ACK frame **2115** from the STA-r to the AP, the STA-c may have its turn to use the medium (e.g., based on the scheduling policy of the AP, such as round-robin, by access class, etc.).

[0118] However, because the Wi-Fi radio of the STA-c may be unavailable due to the first interference time window **2105**-*a*, there may be only a small time window to send data to the STA-c. When the time window is too small for at least k (e.g., with a default value of 1) packet transmissions to the STA-c, allowing transmissions to other STAs (e.g., STA-r) from the AP may provide a better utilization of the medium rather than

waiting for the STA-c to become available for reception (e.g., waiting for the interference time window to transpire). Thus, because the transmission of data waiting at the AP for the STA-c may be delayed, the AP may bypass the turn of the STA-c and set a flag, denoted **2120** in FIG. **21**, to indicate that the STA-c has been bypassed due to the interference schedule of the STA-c.

[0119] The AP may choose a random regular station (e.g., STA-r) if multiple regular stations have data pending at the AP, which may avoid favoring one particular regular station. In this example, a transmission **2125** to the STA-r, including a corresponding ACK frame **2130** from the STA-r to the AP may occur and end slightly after the first interference time window **2105**-*a*. For example, even though there may be ten sub-frames of data waiting at the AP for the STA-r, the AP may adjust the size (e.g., truncate) the A-MPDU of the transmission **2125** to include only two sub-frames, denoted by **2135**, so that the transmission **2125** ends soon after the first interference time window **2105**-*a*. This may allow the STA-c to detect the end of this communication (transmission **2125** and ACK frame **2130**) between the AP and the STA-r and to compete for the medium relatively soon thereafter (e.g., almost immediately).

[0120] If the AP knows when the interference is over (e.g., with a certain degree of accuracy, the AP may begin transmitting data to the STA-c right after the transmission **2125** to the STA-r is completed (e.g., acknowledged by the STA-r). If the AP does not know the end time of the first interference time window **2105**-*a*, the STA-c may employ a trigger (TRG) frame **2140** to notify the AP that first interference time window **2105**-*a* has ended and the STA-c is ready to receive data from the AP. In such case, the STA-c may compete for the medium using the trigger frame **2140** with a wait time T (either fixed or dynamically set) that is shorter than a distributed inter-frame space DIFS plus a random backoff. T may be based on DIFS, reduced inter-frame space (RIFS), point coordination function (PCF) inter-frame space (PIFS), or short inter-frame space (SIFS). In some embodiments, a default value for T may be the SIFS. The shorter the wait time T, the greater the chance that the STA-c may win the medium time for the AP.

[0121] After the STA-c wins the medium time using the trigger frame **2120**-*a* as shown in FIG. **21**, the AP may transmit an ACK frame **2130** followed by a transmission **2025** of data to the STA-c. As discussed above, the size of an A-MPDU of the transmission **2025** may be adjusted to fit the available time window before the next interference time window **2025**-*b* of the STA-c so that the transmission **2025** may be successfully completed.

[0122] Upon receiving an ACK frame **2155** from the STA-c indicating that the transmission **2150** was received successfully, the AP may clear the flag, denoted **2160** in FIG. **21**, that was previously set to indicate that the STA-c had been bypassed. After the flag is cleared, a transmission to the STA-r that occurs during the interference time window **2105**-*b* may not be adjusted (e.g., truncated) by the AP based on the interference information, for example, because the STA-c successfully received the transmission **2150**.

[0123] Use of the flag may be modified, as appropriate or desired, based on certain conditions. For example, if a transmission to the STA-c fails, the flag may remain set. Also for example, if the STA-c fails, for a certain number of times (e.g., with a default value being 1), to utilize the medium time allocated to the STA-c, the AP may clear the flag.

[0124] In the case of multiple coexistence stations in the BSS, the AP may track collisions between trigger frames from the coexistence stations. Using such collision information, the AP may backoff the waiting time T for all but one of the coexistence stations. The one of the coexistence stations may be determined randomly, for example, to provide random access to the medium for the multiple coexistence stations.

[0125] Using an order of bypassing, the AP may set different wait time (T) values for the multiple coexistence stations. The different T values may establish a priority for the coexistence stations, such as by setting the T values in accordance with the order with the first bypassed coexistence station having a shortest T value, and so on. The setting of the different T values may involve sending non-standard messages to the multiple coexistence stations. However, the overhead associated with such messages may be reduced by adjusting (e.g., shortening) only the T value for the first bypassed coexistence station and leaving the T value(s) for the other coexistence station(s) at a default value. As the flags are successively removed, the next coexistence station in line may have its T value adjusted.

[0126] In addition to dynamically adjusting the size of A-MPDUs sent to the mobile device/station having coexisting/concurrent communications and/or adjusting the size of A-MPDUs sent to another mobile device/STA that does not have coexisting/concurrent communications, the AP may be configured to identify certain sub-frames errors using the interference information. Sub-frame errors, such as those at the end of an A-MPDU which are corrupted by the scheduled interference, may be predicted using the interference information. For example, based on the actual transmission time and configuration, the AP may find that the last three sub-frames overlap with the interference time window.

[0127] The AP may handle (e.g., resolve, avoid, render innocuous, etc.) the predicted sub-frame errors by treating the errors in rate control. For example, the AP may ignore errors of the last three sub-frames when calculating the packet error rate, which is used in determining the PHY rate for transmissions to the mobile device/station.

[0128] With reference now to FIG. **22**, a block diagram **2200** illustrates a device **2205** that may be used to implement various embodiments of the approaches for dealing with coexistence interference as described herein. The device **2205** may be an example of various aspects of the APs **105** or stations **115** described with reference to FIG. **1**. The device **2205**, or portions thereof, may also be a processor. The device **2205** may include a receiver **2210**, a coexistence interference manager **2215**, and/or a transmitter **2220**. Each of these components may be in communication with each other. The device **2205**, through the receiver **2210**, the coexistence interference manager **2215**, and/or the transmitter **2220**, may be configured to perform the various operations (e.g., determining interference information, transmit/receive interference information, adjusting a size of an A-MPDU (or MPDU), receive/transmit A-MPDUs (or MPDUs), identify sub-frame errors, etc.) described herein. The receiver **2210**, the coexistence interference manager **2215**, and/or the transmitter **2220** also may be configured to cooperate with other components (e.g., a rate adaptation controller—not shown) of the device **2205** to carry out the various operations described herein, such as discussed above with respect to FIGS. **18**-**21**. Either alone or in combination with each other and/or other compo-

nents not shown, the foregoing components of the device **2205** may be examples of means for performing the various operations described herein.

[0129] Turning to FIG. **23**, a diagram **2300** is shown that illustrates a station **115**-*c* that may be used to implement various embodiments of the approaches for dealing with coexistence interference as described herein. The station **115**-*c* may have various other configurations and may be included or be part of a personal computer (e.g., laptop computer, netbook computer, tablet computer, etc.), a cellular telephone, a PDA, a digital video recorder (DVR), an internet appliance, a gaming console, an e-readers, etc. The station **115**-*c* may have an internal power supply (not shown), such as a small battery, to facilitate mobile operation. The station **115**-*c* may be an example of the stations **115** of FIG. **1**.

[0130] The station **115**-*c* may include a processor **2305**, a memory **2310**, transceiver(s) **2325**, antennas **2330**, and a coexistence interference manager **2320**. The coexistence interference manager **2320** may be an example of the coexistence interference manager **2215** of FIG. **22**. Each of these components may be in communication with each other, directly or indirectly, over a bus(es) for example. The coexistence interference manager **2320** may be a computer program product and/or a controller element(s) of the processor **2305**.

[0131] The memory **2310** may include random access memory (RAM) and read-only memory (ROM). The memory **2310** may store computer-readable, computer-executable software (SW) code **2315** containing instructions that are configured to, when executed, cause the processor **2305** to perform the various functions described herein for dealing with coexistence interference. Alternatively, the software code **2315** may not be directly executable by the processor **2305** but may be configured to cause the computer (e.g., when compiled and executed) to perform functions described herein.

[0132] The processor **2305** may include an intelligent hardware device, e.g., a central processing unit (CPU), a microcontroller, an application-specific integrated circuit (ASIC), etc. The processor **2305** may process information received through the transceiver **2325** and/or to be sent to the transceiver **2325** for transmission through the antennas **2330**. The processor **2305** may handle, alone or in connection with the coexistence interference manager **2320**, various aspects for dealing with coexistence interference.

[0133] The transceiver(s) **2325** may be configured to communicate bi-directionally with APs **105** in FIG. **1**. The transceiver(s) **2325** may be implemented as a transmitter(s) and a separate receiver(s), for example, to operate the station **115**-*c* in accordance with different radio access technologies (e.g., WLAN, BT, LTE, etc.). The transceiver(s) **2325** may include a modem configured to modulate packets and provide the modulated packets to the antennas **2330** for transmission, and to demodulate packets received from the antennas **2330**. While the station **115**-*c* may include a single antenna, there may be examples in which the station **115**-*c* may include multiple antennas **2330**.

[0134] The components of the station **115**-*c* may be configured to implement aspects discussed above with respect to FIGS. **18**-**21**, and those aspects may not be repeated here for the sake of brevity. Moreover, the components of the station **115**-*c* may be configured to implement aspects discussed below with respect to FIG. **25**, and those aspects may not be repeated here also for the sake of brevity. Thus, either alone or in combination with each other and/or other components not shown, the foregoing components of the station **115**-*c* may be examples of means for performing the various operations associated with the stations as described herein.

[0135] Turning to FIG. **24**, a diagram **2400** is shown that illustrates an access point or AP **105**-*c* that may be used to implement various embodiments of the approaches for dealing with coexistence interference as described herein. In some examples, the AP **105**-*c* may be an example of the APs **105** of FIG. **1**. The AP **105**-*c* may include a processor **2410**, a memory **2420**, a transceiver **2430**, antennas **2440**, a coexistence interference manager **2445** and/or an A-MPDU generator **2450**. The A-MPDU generator **2450** and/or the coexistence interference manager **2445** may be an example of the coexistence interference manager **2215** of FIG. **22**.

[0136] In some examples, the AP **105**-*c* may also include one or both of an AP communicator **2480** and a network communicator **2485**. Each of these components may be in communication with each other, directly or indirectly, over a bus(es) **2415**.

[0137] The memory **2420** may include RAM and ROM. The memory **2420** may also store computer-readable, computer-executable software (SW) code **2425** containing instructions that are configured to, when executed, cause the processor **2410** to perform various functions described herein for dealing with coexistence interference. Alternatively, the software code **2425** may not be directly executable by the processor **2410** but may be configured to cause the computer, e.g., when compiled and executed, to perform functions described herein.

[0138] The processor **2410** may include an intelligent hardware device, e.g., a CPU, a microcontroller, an ASIC, etc. The processor **2410** may process information received through the transceiver **2430**, the AP communicator **2480**, and/or the network communicator **2485**. The processor **2410** may also process information to be sent to the transceiver **2430** for transmission through the antennas **2440**, to the AP communicator **2480**, and/or to the network communicator **2485**. The processor **2410** may handle, alone or in connection with the A-MPDU generator **2450** and/or the coexistence interference manager **2445**, various aspects related to coexistence interference as discussed above and further below.

[0139] The transceiver **2430** may include a modem configured to modulate packets and provide the modulated packets to the antennas **2440** for transmission, and to demodulate packets received from the antennas **2440**. The transceiver **2430** may be implemented as a transmitter(s) and a separate receiver(s). The transceiver **2430** may be configured to communicate bi-directionally, via the antennas **2440**, with a station(s) **115** as illustrated in FIG. **1** or FIG. **23**, for example. The AP **105**-*c* may typically include multiple antennas **2440** (e.g., an antenna array). The AP **105**-*c* may communicate with a core network **2405** through the network communicator **2485**. The AP **105**-*c* may communicate with other APs, such as an access point **105**-*k* and an access point **105**-*m*, using the AP communicator **2480**.

[0140] According to the architecture of FIG. **24**, the AP **105**-*c* may further include a communications manager **2455**. The communications manager **2455** may manage communications with stations and/or other devices as illustrated in the WLAN **100** of FIG. **1**, for example. The communications manager **2455** may be in communication with some or all of the other components of the AP **105**-*c* via the bus or buses **2415**. Alternatively, functionality of the communications

manager **2455** may be implemented as a component of the transceiver **2430**, as a computer program product, and/or as a controller element(s) of the processor **2410**.

[0141] The components of the AP **105**-*c* may be configured to implement aspects discussed above with respect to FIGS. **18-21**, and those aspects may not be repeated here for the sake of brevity. Moreover, the components of the AP **105**-*c* may be configured to implement aspects discussed below with respect to FIG. **26** and those aspects may not be repeated here also for the sake of brevity. Thus, either alone or in combination with each other and/or other components not shown, the foregoing components of the AP **105**-*c* may be examples of means for performing the various operations associated with the APs as described herein.

[0142] Turning next to FIG. **25**, a flow diagram is described for a method **2500** for dealing with coexistence interference in accordance with various examples. The method **2500** may be implemented using, for example, the stations **115** of FIG. **1** or **23**; or the device **2300** of FIG. **23**, for example. At block **2505**, the station may determine interference information relating to activity by an interfering radio thereof. This operation may be performed by the coexistence interference manager **2320** of FIG. **23** or the coexistence interference manager **2215** of FIG. **22**, for example.

[0143] At block **2510**, the station may report (e.g., transmit) the determined interference information to an access point (AP). This operation may be performed by the coexistence interference manager **2320** in conjunction with the processor **2305**, the memory **2310** and/or the transceiver(s) **2325** of FIG. **23** or the coexistence interference manager **2215** in conjunction with the transmitter **2220** of FIG. **22**, for example.

[0144] Then, at block **2515**, the station may receive an MPDU (or A-MPDU) from the AP, which may have adjusted a size of the MPDU (or A-MPDU) using the determined interference information. This operation may be performed by the transceiver(s) **2325** in conjunction with the processor **2305**, and/or a communications manager (not shown) of FIG. **23** or the receiver **2210** in conjunction with a communications manager (not shown) of FIG. **22**, for example.

[0145] Turning next to FIG. **26**, a flow diagram is described for a method **2600** for dealing with coexistence interference in accordance with various examples. The method **2600** may be implemented using, for example, the APs **105** of FIG. **1** or **24**; or the device **2205** of FIG. **22**, for example. At block **2605**, the may determine interference information of a station relating to activity by an interfering radio of the station. This operation may be performed by receiving the interference information from the station and/or by implicitly determining (e.g., estimating) the interference information, such as described above. Thus, this operation may be performed by the coexistence interference manager **2445** in conjunction with the communications manager **2455**, the processor **2410**, the memory **2420** and/or the transceiver **2430** of FIG. **24**, or the coexistence interference manager **2215** in conjunction with the receiver **2210** of FIG. **22**.

[0146] At block **2310**, the AP may adjust a size of an MPDU (or A-MPDU) using the determined interference information. This operation may be performed by generating the MPDU (or A-MPDU) with a desired number of subframes and/or fragmenting the MPDU (or A-MPDU), such as described above. Thus, this operation also may be performed by the coexistence interference manager **2445** and/or the A-MPDU generator **2450** in conjunction with the processor **2410** and/or the memory **2420** of FIG. **24**, or the coexistence interference manager **2215** of FIG. **22**.

[0147] Then, at block **2615**, the AP may transmit the size-adjusted MPDU (or A-MPDU) to the station in accordance with the determined interference information. This operation may be performed, for example, in response to a triggering frame received by the AP from the station, or may be performed using the AP's knowledge of the end of a preceding transmission to a different station, such as described above. Thus, this operation also may be performed by the coexistence interference manager **2445** and/or the A-MPDU generator **2450** in conjunction with the communications manager **2455** and/or transceiver **2430** of FIG. **24**, or the coexistence interference manager **2215** in conjunction with a communications manager (not shown) and/or the transmitter **2220** of FIG. **22**, for example.

[0148] The methods described above with respect to FIGS. **25** and **26** are only examples of method that may be employed to deal with coexistence interference of a station. As such, various modifications of the operations may be made and/or additional operations may be added to achieve other methods in accordance with this disclosure.

[0149] The detailed description set forth above in connection with the appended drawings describes exemplary examples and does not represent the only examples that may be implemented or that are within the scope of the claims. The term "exemplary" when used in this description means "serving as an example, instance, or illustration," and not "preferred" or "advantageous over other examples." The detailed description includes specific details for the purpose of providing an understanding of the described techniques. These techniques, however, may be practiced without these specific details. In some instances, well-known structures and devices are shown in block diagram form in order to avoid obscuring the concepts of the described examples.

[0150] Information and signals may be represented using any of a variety of different technologies and techniques. For example, data, instructions, commands, information, signals, bits, symbols, and chips that may be referenced throughout the above description may be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof.

[0151] The various illustrative blocks and modules described in connection with the disclosure herein may be implemented or performed with a general-purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general-purpose processor may be a microprocessor, but in the alternative, the processor may be any conventional processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, multiple microprocessors, a microprocessor(s) in conjunction with a DSP core, or any other such configuration.

[0152] The functions described herein may be implemented in hardware, software executed by a processor, firmware, or any combination thereof. If implemented in software executed by a processor, the functions may be stored on or transmitted over as an instruction(s) or code on a computer-readable medium. Other examples and implementations are

within the scope and spirit of the disclosure and appended claims. For example, due to the nature of software, functions described above can be implemented using software executed by a processor, hardware, firmware, hardwiring, or combinations of any of these. Features implementing functions may also be physically located at various positions, including being distributed such that portions of functions are implemented at different physical locations. Also, as used herein, including in the claims, "or" as used in a list of items prefaced by "at least one of" indicates a disjunctive list such that, for example, a list of "at least one of A, B, or C" means A or B or C or AB or AC or BC or ABC (i.e., A and B and C).

[0153] Computer-readable media includes both computer storage media and communication media including any medium that facilitates transfer of a computer program from one place to another. A storage medium may be any available medium that can be accessed by a general purpose or special purpose computer. By way of example, and not limitation, computer-readable media can comprise RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to carry or store desired program code means in the form of instructions or data structures and that can be accessed by a general-purpose or special-purpose computer, or a general-purpose or special-purpose processor. Also, any connection is properly termed a computer-readable medium. For example, if the software is transmitted from a website, server, or other remote source using a coaxial cable, fiber optic cable, twisted pair, digital subscriber line (DSL), or wireless technologies such as infrared, radio, and microwave, then the coaxial cable, fiber optic cable, twisted pair, DSL, or wireless technologies such as infrared, radio, and microwave are included in the definition of medium. Disk and disc, as used herein, include compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk and blu-ray disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Combinations of the above are also included within the scope of computer-readable media.

[0154] The previous description of the disclosure is provided to enable a person skilled in the art to make or use the disclosure. Various modifications to the disclosure will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other variations without departing from the spirit or scope of the disclosure. Throughout this disclosure the term "example" or "exemplary" indicates an example or instance and does not imply or require any preference for the noted example. Thus, the disclosure is not to be limited to the examples and designs described herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

What is claimed is:

1. A method for wireless communications, comprising:
determining interference information for a node having a WLAN radio, the interference information relating to operations by an interfering radio of the node that interfere with WLAN communications of the node; and
scheduling a transmission to the node based at least in part on the interference information.

2. The method of claim **1**, further comprising:
adjusting a number of packets included in a physical layer convergence protocol (PLCP) protocol data unit (PPDU) of the transmission to the node based at least in part on the interference information.

3. The method of claim **1**, further comprising:
fragmenting a media access control (MAC) protocol data unit (MPDU) of the transmission to the node based at least in part on the interference information.

4. The method of claim **1**, further comprising:
adjusting a number of packets included in a physical layer convergence protocol (PLCP) protocol data unit (PPDU) of a transmission to a different node based at least in part on the interference information.

5. The method of claim **1**, further comprising:
fragmenting a media access control (MAC) protocol data unit (MPDU) of a transmission to a different node based at least in part on the interference information.

6. The method of claim **1**, wherein determining interference information for the node comprises:
receiving at least part of the interference information from the node.

7. The method of claim **1**, wherein determining interference information for the node comprises:
estimating at least part of the interference information using transmissions received from the node.

8. The method of claim **1**, further comprising:
determining that a transmission to the node is delayed due to interference;
transmitting a PPDU over a transmission medium to a different node during the interference; and
providing a priority to the node for accessing the transmission medium after the interference ends.

9. The method of claim **8**, wherein providing a priority to the node comprises:
adjusting a size of the PPDU to the different node so that transmission of the PPDU to the different node ends about a same time as the interference ends.

10. The method of claim **8**, further comprising:
receiving a trigger frame from the node after the interference ends; and
transmitting data to the node in response to the trigger frame.

11. The method of claim **10**, wherein the received trigger frame was sent following a space after the interference ended, wherein the space is selected from the group consisting of: a short interframe space (SIFS), a point coordination function (PCF) interframe space (PIFS), a distributed coordination function (DCF) interframe space (DIFS), or a reduced interframe space (RIFS).

12. The method of claim **8**, further comprising:
determining when the interference ends based at least in part on the interference information; and
transmitting data to the node once the interference ends.

13. The method of claim **8**, further comprising:
setting a flag that indicates that the node has been bypassed for transmission; and
when the flag is set, adjusting a size of the PPDU to the different node so that transmission of the PPDU to the different node ends about a same time as the interference ends.

14. The method of claim **13**, further comprising:
clearing the flag upon successfully transmitting data to the node.

15. The method of claim **13**, further comprising:
clearing the flag upon a certain number of unsuccessful transmissions of data to the node.

16. The method of claim **1**, wherein the transmissions of the interfering radio use a different radio access technology than WLAN.

17. The method of claim **1**, wherein:

the interfering radio is the WLAN radio; and

the interference information is based at least in part on a schedule of the WLAN radio for operating on a channel other than a channel for communicating with a node performing scheduling of the transmission.

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

identifying a sub-frame error based at least in part on the interference information; and

handling the identified sub-frame error in rate control.

19. An apparatus for wireless communications, comprising:

a coexistence interference manager configured to determining interference information for a node having a WLAN radio, the interference information relating to operations by an interfering radio of the node that interfere with WLAN communications of the node; and

a communications manager configured to schedule a transmission to the node based at least in part on the interference information.

20. The apparatus of claim **19**, wherein the coexistence interference manager is configured to adjust a number of packets included in a physical layer convergence protocol (PLCP) protocol data unit (PPDU) of the transmission to the node based at least in part on the interference information.

21. The apparatus of claim **19**, wherein the coexistence interference manager is configured to fragment a media access control (MAC) protocol data unit (MPDU) of the transmission to the node based at least in part on the interference information.

22. The apparatus of claim **19**, wherein the coexistence interference manager is configured to adjust a number of packets included in a physical layer convergence protocol (PLCP) protocol data unit (PPDU) of a transmission to a different node based at least in part on the interference information.

23. The apparatus of claim **19**, wherein the coexistence interference manager is configured to fragment a media access control (MAC) protocol data unit (MPDU) of a transmission to a different node based at least in part on the interference information.

24. The apparatus of claim **19**, further comprising:

a receiver configured to receive at least part of the interference information for the node, the coexistence interference manager being configured to obtain the at least part of the interference information received by the receiver.

25. The apparatus of claim **19**, wherein the coexistence interference manager is configured to determine at least part of the interference information for the node by estimating the at least part of the interference information using transmissions received from the node.

26. The apparatus of claim **19**, wherein:

the coexistence interference manager is configured to determine that a transmission to the node is delayed due to interference;

the communications manager is configured to schedule a transmission of a PPDU over a transmission medium to a different node during the interference; and

the coexistence interference manager is further configured to provide a priority to the node for accessing the transmission medium after the interference ends.

27. An apparatus for wireless communications, comprising:

means for determining interference information for a node having a WLAN radio, the interference information relating to operations by an interfering radio of the node that interfere with WLAN communications of the node; and

means for scheduling a transmission to the node based at least in part on the interference information.

28. The apparatus of claim **27**, further comprising:

means for adjusting a number of packets included in a physical layer convergence protocol (PLCP) protocol data unit (PPDU) of the transmission to the node based at least in part on the interference information.

29. The method of claim **27**, further comprising:

means for adjusting a number of packets included in a physical layer convergence protocol (PLCP) protocol data unit (PPDU) of a transmission to a different node based at least in part on the interference information.

30. A computer program product for wireless communications, the computer program product comprising a non-transitory computer-readable medium storing instructions executable by a processor to:

determine interference information for a node having a WLAN radio, the interference information relating to operations by an interfering radio of the node that interfere with WLAN communications of the node; and

schedule a transmission to the node based at least in part on the interference information.

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