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(54) **COMMUNICATION DEVICE AND COMMUNICATION METHOD FOR MULTI-LINK BLOCK ACKNOWLEDGEMENT**

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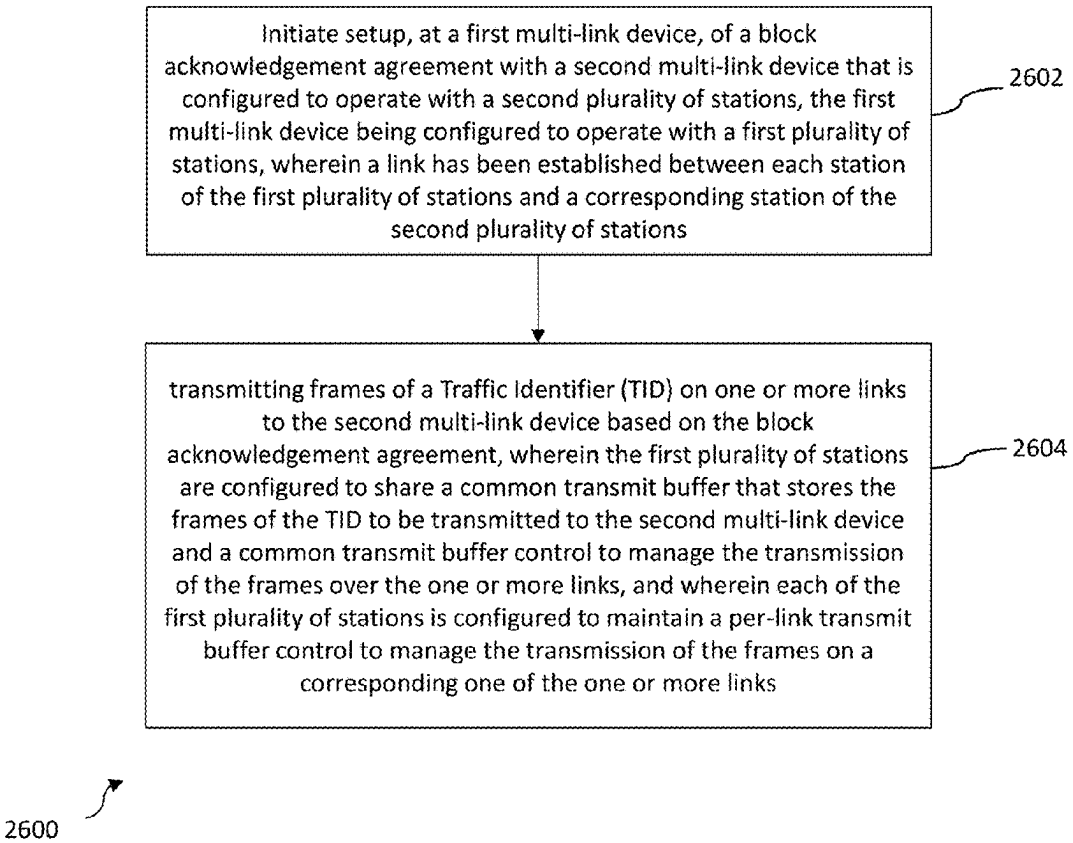
(52) **U.S. Cl.**

CPC ***H04W 76/15*** (2018.02); ***H04L 1/1621*** (2013.01); ***H04W 74/0816*** (2013.01)

(57) **ABSTRACT**

Communication devices and methods for multi-link block acknowledgement are provided. One exemplary embodiment provides a multi-link device (MLD) configured to operate with a first plurality of affiliated stations, the first multi-link device comprising: circuitry, which in operation, initiates setup of a block acknowledgement agreement with a second multi-link device that is configured to operate with a second plurality of affiliated stations, wherein a link has been established between each station of the first plurality of stations and a corresponding station of the second plurality of stations; and a transmitter, which in operation, transmits frames of a Traffic Identifier (TID) on one or more links to the second multi-link device based on the block acknowledgement agreement, wherein the first plurality of stations are configured to share a common transmit buffer that stores the frames of the TID to be transmitted to the second multi-link device and a common transmit buffer control to manage the transmission of the frames over the one or more links, and wherein each of the first plurality of stations is configured to maintain a per-link transmit buffer control to manage the transmission of the frames on a corresponding one of the one or more links.



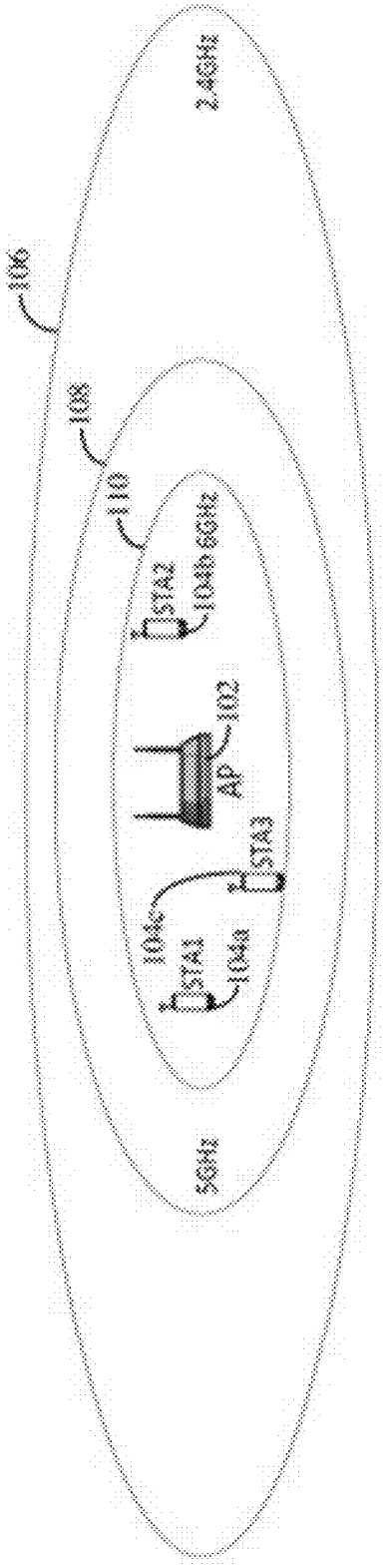

106
2.4GHz
108
110
STA2
104b
60Hz
102
AP
STA3
104c
STA1
104a
5GHz
100

Figure 1

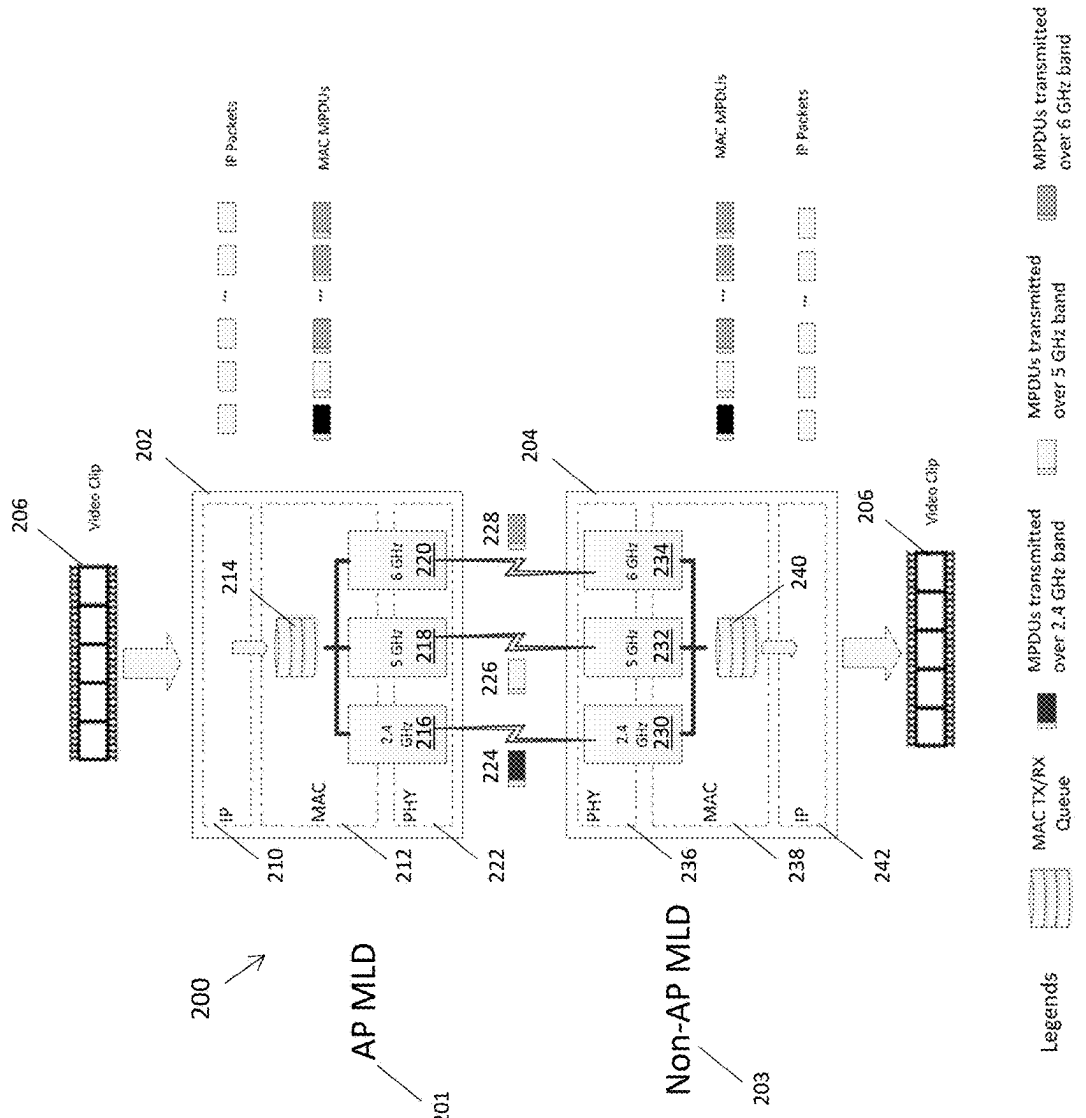

200
AP MLD
201
Non-AP MLD
203
202
204
206
Video Clip
IP
MAC
PHY
2.4 GHz
5 GHz
6 GHz
210
212
214
216
218
220
222
224
226
228
230
232
234
236
238
240
242
IP Packets
MAC MPDUs
Legends
MAC TX/RX Queue
MPDUs transmitted over 2.4 GHz band
MPDUs transmitted over 5 GHz band
MPDUs transmitted over 6 GHz band

Figure 2

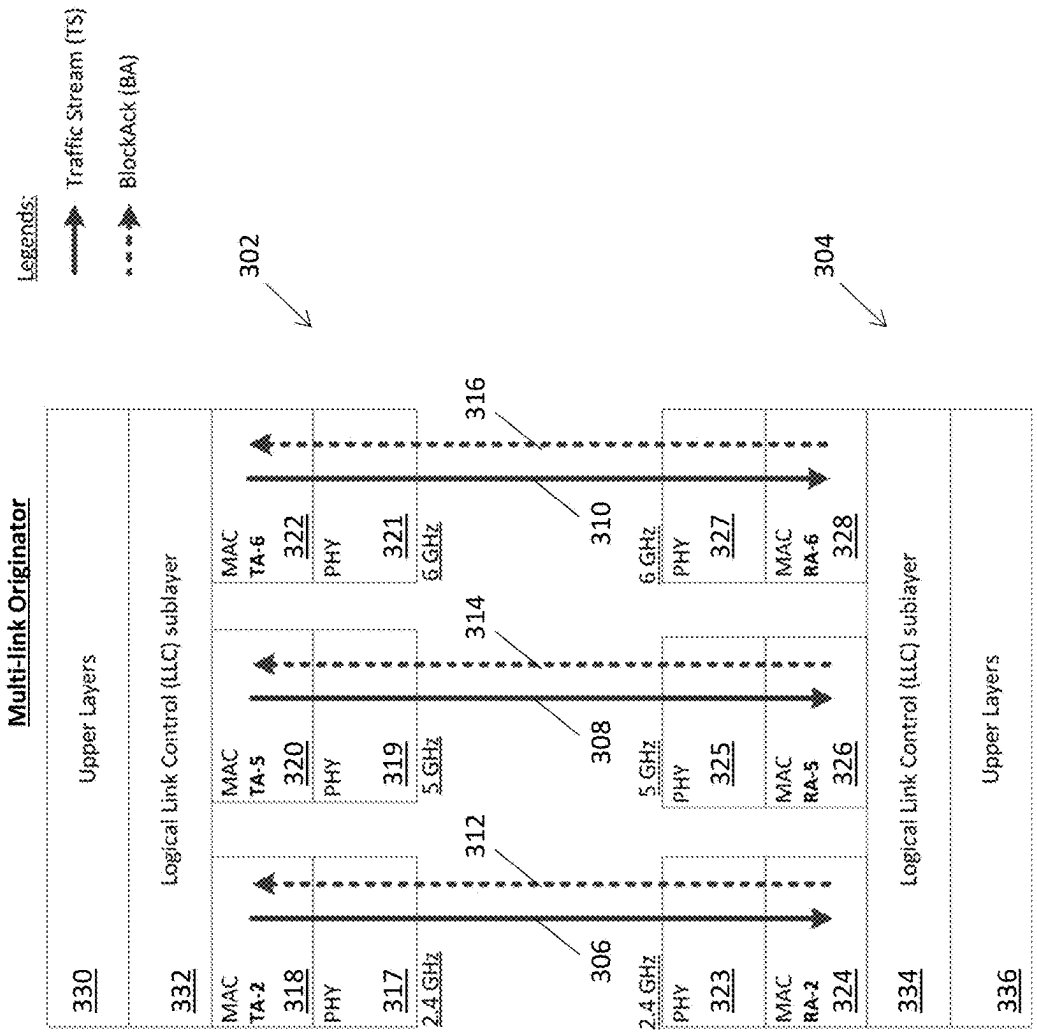

Legends:
Traffic Stream (TS)
BlockAck (BA)
302
304
Multi-link Originator
Multi-link Recipient
330
Upper Layers
332
Logical Link Control (LLC) sublayer
MAC
TA-2
318
PHY
317
2.4 GHz
MAC
TA-5
320
PHY
319
5 GHz
MAC
TA-6
322
PHY
321
6 GHz
2.4 GHz
PHY
323
MAC
RA-2
324
5 GHz
PHY
325
MAC
RA-5
326
6 GHz
PHY
327
MAC
RA-6
328
334
Logical Link Control (LLC) sublayer
336
Upper Layers
306
308
310
312
314
316

Figure 3

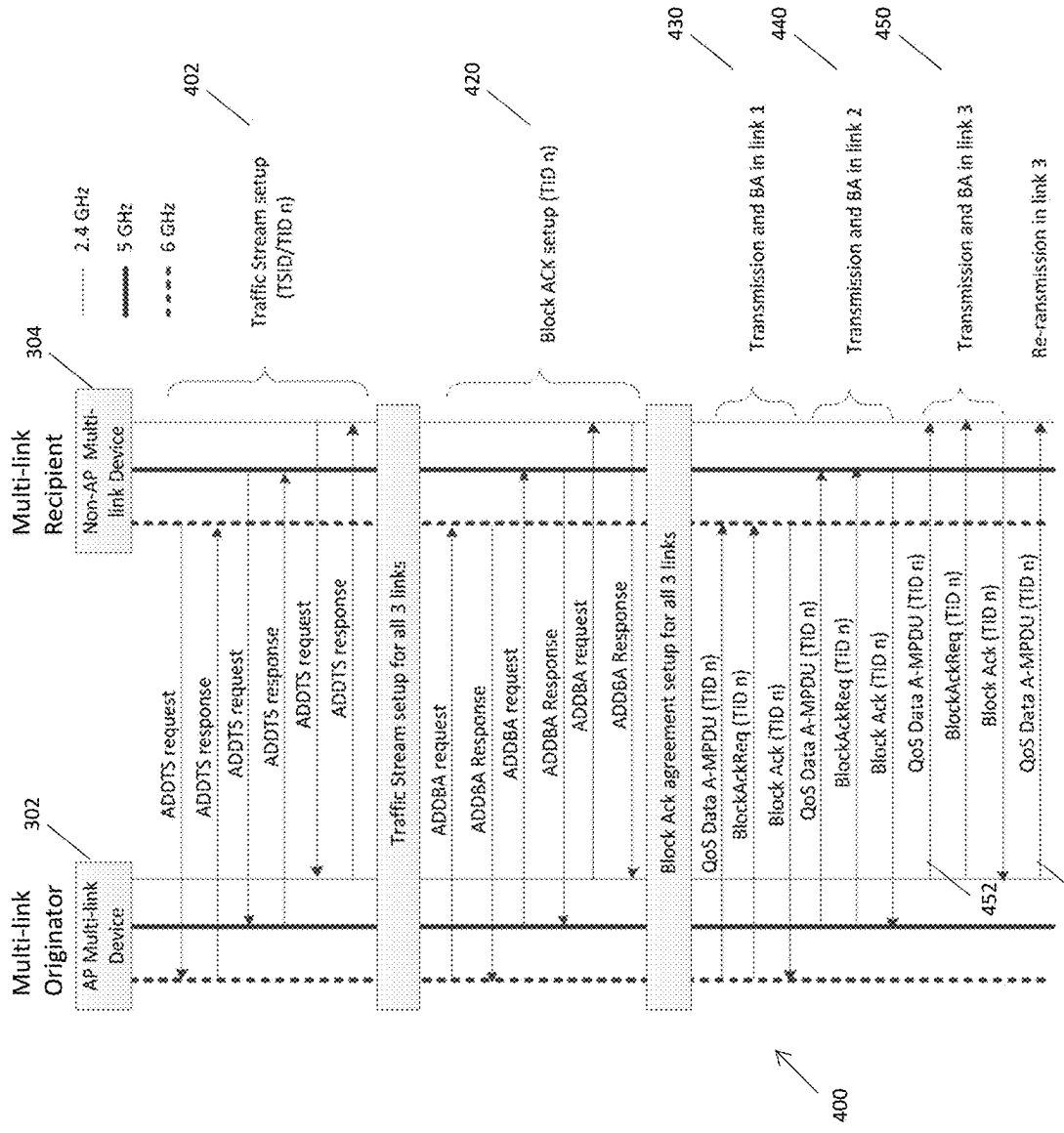

Multi-link Originator
AP Multi-link Device
302
Multi-link Recipient
Non-AP Multi-link Device
304
2.4 GHz
5 GHz
6 GHz
402
Traffic Stream setup (TSID/TID n)
420
Block ACK setup (TID n)
430
Transmission and BA in link 1
440
Transmission and BA in link 2
450
Transmission and BA in link 3
Re-transmission in link 3
ADDTS request
ADDTS response
ADDTS request
ADDTS response
ADDTS request
ADDTS response
Traffic Stream setup for all 3 links
ADDBA request
ADDBA Response
ADDBA request
ADDBA Response
ADDBA request
ADDBA Response
Block Ack agreement setup for all 3 links
QoS Data A-MPDU (TID n)
BlockAckReq (TID n)
Block Ack (TID n)
QoS Data A-MPDU (TID n)
BlockAckReq (TID n)
Block Ack (TID n)
QoS Data A-MPDU (TID n)
BlockAckReq (TID n)
Block Ack (TID n)
QoS Data A-MPDU (TID n)
452
454
400

Figure 4

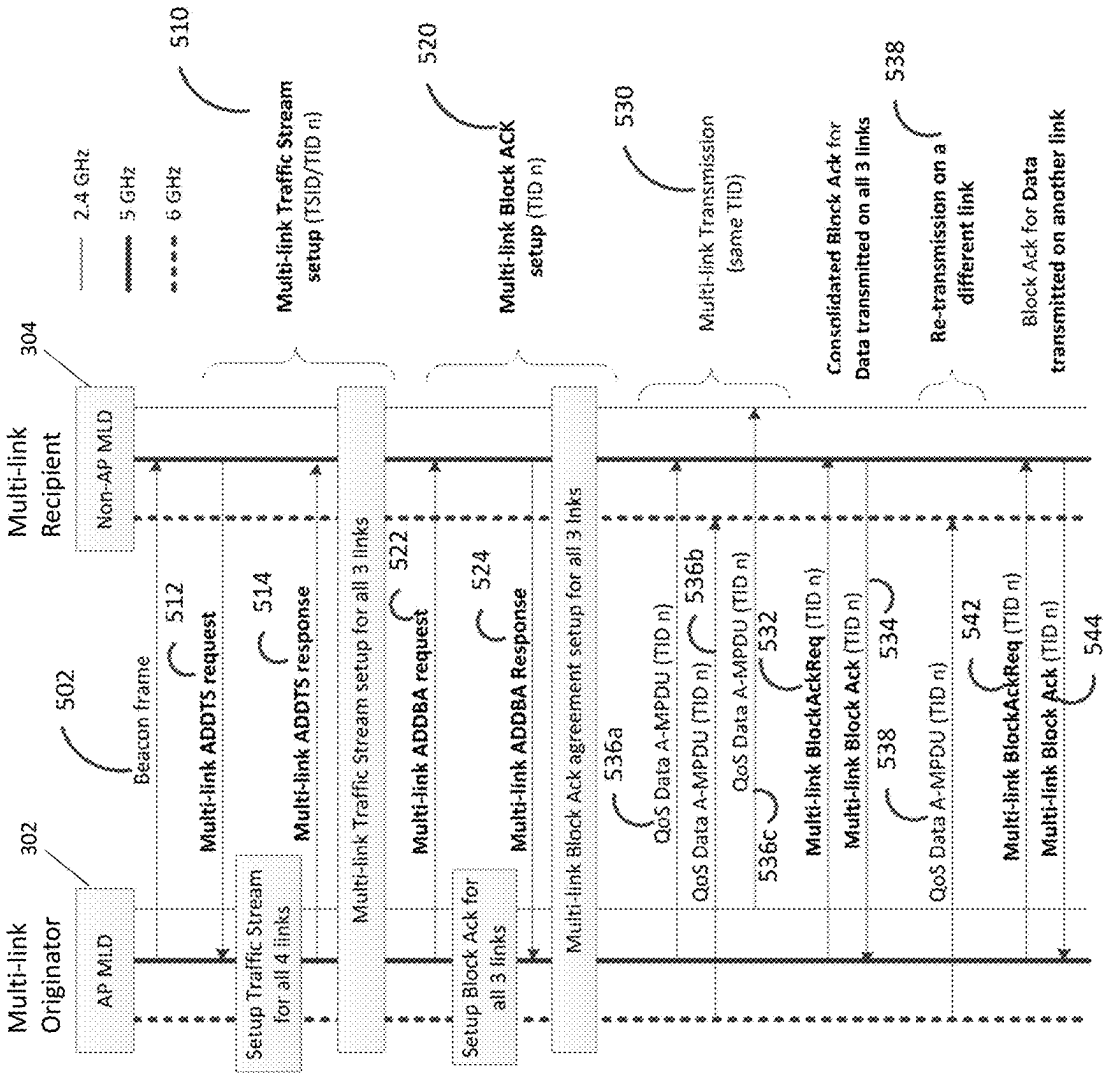

Multi-link Originator
302
AP MLD
Multi-link Recipient
304
Non-AP MLD
2.4 GHz
5 GHz
6 GHz
510
Multi-link Traffic Stream setup (TSID/TID n)
520
Multi-link Block ACK setup (TID n)
530
Multi-link Transmission (same TID)
538
Consolidated Block Ack for Data transmitted on all 3 links
Re-transmission on a different link
Block Ack for Data transmitted on another link
502
Beacon frame
512
Multi-link ADDTS request
514
Multi-link ADDTS response
522
Multi-link ADDBA request
524
Multi-link ADDBA Response
Setup Traffic Stream for all 4 links
Multi-link Traffic Stream setup for all 3 links
Setup Block Ack for all 3 links
Multi-link Block Ack agreement setup for all 3 links
536a
QoS Data A-MPDU (TID n)
536b
QoS Data A-MPDU (TID n)
532
QoS Data A-MPDU (TID n)
536c
Multi-link BlockAckReq (TID n)
534
Multi-link Block Ack (TID n)
538
QoS Data A-MPDU (TID n)
542
Multi-link BlockAckReq (TID n)
544
Multi-link Block Ack (TID n)

Figure 5

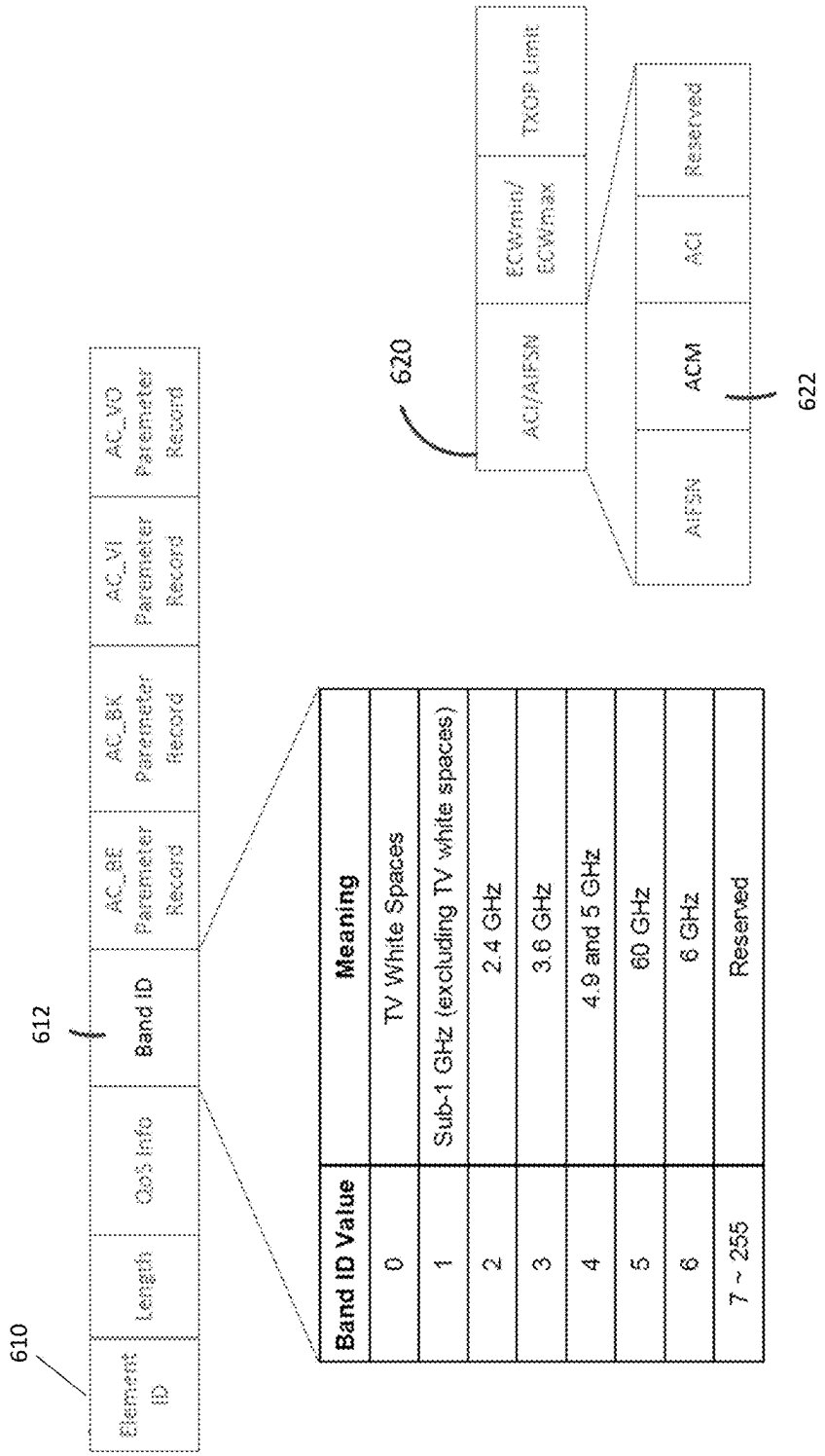

610
Element ID
Length
QoS Info
612
Band ID
AC_BE Parameter Record
AC_BK Parameter Record
AC_VI Parameter Record
AC_VO Parameter Record
620
ACI/AIFSN
ECWmin/ ECWmax
TXOP Limit
AIFSN
ACM
ACI
Reserved
622
Band ID Value
Meaning
0
TV White Spaces
1
Sub-1 GHz (excluding TV white spaces)
2
2.4 GHz
3
3.6 GHz
4
4.9 and 5 GHz
5
60 GHz
6
6 GHz
7 ~ 255
Reserved

Figure 6

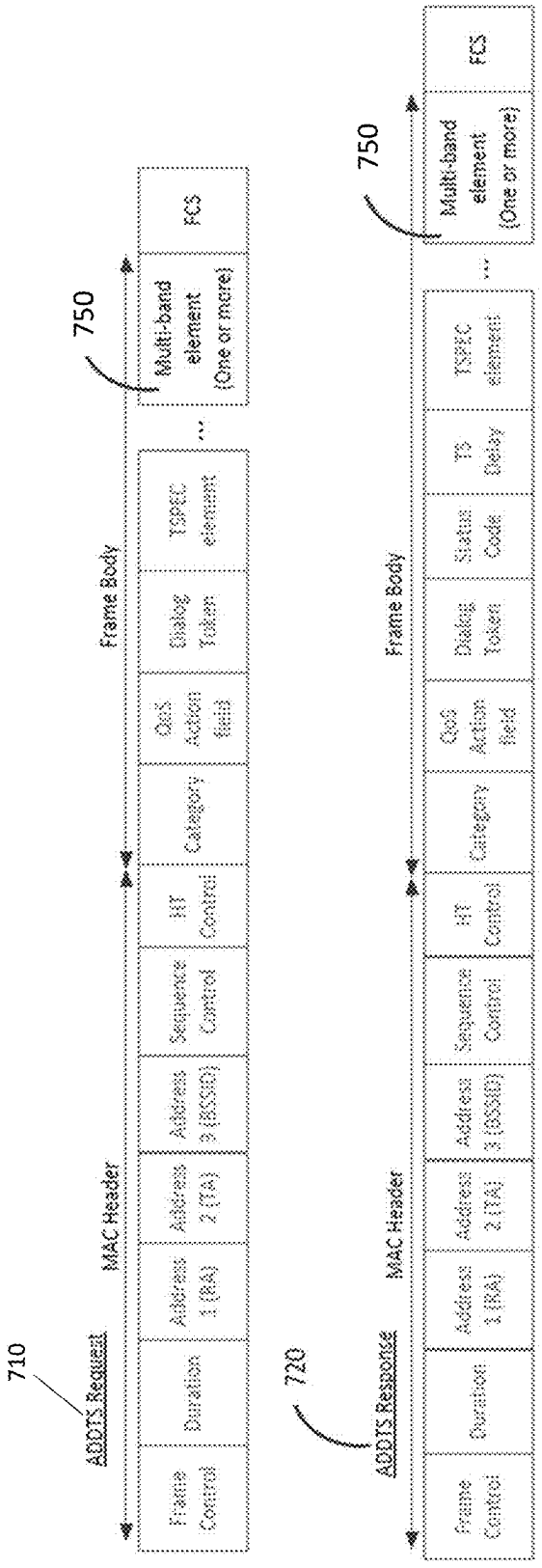

710
ADDTS Request
MAC Header
Frame Control
Duration
Address 1 (RA)
Address 2 (TA)
Address 3 (BSSID)
Sequence Control
HT Control
Category
QoS Action field
Dialog Token
TSPEC element
Frame Body
750
Multi-band element (One or more)
FCS
720
ADDTS Response
MAC Header
Frame Control
Duration
Address 1 (RA)
Address 2 (TA)
Address 3 (BSSID)
Sequence Control
HT Control
Category
QoS Action field
Dialog Token
Status Code
TS Delay
TSPEC element
Frame Body
750
Multi-band element (One or more)
FCS

Figure 7

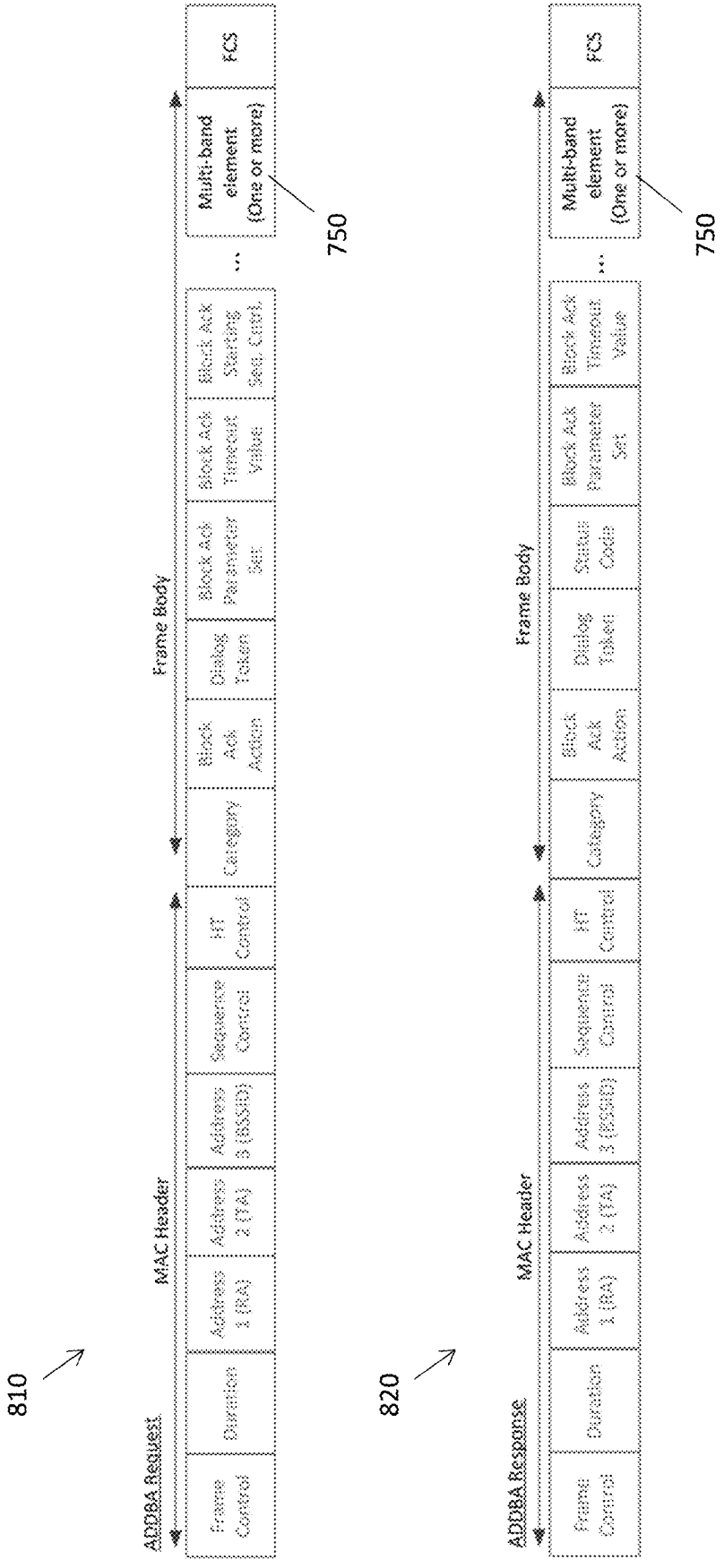

810
ADDBA Request
MAC Header
Frame Body
Frame Control
Duration
Address 1 (RA)
Address 2 (TA)
Address 3 (BSSID)
Sequence Control
HT Control
Category
Block Ack Action
Dialog Token
Block Ack Parameter Set
Block Ack Timeout Value
Block Ack Starting Seq. Cntrl.
...
Multi-band element (One or more)
FCS
750
820
ADDBA Response
MAC Header
Frame Body
Frame Control
Duration
Address 1 (RA)
Address 2 (TA)
Address 3 (BSSID)
Sequence Control
HT Control
Category
Block Ack Action
Dialog Token
Status Code
Block Ack Parameter Set
Block Ack Timeout Value
...
Multi-band element (One or more)
FCS
750

Figure 8

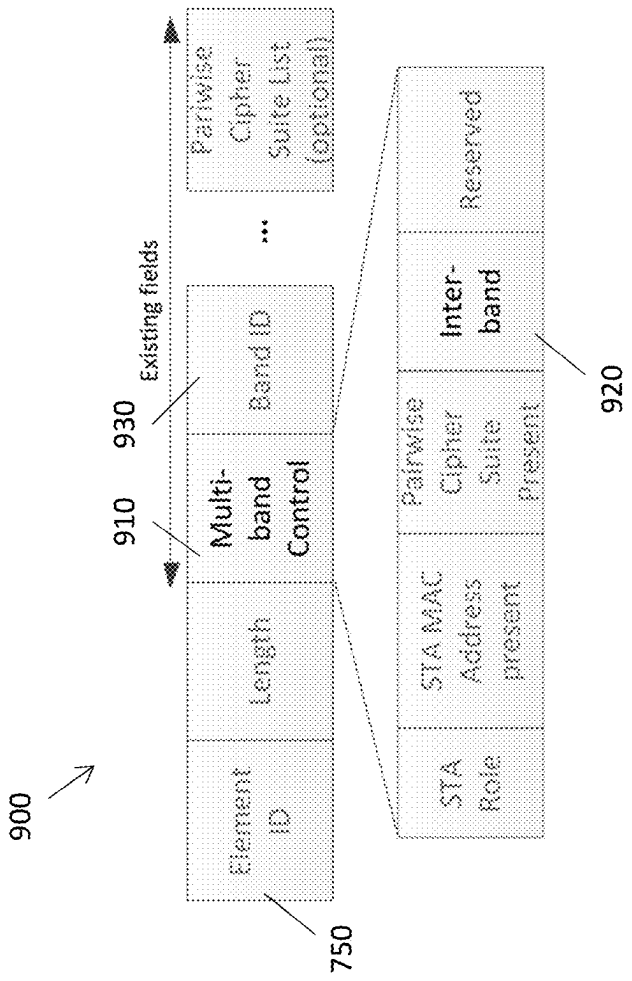

900
Element ID
Length
Multi-band Control
Band ID
Existing fields
930
910
Pairwise Cipher Suite List (optional)
...
750
STA Role
STA MAC Address present
Pairwise Cipher Suite Present
Inter-band
Reserved
920

Figure 9

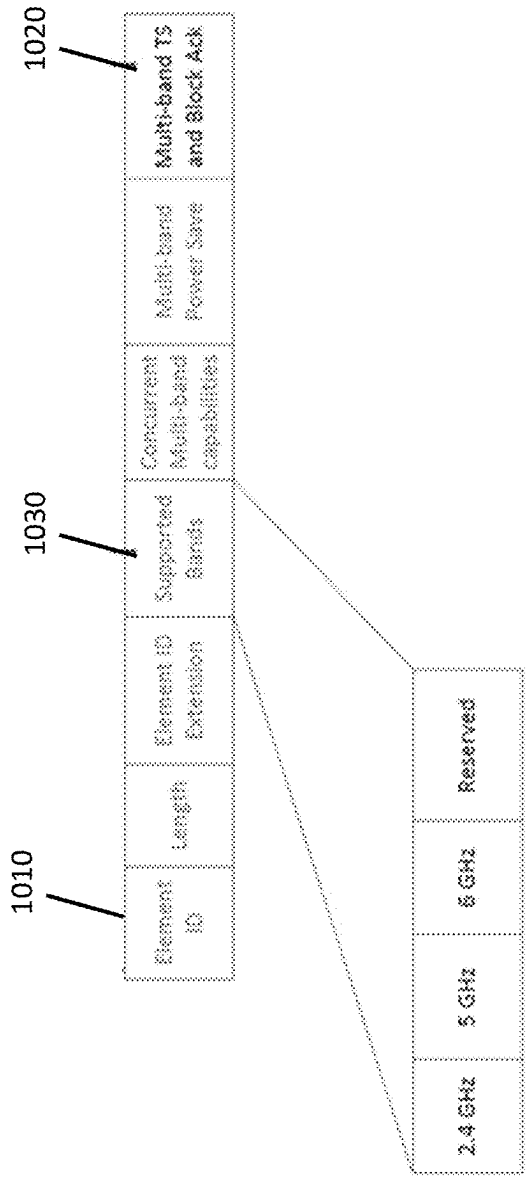

1020
1030
1010
Element ID
Length
Element ID Extension
Supported Bands
Concurrent Multi-band capabilities
Multi-band Power Save
Multi-band TS and Block Ack
2.4 GHz
5 GHz
6 GHz
Reserved

Figure 10

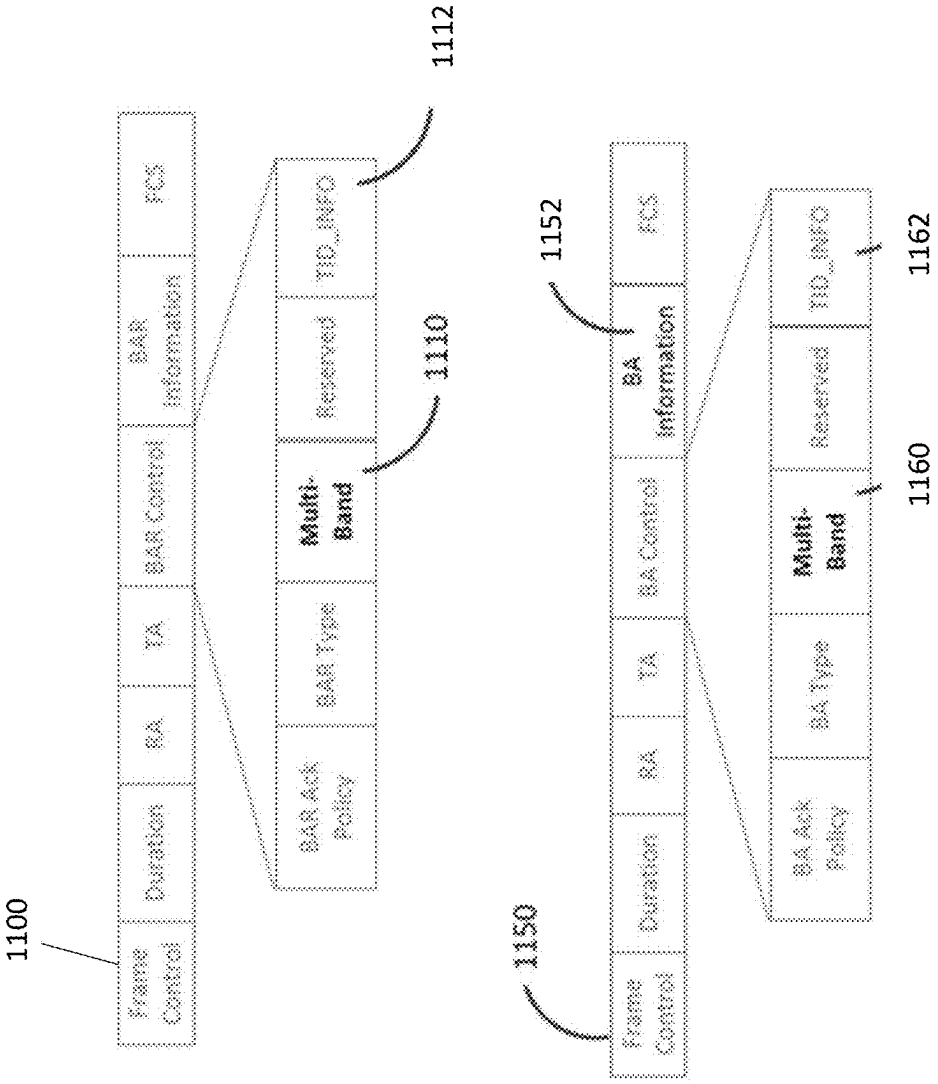

1100
Frame Control
Duration
RA
TA
BAR Control
BAR Information
FCS
BAR Ack Policy
BAR Type
Multi-Band
Reserved
TID_INFO
1110
1112
1150
Frame Control
Duration
RA
TA
BA Control
BA Information
FCS
BA Ack Policy
BA Type
Multi-Band
Reserved
TID_INFO
1152
1160
1162

Figure 11

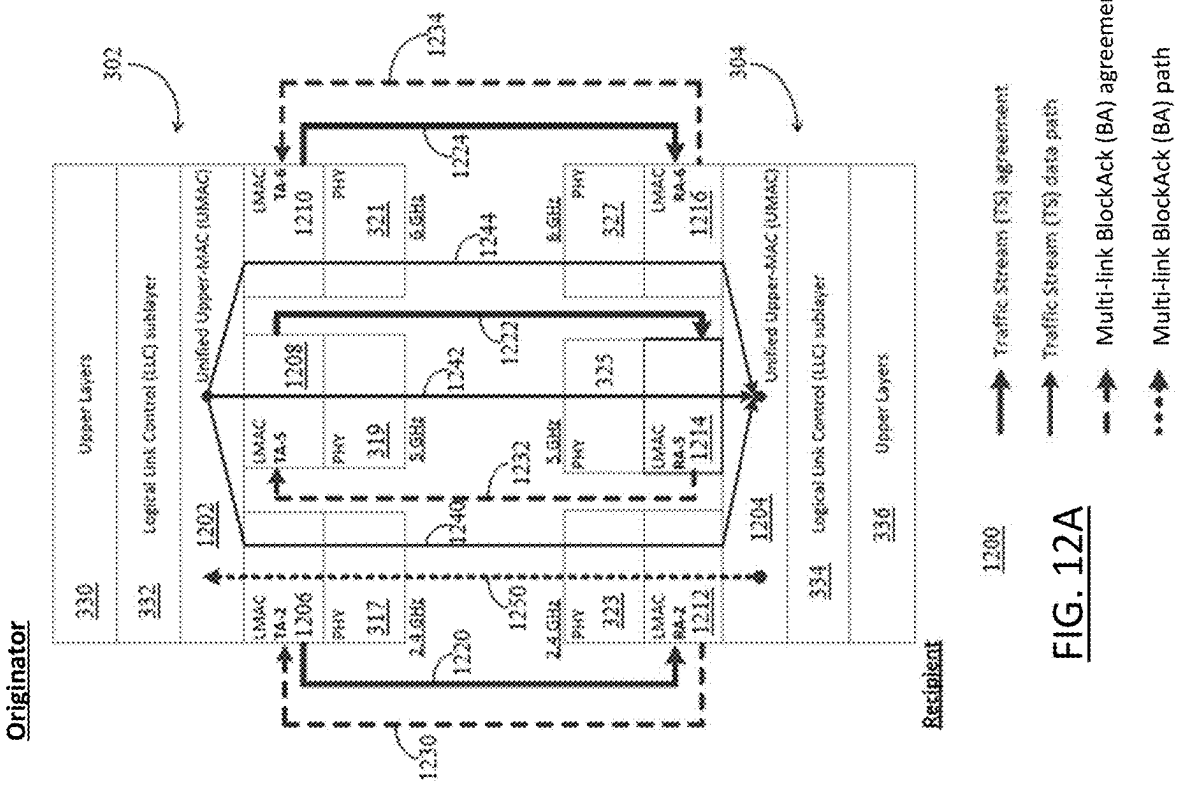

Originator
Recipient
Upper Layers
Logical Link Control (LLC) sublayer
Unified Upper-MAC (UMAC)
Logical Link Control (LLC) sublayer
Unified Upper-MAC (UMAC)
Upper Layers
330
332
1202
1204
334
336
302
304
1206
317
323
1212
1208
319
325
1214
1210
321
327
1216
1220
1222
1224
1230
1232
1234
1240
1242
1244
1250
Traffic Stream (TS) agreement
Traffic Stream (TS) data path
Multi-link BlockAck (BA) agreement
Multi-link BlockAck (BA) path
1200

FIG. 12A

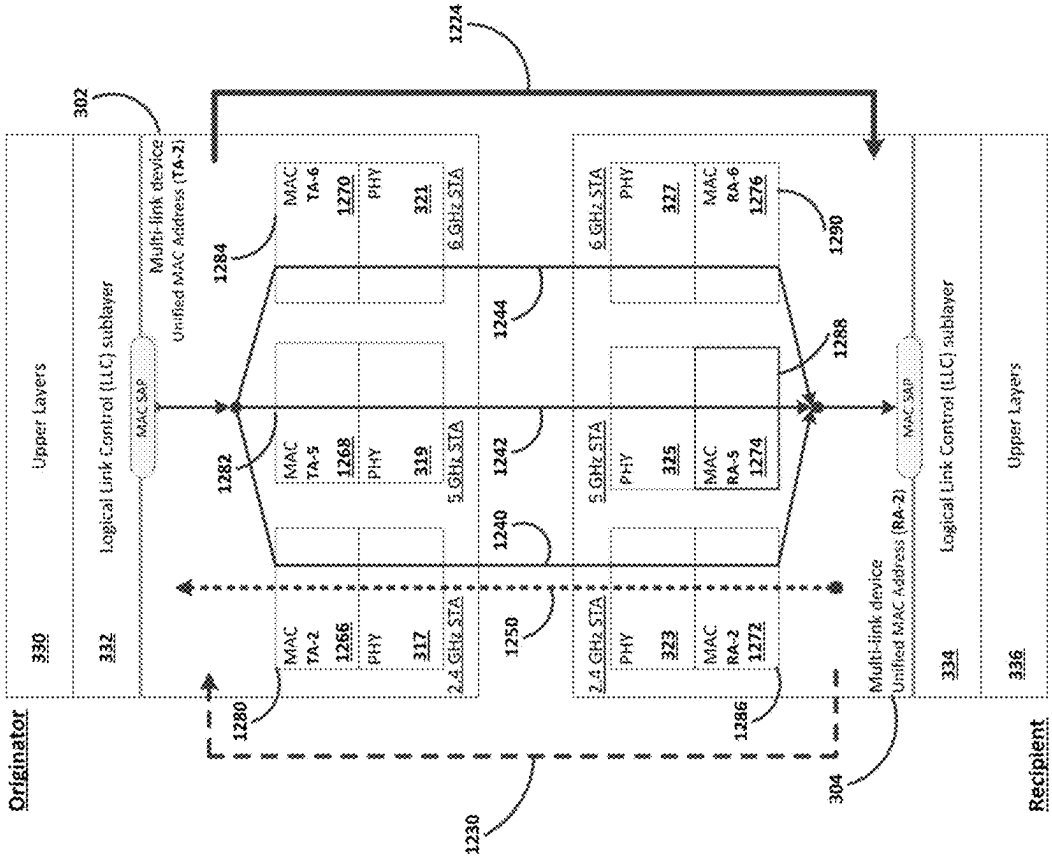
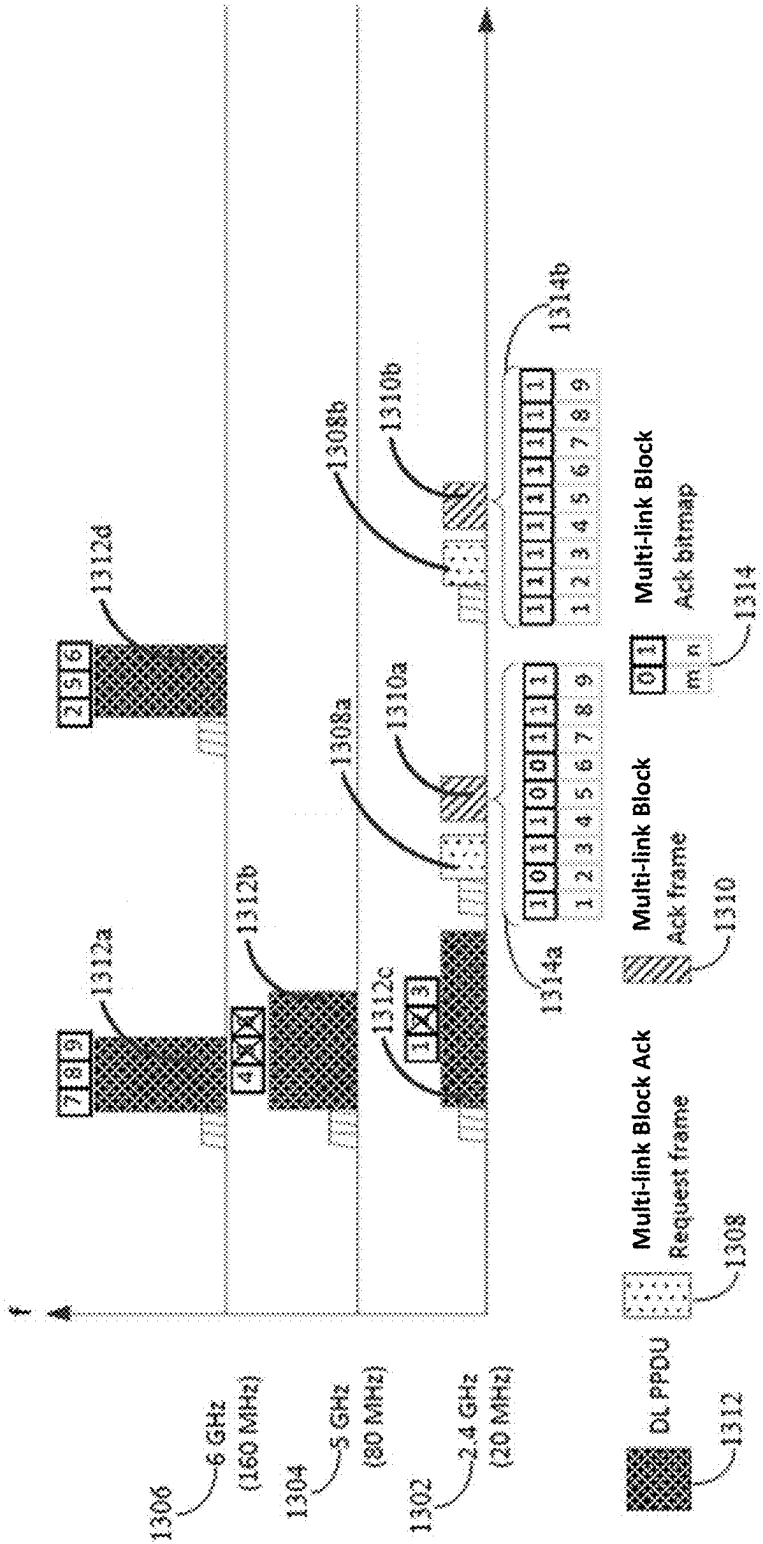

Originator
Recipient
Upper Layers
330
Logical Link Control (LLC) sublayer
332
MAC SAP
Multi-link device
Unified MAC Address (TA-2)
302
2.4 GHz STA
5 GHz STA
6 GHz STA
MAC TA-2 1266
PHY 317
MAC TA-5 1268
PHY 319
MAC TA-6 1270
PHY 321
MAC RA-2 1272
PHY 323
MAC RA-5 1274
PHY 325
MAC RA-6 1276
PHY 327
1280
1282
1284
1286
1288
1290
1224
1230
1240
1242
1244
1250
304
Multi-link device
Unified MAC Address (RA-2)
MAC SAP
Logical Link Control (LLC) sublayer
334
Upper Layers
336
Legends:
Traffic Stream (TS) agreement
Traffic Stream (TS) data path
1260

FIG. 12B


f
1306
6 GHz
(160 MHz)
1304
5 GHz
(80 MHz)
1302
2.4 GHz
(20 MHz)
DL PPDU
1312
Multi-link Block Ack
Request frame
1308
Multi-link Block
Ack frame
1310
Multi-link Block
Ack bitmap
m n
1314
1312a
1312b
1312c
1312d
1308a
1308b
1310a
1310b
1314a
1314b

1300

FIG. 13

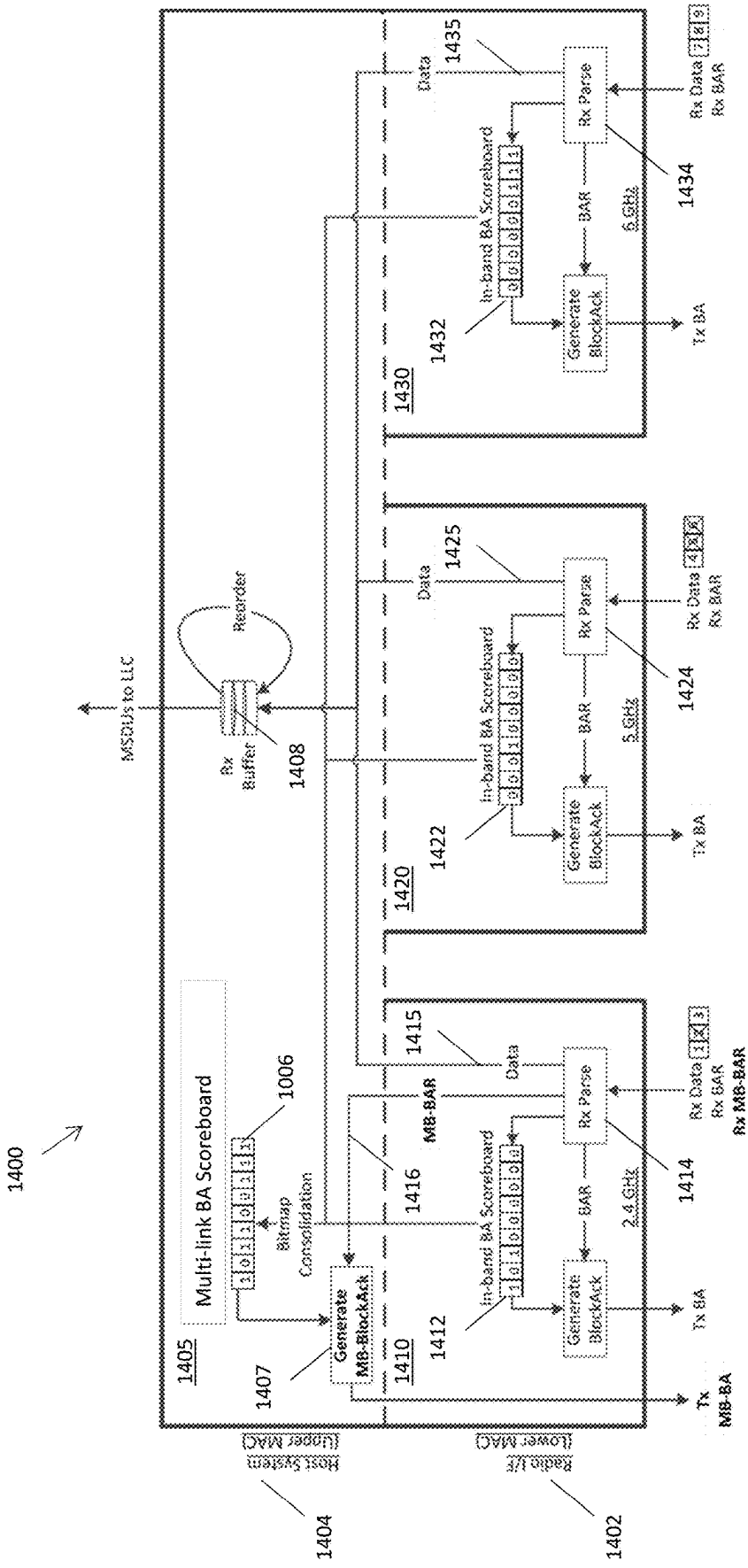

1400
1404
Host System
Upper MAC
1402
Radio I/F
Lower MAC
1405
Multi-link BA Scoreboard
1006
Bitmap Consolidation
1407
Generate MB-BlockAck
1410
1412
In-band BA Scoreboard
BAR
Rx Parse
1414
2.4 GHz
1415
Data
MB-BAR
1416
Rx Data
Rx BAR
Rx MB-BAR
Tx MB-BA
Tx BA
1420
1422
5 GHz
1424
1425
1430
1432
6 GHz
1434
1435
Rx Buffer
1408
Reorder
MSDUs to LLC

Figure 14

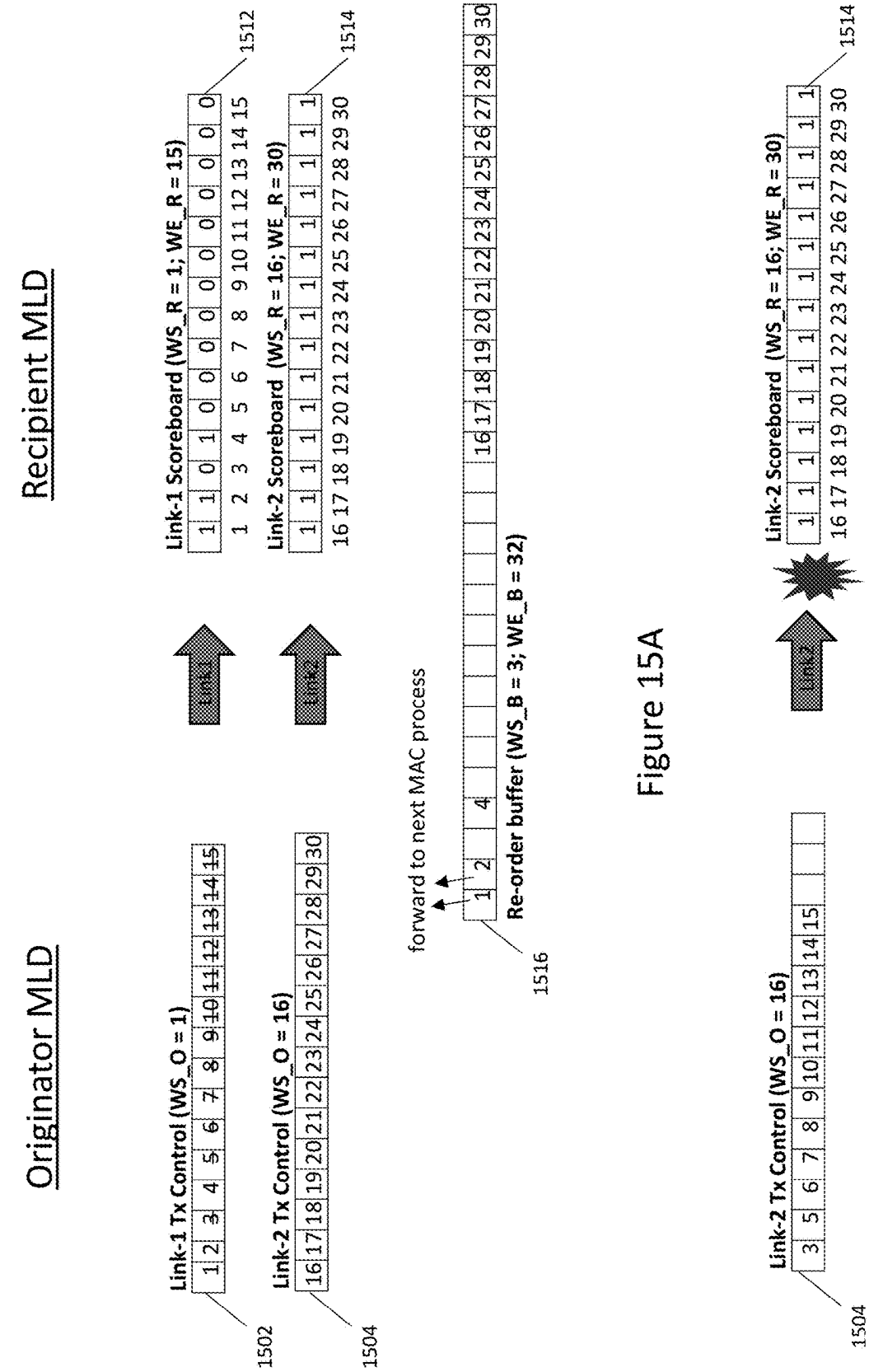


Figure 15A

Figure 15B

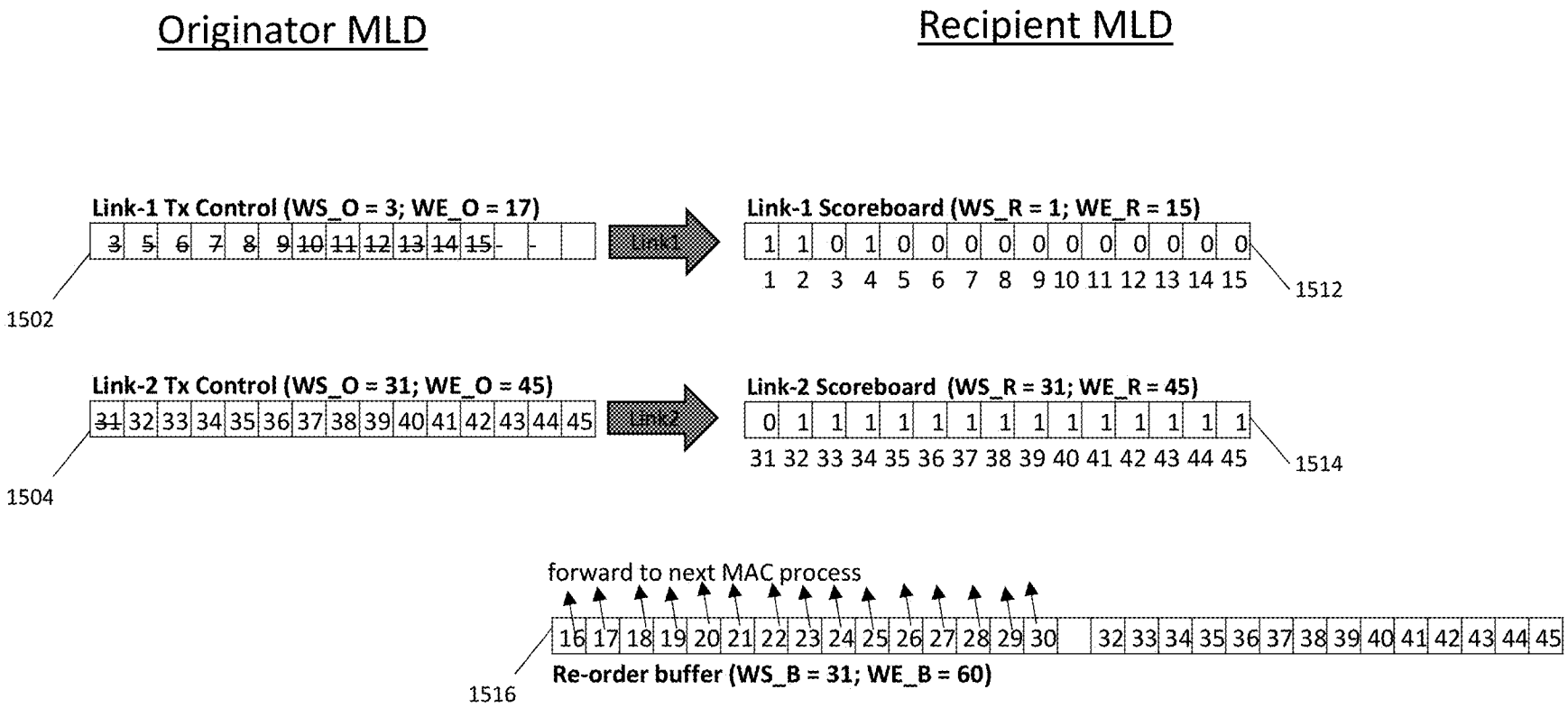

Originator MLD
Recipient MLD
Link-1 Tx Control (WS_O = 3; WE_O = 17)
3 5 6 7 8 9 10 11 12 13 14 15 - -
Link1
Link-1 Scoreboard (WS_R = 1; WE_R = 15)
1 1 0 1 0 0 0 0 0 0 0 0 0 0 0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
1502
1512
Link-2 Tx Control (WS_O = 31; WE_O = 45)
31 32 33 34 35 36 37 38 39 40 41 42 43 44 45
Link2
Link-2 Scoreboard (WS_R = 31; WE_R = 45)
0 1 1 1 1 1 1 1 1 1 1 1 1 1 1
31 32 33 34 35 36 37 38 39 40 41 42 43 44 45
1504
1514
forward to next MAC process
16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 32 33 34 35 36 37 38 39 40 41 42 43 44 45
Re-order buffer (WS_B = 31; WE_B = 60)
1516

Figure 15C

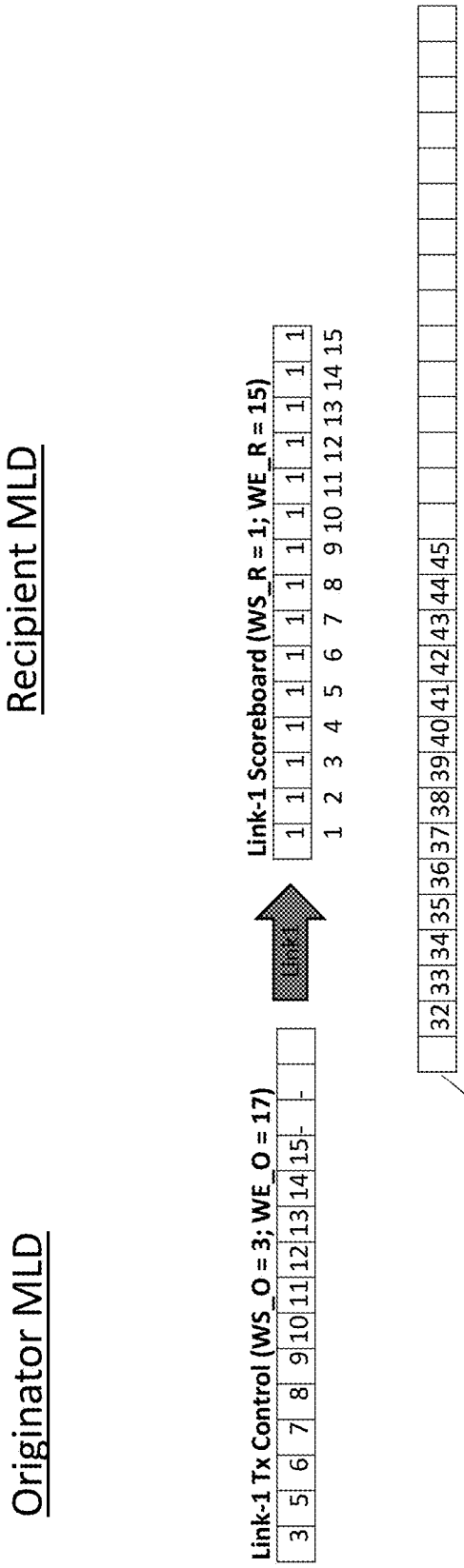

Originator MLD
Recipient MLD
Link-1 Tx Control (WS_O = 3; WE_O = 17)
3 5 6 7 8 9 10 11 12 13 14 15 - -
Link
Link-1 Scoreboard (WS_R = 1; WE_R = 15)
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Re-order buffer (WS_B = 31; WE_B = 60)
32 33 34 35 36 37 38 39 40 41 42 43 44 45
1516

Figure 15D

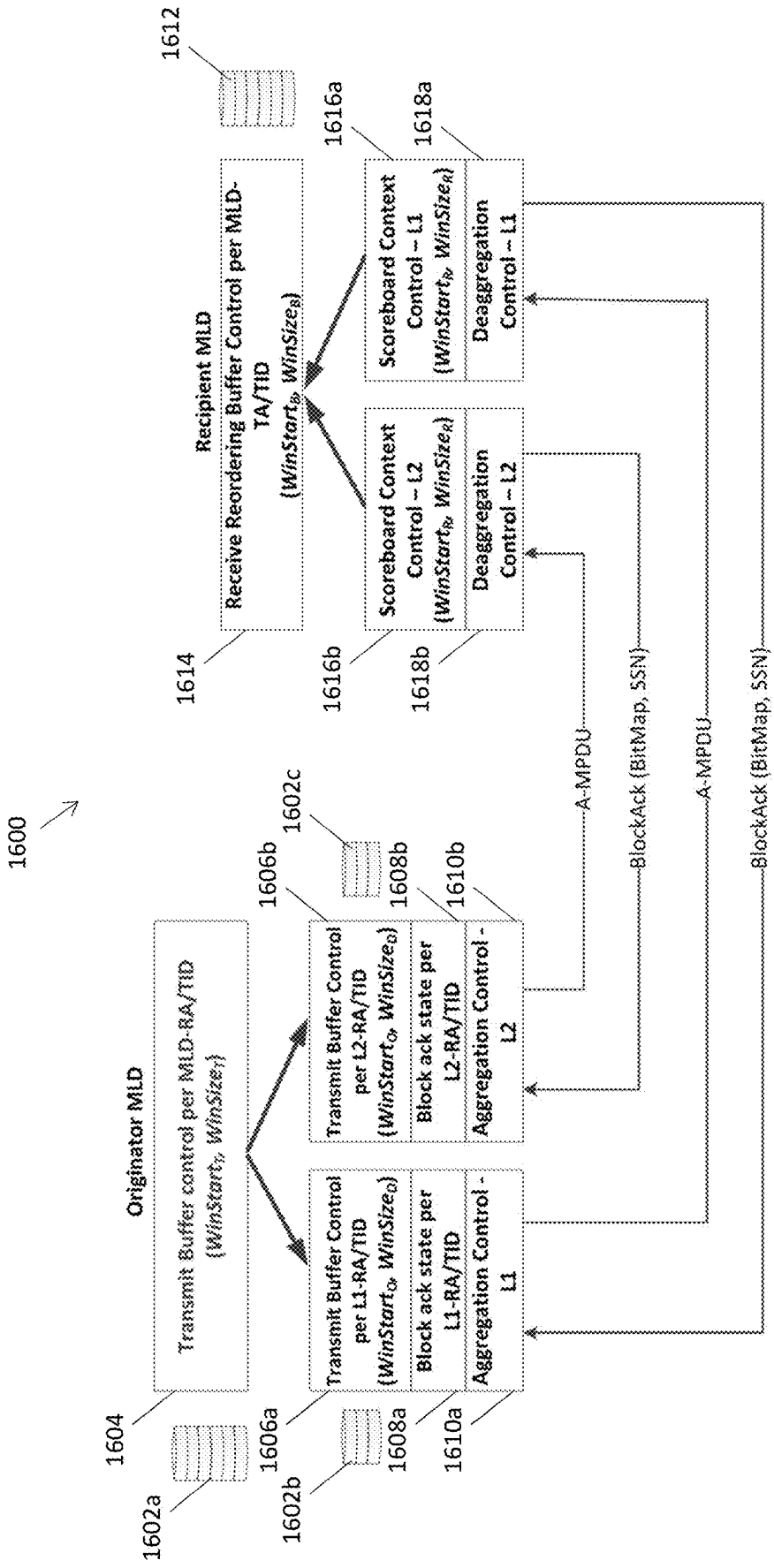

1600
Originator MLD
Transmit Buffer control per MLD-RA/TID
(WinStart_T, WinSize_T)
Transmit Buffer Control per L1-RA/TID
(WinStart_O, WinSize_O)
Block ack state per L1-RA/TID
Aggregation Control - L1
Transmit Buffer Control per L2-RA/TID
(WinStart_O, WinSize_O)
Block ack state per L2-RA/TID
Aggregation Control - L2
Recipient MLD
Receive Reordering Buffer Control per MLD-TA/TID
(WinStart_R, WinSize_R)
Scoreboard Context Control – L1
(WinStart_R, WinSize_R)
Deaggregation Control – L1
Scoreboard Context Control – L2
(WinStart_R, WinSize_R)
Deaggregation Control – L2
A-MPDU
BlockAck (BitMap, SSN)
A-MPDU
BlockAck (BitMap, SSN)
1602a
1602b
1602c
1604
1606a
1606b
1608a
1608b
1610a
1610b
1612
1614
1616a
1616b
1618a
1618b

Figure 16

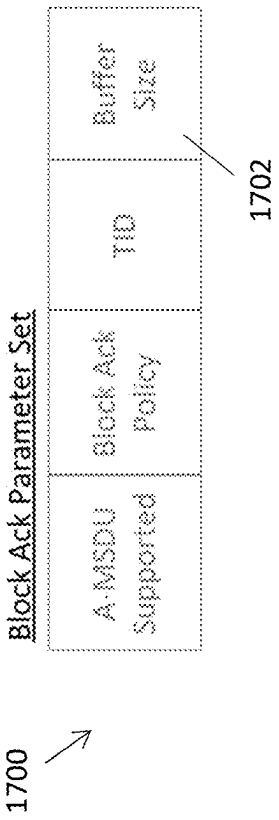


Figure 17A

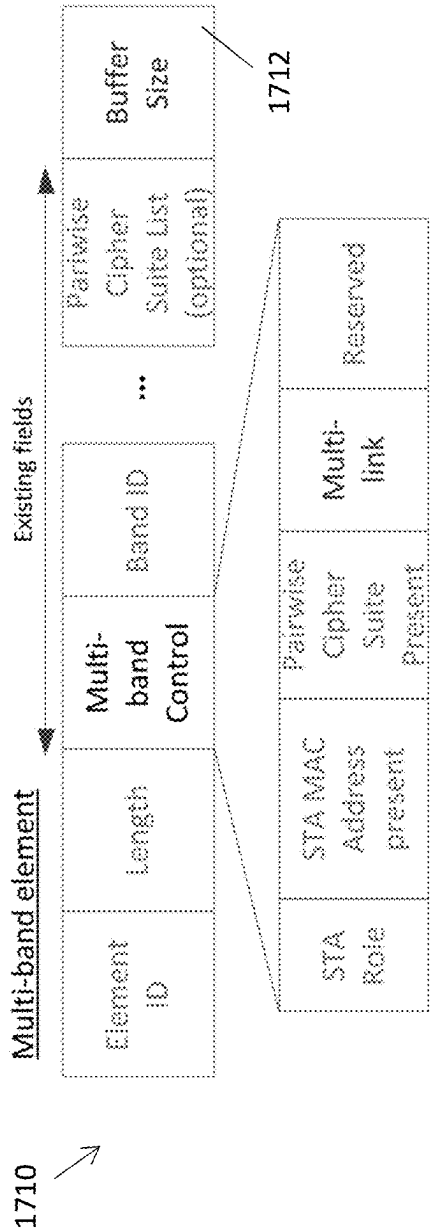


Figure 17B

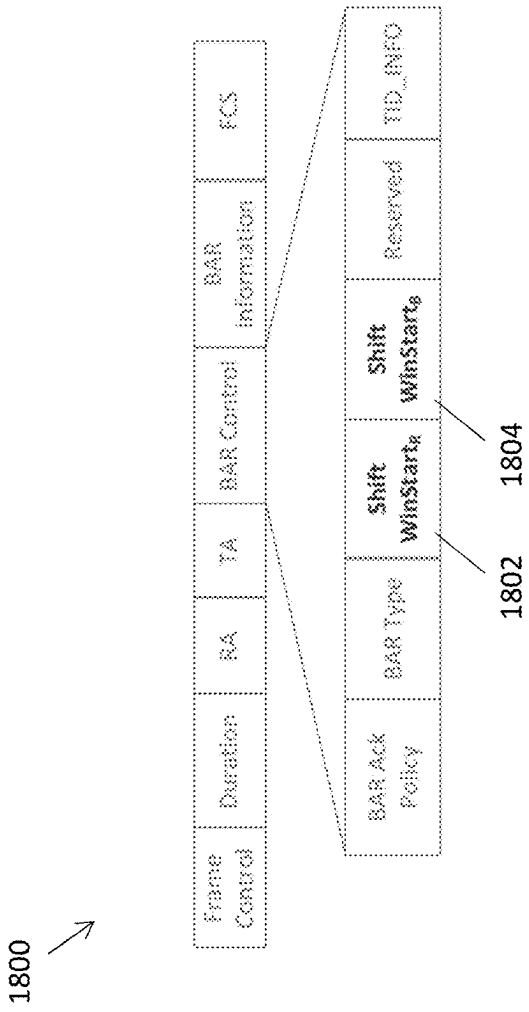

1800
Frame Control
Duration
RA
TA
BAR Control
BAR Information
FCS
BAR Ack Policy
BAR Type
Shift WinStart$_B$
Shift WinStart$_B$
Reserved
TID_INFO
1802
1804

Figure 18

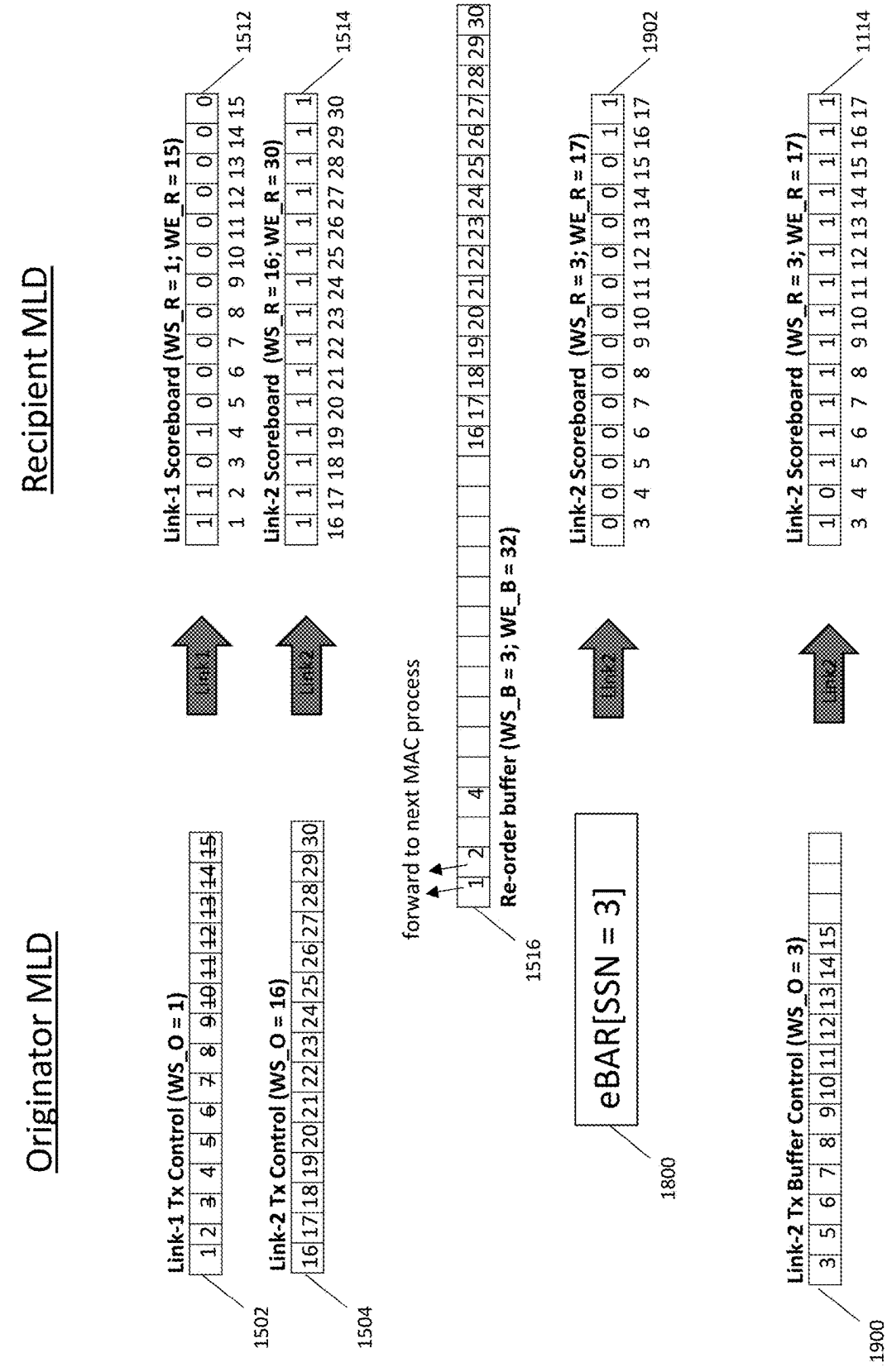

Originator MLD
Recipient MLD
Link-1 Tx Control (WS_O = 1)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
1502
Link-2 Tx Control (WS_O = 16)
16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
1504
Link-1
Link-2
Link-1 Scoreboard (WS_R = 1; WE_R = 15)
1 1 0 1 0 0 0 0 0 0 0 0 0 0 0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
1512
Link-2 Scoreboard (WS_R = 16; WE_R = 30)
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
1514
forward to next MAC process
1 2 4 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Re-order buffer (WS_B = 3; WE_B = 32)
1516
eBAR[SSN = 3]
1800
Link-2
Link-2 Scoreboard (WS_R = 3; WE_R = 17)
0 0 0 0 0 0 0 0 0 0 0 0 0 1 1
3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
1902
Link-2
Link-2 Scoreboard (WS_R = 3; WE_R = 17)
1 0 1 1 1 1 1 1 1 1 1 1 1 1 1
3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
1114
Link-2 Tx Buffer Control (WS_O = 3)
3 5 6 7 8 9 10 11 12 13 14 15
1900

Figure 19

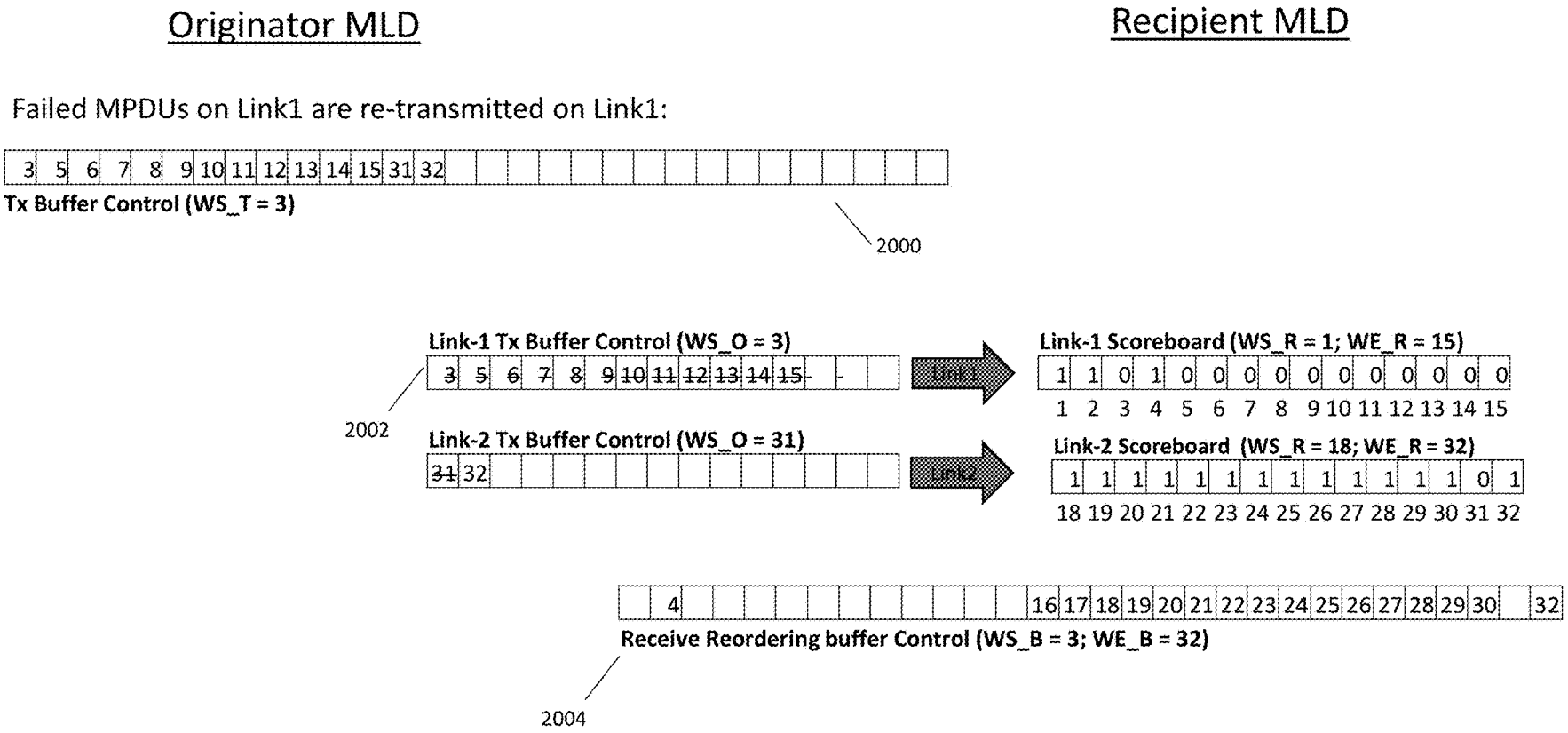

Originator MLD
Recipient MLD
Failed MPDUs on Link1 are re-transmitted on Link1:
3 5 6 7 8 9 10 11 12 13 14 15 31 32
Tx Buffer Control (WS_T = 3)
2000
Link-1 Tx Buffer Control (WS_O = 3)
3 5 6 7 8 9 10 11 12 13 14 15
Link-1
Link-1 Scoreboard (WS_R = 1; WE_R = 15)
1 1 0 1 0 0 0 0 0 0 0 0 0 0 0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
2002
Link-2 Tx Buffer Control (WS_O = 31)
31 32
Link-2
Link-2 Scoreboard (WS_R = 18; WE_R = 32)
1 1 1 1 1 1 1 1 1 1 1 1 1 0 1
18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
4 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 32
Receive Reordering buffer Control (WS_B = 3; WE_B = 32)
2004

Figure 20

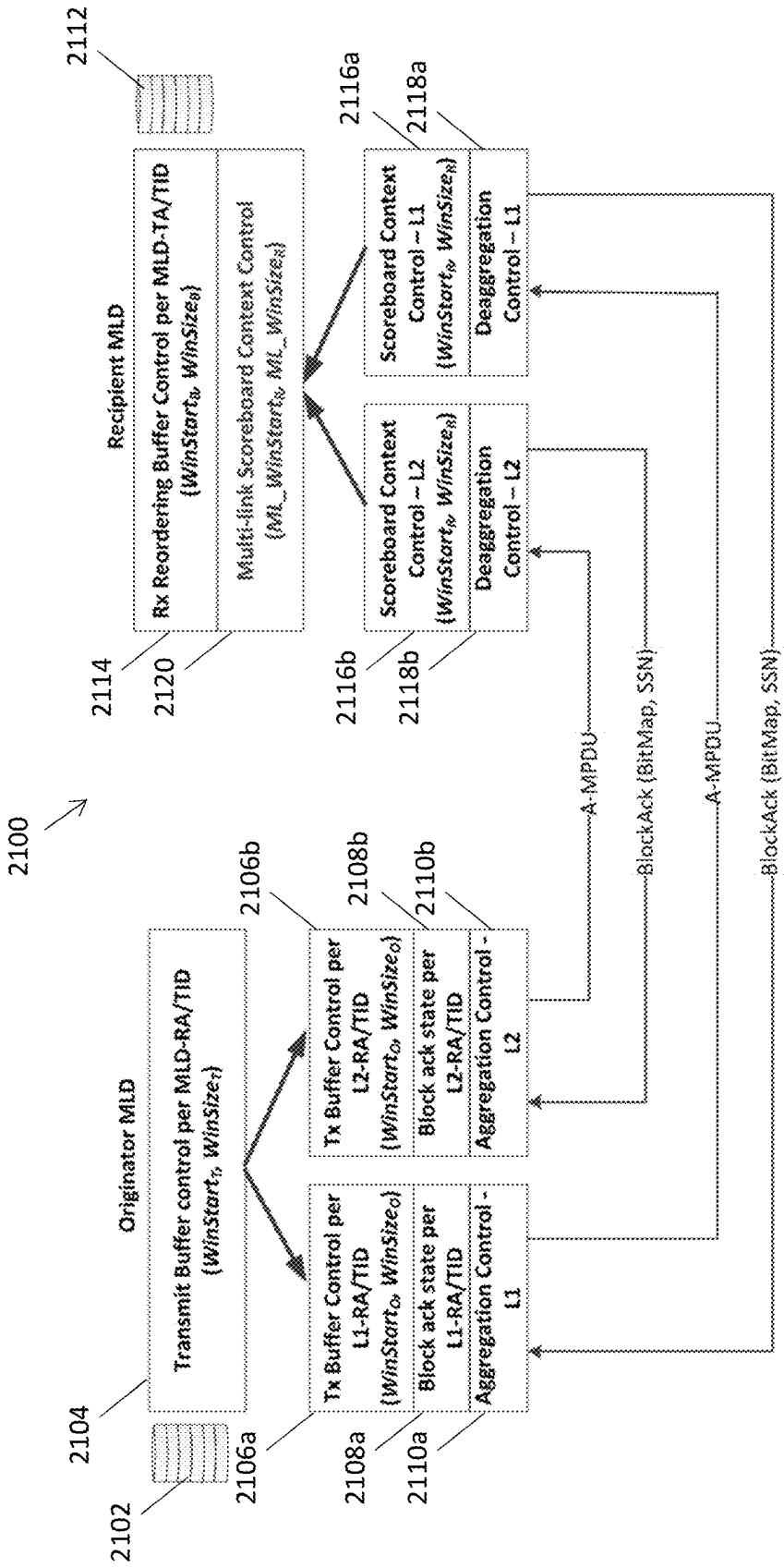

2100
Originator MLD
Transmit Buffer control per MLD-RA/TID
{WinStart_T, WinSize_T}
Tx Buffer Control per L1-RA/TID
{WinStart_O, WinSize_O}
Block ack state per L1-RA/TID
Aggregation Control - L1
Tx Buffer Control per L2-RA/TID
{WinStart_O, WinSize_O}
Block ack state per L2-RA/TID
Aggregation Control - L2
A-MPDU
BlockAck (BitMap, SSN)
A-MPDU
BlockAck (BitMap, SSN)
Recipient MLD
Rx Reordering Buffer Control per MLD-TA/TID
{WinStart_R, WinSize_R}
Multi-link Scoreboard Context Control
{ML_WinStart_R, ML_WinSize_R}
Scoreboard Context Control – L2
{WinStart_R, WinSize_R}
Deaggregation Control – L2
Scoreboard Context Control – L1
{WinStart_R, WinSize_R}
Deaggregation Control – L1
2102
2104
2106a
2106b
2108a
2108b
2110a
2110b
2112
2114
2116a
2116b
2118a
2118b
2120

Figure 21

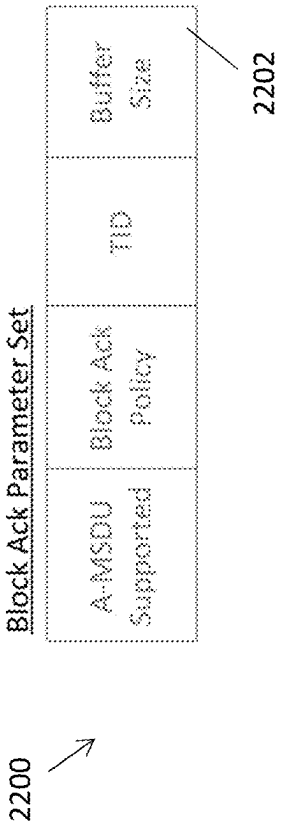


Figure 22A

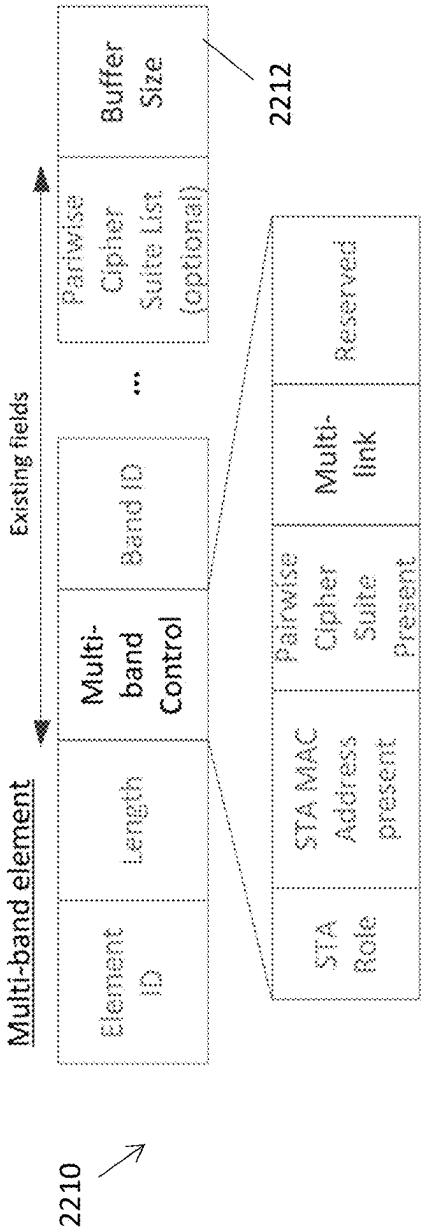


Figure 22B

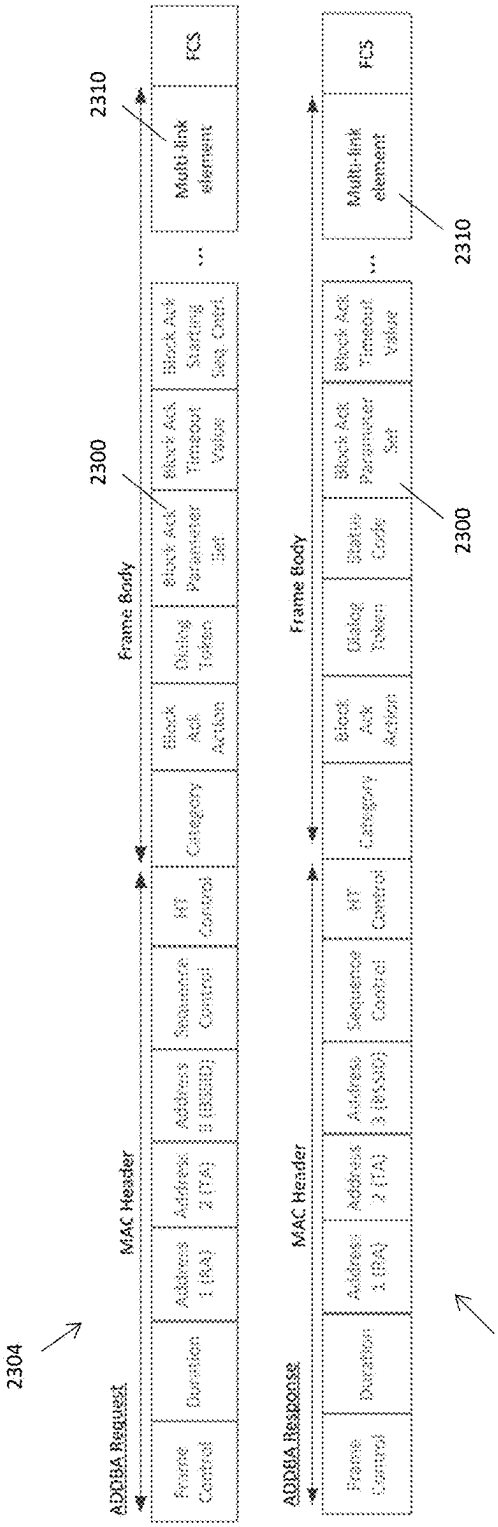


Figure 23A

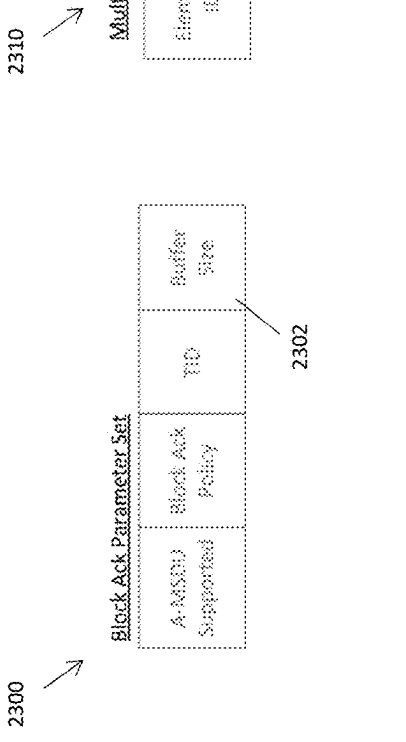


Figure 23B

Figure 23C

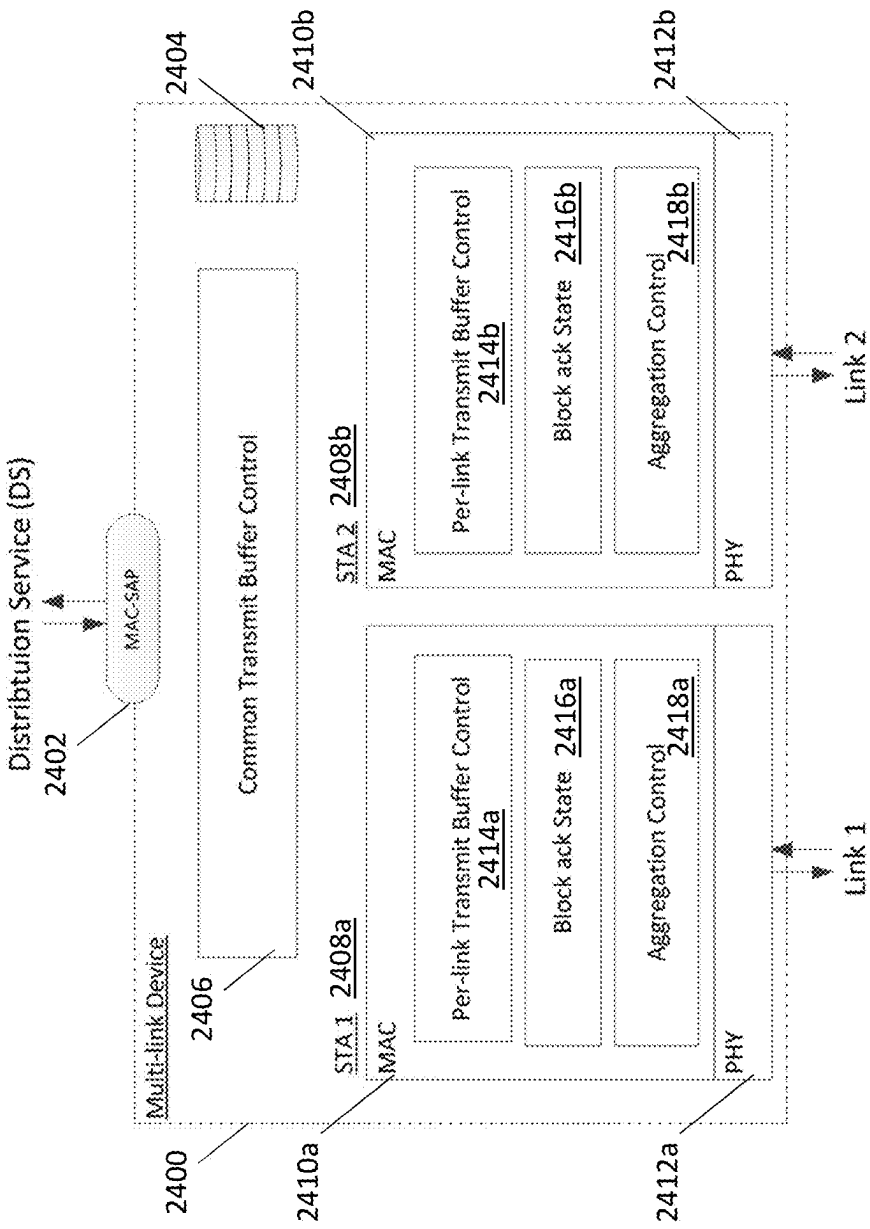

Distribtuion Service (DS)
2402
MAC SAP
2404
2410b
2412b
Multi-link Device
2406
Common Transmit Buffer Control
STA 2 2408b
MAC
Per-link Transmit Buffer Control 2414b
Block ack State 2416b
Aggregation Control 2418b
PHY
Link 2
STA 1 2408a
MAC
Per-link Transmit Buffer Control 2414a
Block ack State 2416a
Aggregation Control 2418a
PHY
Link 1
2400
2410a
2412a

Figure 24

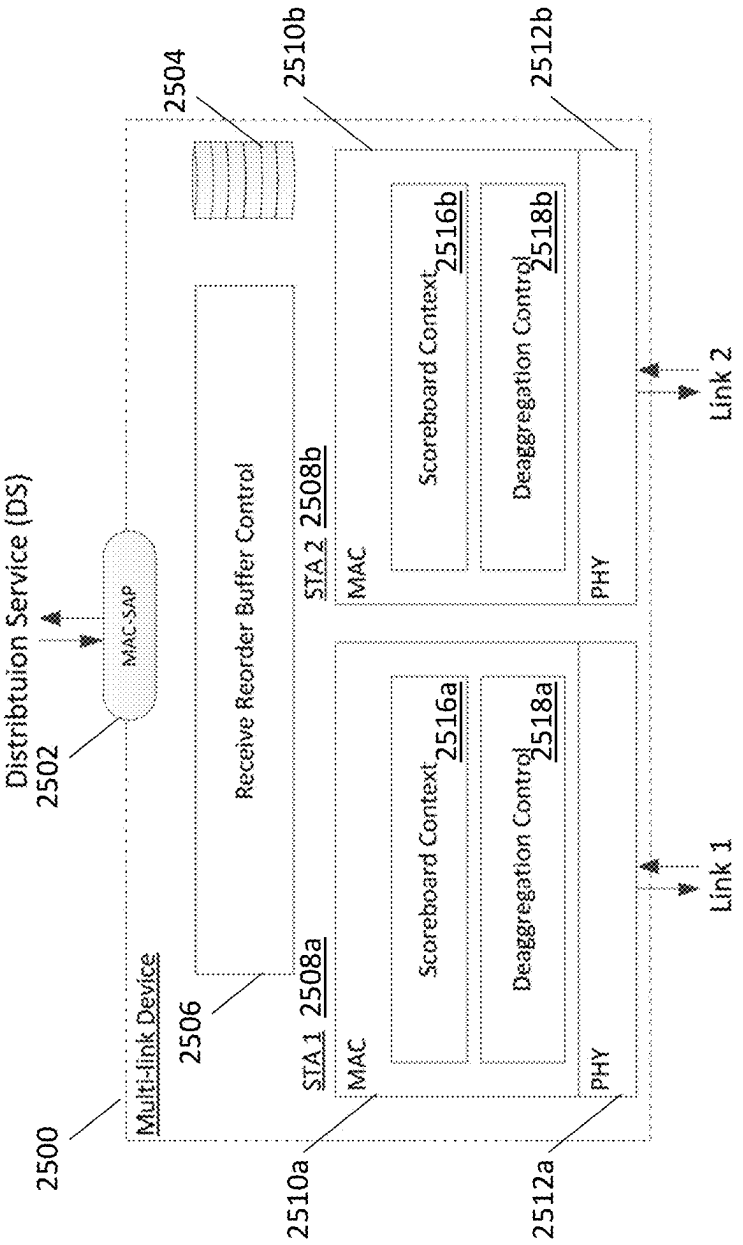

2500
Multi-link Device
2502
Distribtuion Service (DS)
MAC-SAP
2504
2506
Receive Reorder Buffer Control
STA 1 2508a
STA 2 2508b
2510a
2510b
2512a
2512b
MAC
PHY
Scoreboard Context 2516a
Deaggregation Control 2518a
Scoreboard Context 2516b
Deaggregation Control 2518b
Link 1
Link 2

Figure 25

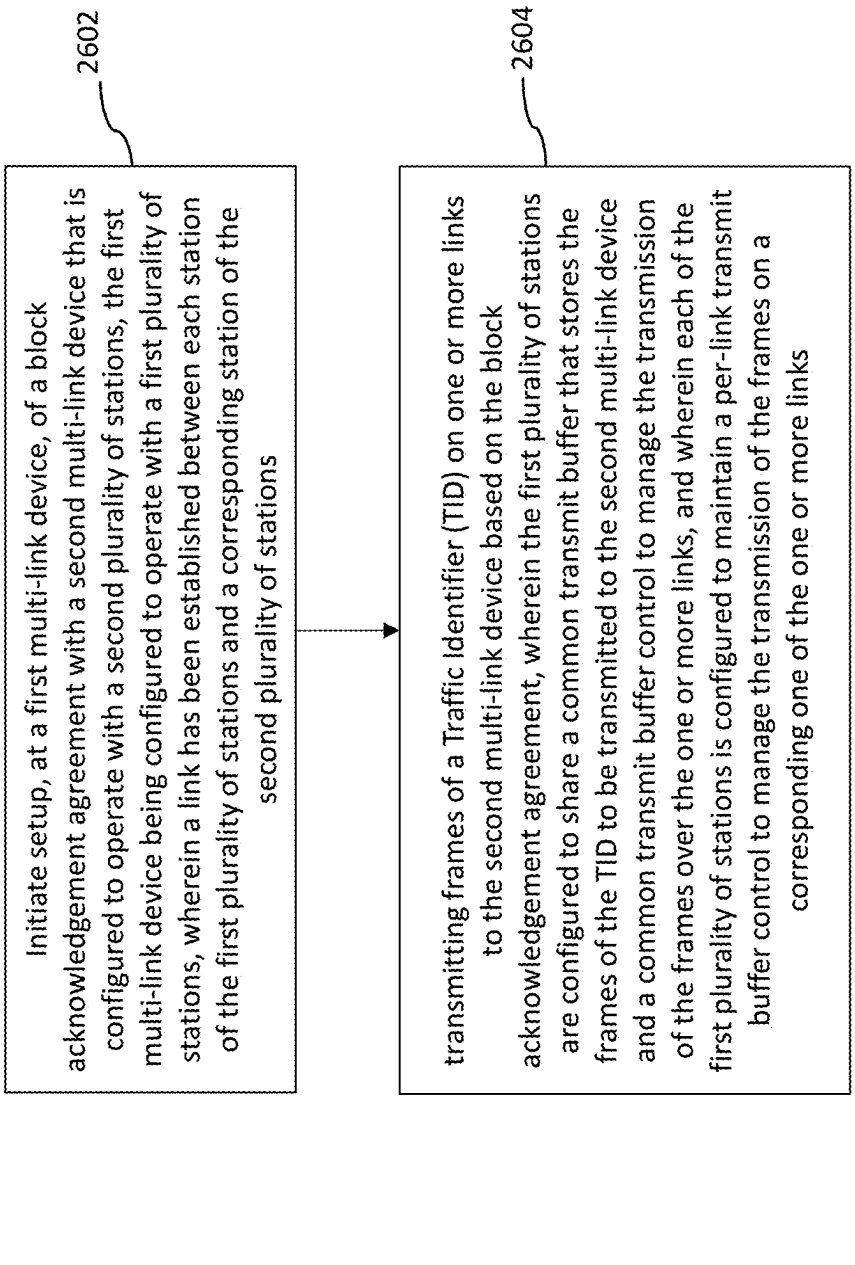

2602
Initiate setup, at a first multi-link device, of a block acknowledgement agreement with a second multi-link device that is configured to operate with a second plurality of stations, the first multi-link device being configured to operate with a first plurality of stations, wherein a link has been established between each station of the first plurality of stations and a corresponding station of the second plurality of stations
2604
transmitting frames of a Traffic Identifier (TID) on one or more links to the second multi-link device based on the block acknowledgement agreement, wherein the first plurality of stations are configured to share a common transmit buffer that stores the frames of the TID to be transmitted to the second multi-link device and a common transmit buffer control to manage the transmission of the frames over the one or more links, and wherein each of the first plurality of stations is configured to maintain a per-link transmit buffer control to manage the transmission of the frames on a corresponding one of the one or more links
2600

Fig. 26

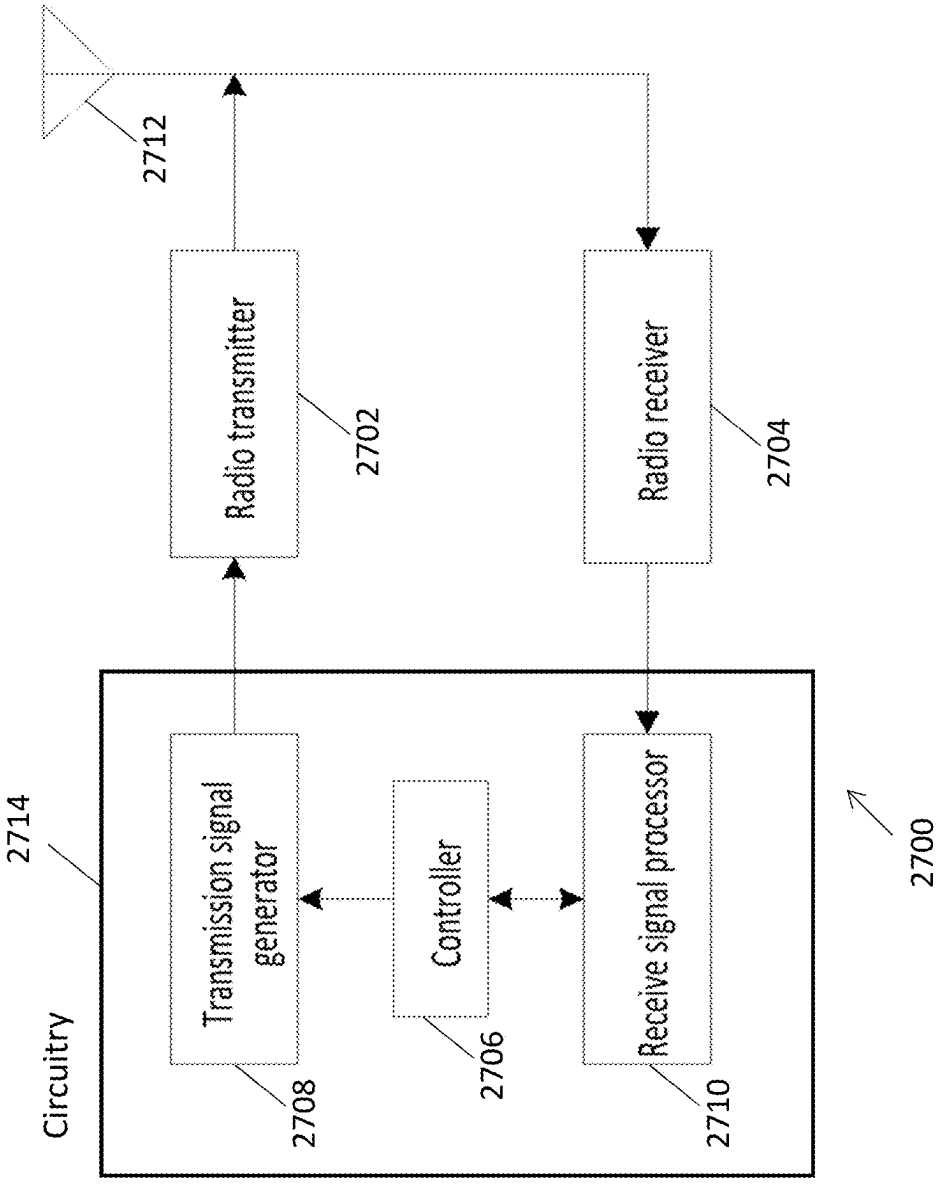

2712
Radio transmitter
2702
Radio receiver
2704
2714
Circuitry
Transmission signal generator
2708
Controller
2706
Receive signal processor
2710
2700

Fig. 27

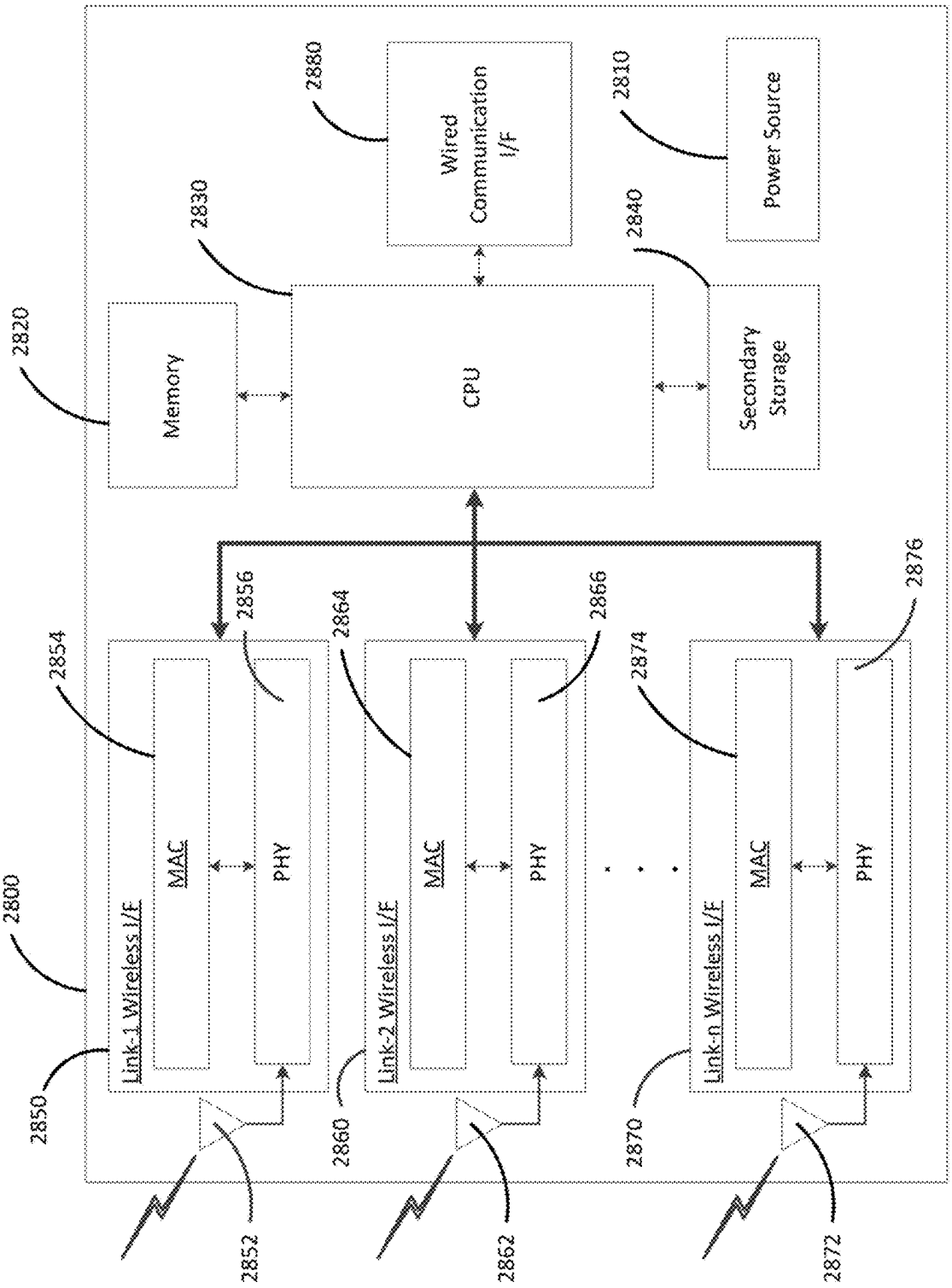

2800
2820
Memory
2830
CPU
2840
Secondary Storage
2880
Wired Communication I/F
2810
Power Source
2850
Link-1 Wireless I/F
2854
MAC
2856
PHY
2852
2860
Link-2 Wireless I/F
2864
MAC
2866
PHY
2862
2870
Link-n Wireless I/F
2874
MAC
2876
PHY
2872

Fig. 28

COMMUNICATION DEVICE AND COMMUNICATION METHOD FOR MULTI-LINK BLOCK ACKNOWLEDGEMENT

BACKGROUND

1. Technical Field

[0001] The present embodiments generally relate to communication devices, and more particularly relate to methods and devices for multi-link block acknowledgement that involves multi-link traffic streams.

2. Description of the Related Art

[0002] In today's world, communication devices are expected to wirelessly operate with the same capabilities as wired computing devices. For example, a user expects to be able to seamlessly watch a high definition movie streamed to the user's wireless communication device. This presents challenges for communication devices as well as the access points to which the communication devices wirelessly connect.

[0003] The Institute of Electrical and Electronics Engineers (IEEE) 802.11 group has recently formed the Extreme High Throughput (EHT) study group to address these challenges. Multi-link operation in the 2.4 GHz, 5 GHz and 6 GHz frequency bands has been identified as a key candidate technology for such communication. Multi-channel aggregation over multiple links is a natural way to create multi-fold increase in communication data throughput. In current IEEE 802.11 devices, when Admission Control is mandated for an Access Category (AC) by an access point (AP) (via, for example, Admission Control Mandatory (ACM) subfield (s) in an Enhanced Distributed Channel Access (EDCA) Parameter Set element), a communication device (STA) is required to set up a Traffic Stream (TS) for the AC with the AP (via an Add Traffic Stream (ADDTS) Request/Response exchange). A Block Ack agreement for the corresponding TIDs also needs to be performed (via an Add Block Ack (ADDBA) Request/Response exchange).

SUMMARY

[0004] One non-limiting and exemplary embodiment facilitates providing a multi-link device configured to operate with a first plurality of affiliated stations, the first multi-link device comprising: circuitry, which in operation, initiates setup of a block acknowledgement agreement with a second multi-link device that is configured to operate with a second plurality of affiliated stations, wherein a link has been established between each station of the first plurality of stations and a corresponding station of the second plurality of stations; and a transmitter, which in operation, transmits frames of a Traffic Identifier (TID) on one or more links to the second multi-link device based on the block acknowledgement agreement, wherein the first plurality of stations are configured to share a common transmit buffer that stores the frames of the TID to be transmitted to the second multi-link device and a common transmit buffer control to manage the transmission of the frames over the one or more links, and wherein each of the first plurality of stations is configured to maintain a per-link transmit buffer control to manage the transmission of the frames on a corresponding one of the one or more links.

[0005] Another non-limiting and exemplary embodiment facilitates providing a method for multi-link communication, comprising: initiating setup, at a first multi-link device, of a block acknowledgement agreement with a second multi-link device that is configured to operate with a second plurality of stations, the first multi-link device being configured to operate with a first plurality of stations, wherein a link has been established between each station of the first plurality of stations and a corresponding station of the second plurality of stations; and transmitting frames of a Traffic Identifier (TID) on one or more links to the second multi-link device based on the block acknowledgement agreement, wherein the first plurality of stations are configured to share a common transmit buffer that stores the frames of the TID to be transmitted to the second multi-link device and a common transmit buffer control to manage the transmission of the frames over the one or more links, and wherein each of the first plurality of stations is configured to maintain a per-link transmit buffer control to manage the transmission of the frames on a corresponding one of the one or more links.

[0006] It should be noted that general or specific embodiments may be implemented as a system, a method, an integrated circuit, a computer program, a storage medium, or any selective combination thereof. Additional benefits and advantages of the disclosed embodiments will become apparent from the specification and drawings. The benefits and/or advantages may be individually obtained by the various embodiments and features of the specification and drawings, which need not all be provided in order to obtain one or more of such benefits and/or advantages.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] The accompanying figures, where like reference numerals refer to identical or functionally similar elements throughout the separate views and which together with the detailed description below are incorporated in and form part of the specification, serve to illustrate various embodiments and to explain various principles and advantages in accordance with present embodiments.

[0008] FIG. **1** depicts an illustration of an overview of an 802.11 wireless network basic service set (BSS) in accordance with various embodiments.

[0009] FIG. **2** depicts an illustration of communication from an originator multi-link device (MLD) to a recipient MLD in accordance with various embodiments.

[0010] FIG. **3** depicts an illustration of setup of Traffic Stream (TS) and Block Ack (BA) agreements for a traffic identifier (TID) in accordance with various embodiments.

[0011] FIG. **4** depicts communication flow between an AP MLD **102** and a non-AP MLD **104** for TS and BA setup over multiple bands/links and communication thereafter in accordance with current multi-link communication.

[0012] FIG. **5** depicts communication flow between the AP MLD **102** and the non-AP MLD **104** for multi-link TS and multi-link BA setup and communication thereafter in accordance with various embodiments.

[0013] FIG. **6** depicts an illustration of a multi-link Enhanced Distributed Channel Access (EDCA) parameter set element in accordance with various embodiments.

[0014] FIG. **7** depicts an illustration of a multi-link ADDTS Request frame and a multi-link ADDTS Response frame in accordance with various embodiments.

[0015] FIG. **8** depicts an illustration of a multi-link ADDBA Request frame and a multi-link ADDBA Response frame in accordance with various embodiments.

[0016] FIG. **9** depicts an illustration of a multi-band element in FIGS. **7** and **8** in accordance with various embodiments.

[0017] FIG. **10** depicts an illustration of a multi-band capability element in accordance with various embodiments.

[0018] FIG. **11** depicts an illustration of a multi-link BlockAckReq frame and a multi-link BlockAck frame in accordance with various embodiments.

[0019] FIG. **12**A depicts an illustration of a Traffic Stream and Block Ack architecture in accordance with various embodiments.

[0020] FIG. **12**B depicts an illustration of a Traffic Stream and Block Ack architecture purpose defined to take care of Multi-link transmission and Multi-link Block Ack in accordance with various embodiments.

[0021] FIG. **13** depicts an illustration of an exemplary multi-link transmission in accordance with various embodiments.

[0022] FIG. **14** depicts an illustration of an exemplary reference model for Multi-link Block Ack implementation in accordance with various embodiments.

[0023] FIG. **15**A to **15**D depicts illustrations of how failed multi-link transmissions may result in out of range scoreboard context and receive reordering buffer overflow in accordance with various embodiments.

[0024] FIG. **16** depicts an illustration of a multi-link Block Ack architecture **1600** in accordance with present embodiments.

[0025] FIGS. **17**A and **17**B depicts an illustration of a multi-link Block Ack Parameter Set **1700** and Multi-band element **1710** for use with the Block Ack architecture **1600** in accordance with the present embodiments.

[0026] FIG. **18** depicts a format of an enhanced BlockAck Request (eBAR) frame **1800** for use with the multi-link Block Ack architecture **1600** in accordance with present embodiments.

[0027] FIG. **19** depicts an illustration of how eBAR frame **1800** is utilised to resolve the issue of scoreboard context out of range as previously illustrated in FIG. **15**A.

[0028] FIG. **20** depicts an illustration of how common transmit buffer control of multi-link Block Ack architecture **1600** prevents the receive reordering buffer overflow issue as shown in FIGS. **15**C and **15**D.

[0029] FIG. **21** depicts an illustration of a multi-link Block Ack architecture **2100** with a common Multi-link scoreboard context control in accordance with a variant of the present embodiments.

[0030] FIGS. **22**A and **22**B depicts an illustration of a multi-link Block Ack Parameter Set **2200** and Multi-band element **2210** for use with the Block Ack architecture **2100** in accordance with the present embodiments.

[0031] FIG. **23**A to **23**C depicts an illustration of an ADDBA request frame **2304**, ADDBA response frame **2306**, Block Ack Parameter Set **2300** and Multi-link element **2310** in accordance with another variant of the present embodiments.

[0032] FIG. **24** depicts a schematic of an originator MLD **2400** in accordance with various embodiments.

[0033] FIG. **25** depicts a schematic of a recipient MLD **2500** in accordance with various embodiments.

[0034] FIG. **26** shows a flow diagram **2600** illustrating a method for multi-link communication according to various embodiments.

[0035] FIG. **27** shows a schematic, partially sectioned view of a multi-link device **2700** that can be implemented for multilink communication in accordance with various embodiments as shown in FIGS. **1** to **26**.

[0036] And FIG. **28** depicts a detailed block diagram of a multi-link device in accordance with the present embodiments.

[0037] Skilled artisans will appreciate that elements in the figures are illustrated for simplicity and clarity and have not necessarily been depicted to scale.

DETAILED DESCRIPTION

[0038] The following detailed description is merely exemplary in nature and is not intended to limit the embodiments or the application and uses of the embodiments. Furthermore, there is no intention to be bound by any theory presented in the preceding Background or this Detailed Description. Furthermore, other desirable features and characteristics will become apparent from the subsequent detailed description and the appended claims, taken in conjunction with the accompanying drawings and this background of the disclosure.

[0039] Referring to FIG. **1**, an illustration depicts an overview of an 802.11 wireless network, also known as a basic service set (BSS), **100** which includes an access point (AP) **102**, and multiple communication devices (STA) **104** connected to the AP **102**; the AP **102** providing access to the Distribution System (DS), for example the internet, to the STAs. Current IEEE 802.11 BSSs operate on a single frequency band with an AP capable of concurrently operating on multiple frequency bands acting as an independent (single link) AP on each frequency band. Most present 802.11 STAs are single band devices and are capable of only joining one BSS (on a particular frequency band) at any one time, while future 802.11 communication devices (e.g., extreme high throughput (EHT) communication devices) are expected to be capable of concurrently operating on multiple frequency bands. A multi-link capable STA may be termed as a non-AP MLD. Such non-AP MLDs may concurrently join multiple BSSs at the same time and may setup multiple communication links with the AP over multiple frequency bands or even on multiple frequency separated channels on the same frequency band. Such APs capable of concurrently communicating with a non-AP MLDs over multiple links may be termed as AP MLDs. In FIG. **1**, AP **102** represents a AP MLD and the STAs **104** represent non-AP MLDs; the AP MLD and non-AP MLDs all capable of concurrently communicating in the 2.4 GHz frequency band, the 5 GHz frequency band, and the 6 GHz frequency band. Such future AP **102** may setup BSSs in the 2.4 GHz frequency band, the 5 GHz frequency band, or the 6 GHz frequency band as separate BSSs as in existing 802.11 systems, in which case legacy STAs may join the BSSs on three frequency bands following legacy Authentication and Association procedures. Alternatively, the AP may also operate a unified/virtual BSS that operates on multiple frequency bands (i.e., the 2.4 GHz frequency band **106**, the 5 GHz frequency band **108**, and the 6 GHz frequency band **110**) as shown in the BSS **100**. In either case, the STA s **104** are assumed to have joined the unified/virtual BSS **100** on all three frequency bands either through individual Authentication and Associa-

tion Request/Responses on each frequency band or through multi-link setup negotiation (e.g. Authentication and Association Request/Responses) on any one of the frequency bands.

[0040] FIG. **2** depicts an illustration **200** of communication of a video file **202** from an AP MLD **201** to a non-AP MLD **203**. In order to fully realize the throughput gains of multi-link aggregation, Traffic Stream (TS) and Block Acknowledgement (BA) mechanisms that operate over multiple links are desired. Such multi-link TS and BA can help to achieve multiple fold increase in device throughput by enabling aggregation of traffic over multiple links (e.g., 2.4 GHz **204**, 5 GHz **206** and 6 GHz **208**). In case there are no restrictions on any link for traffics of any Traffic Identifier (TID) i.e. Admission Control is not mandated for any Access Category (AC) on any link, setup of multi-link TS is optional. Streaming of the high resolution video **206** (e.g. high definition (HD) or 4K or 8K video) may require such multi-link transmissions. At the Internet Protocol (IP) layer **210** of the AP MLD **201**, the video file **206** is split into small IP packets. The 802.11 Media Access Control (MAC) layer **212** of the AP MLD **201** converts the IP packets into 802.11 MAC layer Protocol Data Units (MPDUs) and feeds them into a MAC TX queue **214** which in turn provides the MPDUs to transceivers **216**, **218**, **220** in the lower MAC layer **212** and the physical layer (PHY) **222** for simultaneous transmission on the frequency bands 2.4 GHz, 5 GHz and 6 GHz, respectively. In this manner, the MPDUs **224** are transmitted over the 2.4 GHz frequency band, the MPDUs **226** are transmitted over the 5 GHz frequency band and the MPDUs **228** are transmitted over the 6 GHz frequency band to the non-AP MLD **203**.

[0041] At the non-AP MLD **203**, the MPDUs **224**, **226**, **228** are received by transceivers **230**, **232**, **234** in the PHY layer **236** and the lower MAC layer **238**. The MPDUs **224**, **226**, **228** are collected by the MAC layer **238** and re-ordered if necessary before being passed to the MAC RX queue **240** and up to the P layer **242** where the P packets are combined to form back the original video file **206**.

[0042] In current 802.11 communication devices, Admission Control is usually mandated to maintain Quality of Service (QoS) levels for high priority traffic such as video (AC_VO) or voice (AC_VI). When Admission Control is mandated for an Access Category (AC) by the AP MLD (e.g., via an Admission Control Mandatory (ACM) subfield in the Enhanced Distributed Channel Access (EDCA) parameter Set element), a non-AP MLD may be required to set up a TS for the Access Category (AC) with the AP MLD via an Add Traffic Stream (ADDTS) Request/Response exchange. A Traffic Specification (TSPEC) element in the ADDTS Request frame and the ADDTS Response frame specifies the various parameters related to the TS including Traffic Stream Identifier (TSID), direction, MAC Service Data Unit (MSDU) size, minimum and maximum interval range, and minimum, mean and peak data rates, etc. In case there are no restrictions on any link for traffics of any Access Category (AC) i.e. Admission Control is not mandated for any AC on any link, setup of multi-link TS is optional.

[0043] Block Ack agreement for corresponding TIDs also needs to be performed via an Add Block Ack (ADDBA) Request/Response exchange. Traffic Stream and Block Ack agreements may also be setup for a different frequency band by including a multi-band element in the ADDTS and ADDBA Request/Response exchange respectively or via On-channel Tunneling (OCT).

[0044] Since the unmanaged addition of new high priority traffic to a wireless network may have adverse effect on the QoS of existing traffic, AP MLDs usually mandate Admission Control for such traffic. In the event that there is a high volume of existing traffic, the AP MLD may refuse a non-AP MLD's request to set up Traffic Streams for that Access Category (AC).

[0045] In order to achieve multi-link transmission in accordance with present embodiments, changes to the TS and BA operation will be required since present TS and BA setup is set up between the MAC layers on a particular link. Referring to FIG. **3**, an illustration **300** depicts Traffic Stream (TS) and Block Ack (BA) agreements for a traffic identifier (TID) which are set up between a multi-link originator **302** and a multi-link recipient **304** in accordance with the present embodiment. TS and BA agreements are usually setup up as a pair with the BA agreement being setup in opposite direction to the TS direction. The TSs **306**, **308**, **310** are set up between transmitting MAC layers **318**, **320**, **322** of each link and corresponding receiving MAC layers **324**, **326**, **328** of each link for data transmission from the multi-link originator **302** to the multi-link recipient **304**, while the BA agreements **312**, **314**, **316** are set up in opposite directions between the receiving MAC layers **324**, **326**, **328** and the transmitting MAC layers **318**, **320**, **322** for the transmission of BAs from the multi-link recipient **304** to the multi-link originator **302** to acknowledge the data transmissions corresponding to the TSs **306**, **308**, **310**, respectively.

[0046] At the multi-link originator end, Upper Layers **330** and a Logical Link Control (LLC) layer **332** make decisions of which link to use for transmission for a particular TID. MPDUs of each TS **306**, **308**, **310** are generated at the transmitting MAC layers of each link (MAC layers **318**, **320**, **322**) and addressed to the peer receiving MAC layers of the same link (MAC layers **324**, **326**, **328**). At the receiving end, reordering of MAC Service Data Units (MSDUs) received over different links are done by the receiving LLC layer **334** and passed to receiving Upper Layers **336**. Block Acks (BA) corresponding to the MPDUs of each TS **306**, **308**, **310** are generated at the receiving MAC layers of the same link (MAC layers **324**, **326**, **328**) and addressed to the peer transmitting MAC layers of each link (MAC layers **318**, **320**, **322**). When a BA is not received or MPDUs are not acknowledged in a BA bitmap (the bits corresponding to the MPDUs set to 0), it is determined that transmission has failed for the unacknowledged MPDUs. MAC layer retransmission of the unacknowledged MPDUs occurs in the same frequency band (2.4 GHz, 5 GHz, 6 GHz) as the failed transmission as shown in FIG. **4**. It is also possible that instead of setting up Traffic Streams (TS) to restrict traffic of particular TIDs to a particular link, some sort of TID mapping negotiation may be performed between an AP MLD and a non-AP MLD to map certain TIDs to particular links, e.g. video traffics are exclusively mapped to the 6 GHz link, and audio traffics are exclusively mapped to the 5 GHz link, while rest of the traffic are mapped to the 2.4 GHz link. In absence of either TS setup or TID mapping, it is assumed that traffic of any TID may be transmitted on any link by default.

[0047] FIG. **4** depicts communication flow **400** between the multi-link originator **302** (an AP MLD in this example)

and the multi-link recipient **304** (a non-AP MLD in this example) for TS and BA setup and communication thereafter in accordance with current multi-link communication. If the EDCA parameter Set element received in beacon frames in any link has the Admission Control Mandatory (ACM) bit set for any Access Category (AC), a non-AP MLD (such as the multi-link recipient **304**) is required to set up a Traffic Stream (TS) with the multi-link originator **302** for the corresponding TID(s) prior to transmitting a data frame belonging to that TID/AC on that link. TS setup **402** fora particular TID are performed individually for each link, for example for downlink data transmission (i.e., from an AP MLD to non-AP MLD), by exchanging A D DTS Request/Response frames on each link. ADDTS Requests are always initiated by non-AP MLDs regardless of the direction of the actual data transmission. Similarly, BA setup **404** for a particular TID is performed individually for each link by exchanging ADDBA Request/Response frames on each link. The ADDBA Requests are initiated by the multi-link originator for the corresponding TS. Once the TS and BA have been setup in each link, the data transmissions and corresponding BA transmission can take place in each link, for example **430** in the 6 GHz band, **440** in the 5 GHz band and **450** in the 2.4 GHz band. BlockAck frames for data transmission in each link **430**, **440**, **450** are solicited via BlockAckReq frames and the requested BlockAck frame is transmitted on the same link. Since transmissions **430**, **440** and **450** take place on different links, they may also occur at the same time or during overlapping times, thereby achieving multi-link transmission.

[0048] When it is determined that transmission of a data frame has failed (e.g., within the data transmission **452**, as indicated in the BlockAck frame), the data frame is retransmitted on the same link (e.g., retransmission **454**).

[0049] Although multi-link transmissions may be achieved with this approach, the onus of the scheduling, band selection, re-transmission and other duties are left to the upper layers **330**, **336** (FIG. **3**), which may not have the PHY layers **317**, **319**, **321**, **323**, **325**, **327** information required to make such a decision. It would be better if the multi-link transmission decisions are taken at the MAC layers **318**, **320**, **322**, **324**, **326**, **328** since the MAC layer has much better information/control of the PHY layers.

[0050] FIG. **5** depicts communication flow between the multi-link originator **302** and the multi-link recipient **304** for TS and BA setup and communication thereafter in accordance with present embodiments. The multi-link originator **302** may choose to listen to Beacon frames transmitted on a single link in order to save power. Aside from the legacy EDCA parameter Set element, the Beacon frame **502** on a primary link (e.g., the 5 GHz band) may carry a multi-band EDCA parameter Set element to indicate the EDCA parameters for a link other than the link on which the Beacon frame **502** is transmitted. If an ACM bit in the Beacon frame **502** is set to "1" for any of the AC in any of the links, the multi-link recipient **304** is required to set up a Traffic Stream (TS) for the TIDs corresponding to that AC on the indicated link(s) prior to transmitting a Data frame belonging to that TID/AC on that link(s). Alternatively, the multi-link recipient **304** may also have received Beacon frames separately on each link with the legacy EDCA parameter Set element carrying the ACM bit set to "1".

[0051] If both the originator and recipient support multi-link TS and multi-link BA and have indicated a capability in the Multi-link TS and Block Ack field in the multi-link capability element (the multi-link capability element, including the Multi-link TS and Block Ack field, is discussed in more detail in FIG. **10**), multi-link TS setup **510** (e.g. for downlink traffic) for a particular TID applicable for multi-links (for example the three bands: 2.4 GHz, 5 GHz and 6 GHz) may be performed using a single frame exchange (e.g., on channels in the primary link) in accordance with present embodiments. Similarly, the corresponding multi-link BA setup **520** for the TID applicable for multi-links (for example, the three bands: 2.4 GHz, 5 GHz and 6 GHz) may be performed using a single frame exchange (e.g., on channels in the primary link) in accordance with present embodiments. A Multi-link ADDTS Request frame **512** and a Multi-link ADDTS Response frame **514** are used to negotiate TS setup **516** for a TID over multiple links. Similarly, a Multi-link ADDBA Request **522** and Multi-link ADDBA Response **524** are used to negotiate BA setup **526** for a TID over multiple links. In this downlink traffic example, the Multi-link ADDBA Request **522** is transmitted by the AP **102** to the multi-link recipient **304**, which may be any one of the non-AP MLDs **104**. If the multi-band TS setup **510** was for uplink traffic, the Multi-band ADDBA Request would be would be transmitted in the opposite direction, i.e. by the multi-link recipient **304** to the multi-link originator **302**.

[0052] Once the multi-link TS and the multi-link BA have been setup in multiple links, the multi-link originator **302** may proceed to initiate the multi-link transmission **530** to the multi-link recipient **304**. The multi-link transmission **530** involves simultaneous transmission of frames belonging to the same TS (TID/AC) within the QoS Data A-MPDUs **536***a*, **536***b* and **536***c*, respectively, to the multi-link recipient **304** over the three links.

[0053] Upon completion of the multi-link transmission **530**, the multi-link originator **302** may transmit a multi-link BlockAckReq **532** to the multi-link recipient **304** on any of the links (e.g., on the primary link) to solicit a multi-link Block Ack, acknowledging the frames **536***a*, **536***b*, **536***c* received on the three links. Upon receiving the multi-link BlockAckReq **532** from the multi-link originator **302**, the multi-link recipient **304** transmits the multi-link Block Ack **534** on the same link on which the multi-link BlockAckReq **532** was received to indicate that the multi-link recipient **304** successfully received QoS Data A-MPDUs **536***a* and **536***b* but failed to receive the QoS Data A-MPDU **536***c* transmitted on the 2.4 GHz band. In order to improve the success rate of retransmission by using frequency diversity, the multi-link originator **302** may, in accordance with present embodiments, choose to retransmit the QoS Data A-MPDU **538** on the 6 GHz band instead of the 2.4 GHz band used for the original transmission.

[0054] The multi-link originator **302** subsequently transmits a multi-link BlockAckReq **542** to the multi-link recipient **304** on a different link (e.g., on the primary 5 GHz link) to solicit the multi-link Block Ack **544** which carries a consolidated BA bitmap acknowledging the frames received on the 6 GHz bands. Thus, it can be seen that in accordance with the present embodiments, a Traffic Stream is setup across multiple links using a single Multi-link ADDTS frame exchange **512**, **514** on any one link. The Block Ack is also setup across multiple links using a single Multi-link ADDBA frame exchange **522**, **524** on any one link. In addition, in accordance with present embodiments, a con-

solidated Multi-link BlockAck frame **534** acknowledges a multi-link aggregated transmission, a multi-link BlockAck frame **544** may be used to acknowledge transmission in another link, and failed frames **536***c* may be re-transmitted **538** on a different link.

[0055] Thus, in accordance with present embodiments, an MLD (e.g., AP MLD **102**) includes a plurality of transceivers **216**, **218**, **220** which, in operation, each transmit signal frames **536***c*, **536***a*, **536***b* on different ones of a plurality of frequency bands **204**, **206**, **208**. The MLD also includes Media Access Control (MAC) circuitry **212** coupled to the plurality of transceivers **216**, **218**, **220** which, in operation, generates a multi-link block acknowledgement request frame **532** and transmits the MAC multi-link block acknowledgement request frame **532** on the one of the plurality of frequency bands **206** to solicit the multi-link block acknowledgement frame **534**. The Media Access Control (MAC) circuitry **212** subsequently receives a multi-link block acknowledgement frame **534** on one of the plurality of frequency bands **206** acknowledging the signal frames **536***a*, **536***b*, **536***c* transmitted on the plurality of frequency bands.

[0056] In addition, in accordance with present embodiments, an MLD (e.g., non-AP MLD **104**) includes a plurality of transceivers **230**, **232**, **234** coupled to the MAC circuitry **238**. The plurality of transceivers **230**, **232**, **234**, in operation, each receive signal frames **536***a*, **536***b*, **536***c* on different ones of a plurality of frequency bands **204**, **206**, **208**. The MAC circuitry **238**, in operation, upon receiving the multi-link block acknowledgement request frame **532** on one of the plurality of frequency bands **206**, generates and transmits a multi-link block acknowledgement frame **534** on one of the plurality of frequency bands **206** acknowledging the signal frames **536***a*, **536***b*, **536***c* received on the plurality of frequency bands **204**, **206**, **208**.

[0057] FIG. **6** depicts an illustration **600** of a multi-link EDCA parameter set element **610** in a Beacon frame **402** (FIG. **4**) in accordance with present embodiments. The multi-link EDCA parameter Set element **610** indicates the EDCA parameters for a link other than the link on which the Beacon frame **402** is transmitted. The applicable link is indicated by a Band ID field **612**. A format of each of the Parameter Record field **620** for a particular AC is depicted. If the ACM bit **622** is set to "1" for any of the AC in any of the links, a non-AP MCD is required to set up a Traffic Stream (TS) for the TIDs corresponding to that AC on the indicated link prior to transmitting a Data frame belonging to that TID/AC on that link. Alternatively, instead of the Band ID field **612**, a Multi-link field may be present in the EDCA Parameter set element **610** to indicate the applicable link. Alternatively, the non-AP MCD may also receive Beacon frames separately on each link with the legacy EDCA parameter Set element carrying the ACM bit **622** set to "1".

[0058] FIG. **7** depicts an illustration **700** of a multi-link ADD TS Request frame **710** and a multi-link ADD TS Response frame **720** and FIG. **8** depicts an illustration **800** of a multi-link ADDBA Request frame **810** and a multi-link ADDBA Response frame **820** in accordance with present embodiments. The multi-link ADDTS Request frame **710** and the multi-link ADDTS Response frame **720** are used to negotiate TS setup for a TID over multiple links in response to information in one or more multi-band elements **750** in each of the multi-link ADDTS Request frame **710** and the multi-link ADDTS Response frame **720**. Similarly, the multi-link ADDBA Request frame **810** and the multi-link ADDBA Response frame **820** are used to negotiate BA setup for a TID over multiple links in response to information in one or more multi-band elements **750** in each of the multi-link ADDBA Request frame **810** and the multi-link ADDBA Response frame **820**.

[0059] Referring to FIG. **9**, an illustration **900** depicts the multi-band element **750** in accordance with present embodiments. The multi-band element **750** indicates the additional band (aside from the transmitted link) to which the TS or BA agreement applies. The multi-band element **750** may also include the MAC address used in the link.

[0060] The multi-band element **750** includes among other fields a Multi-band control field **910** which includes several fields including an Inter band field **920**. The Inter-band field **920** is used to differentiate the multi-band element for use in Multi-link TS and BA setup. When the Inter band field **920** is set to "1", it indicates that the corresponding setup applies to the link indicated in the Band ID field **930** in addition to the link on which the frame carrying the element is transmitted. The Inter band field **920** thus serves to differentiate the inclusion of the Multi-band element **750** for multi-link ADDTS and multi-link ADDBA setup in accordance with present embodiments from the legacy usage for A D DTS and ADDBA setup on a different link.

[0061] In FIGS. **7** and **8**, each of the multi-link ADDTS Request frame **710**, the multi-link ADDTS Response frame **720**, the multi-link ADDBA Request frame **810**, and the multi-link ADDBA Response frame **820** include two multi-band elements **750** with the inter band field **920** set to "1" and the Band ID fields **930** set to 2.4 GHz in first multi-band element **750** and 6 GHz in the second multi-band element **750**. Since the frames are transmitted on the 5 GHz band, this indicates a multi-link setup on the three links.

[0062] Although in this example, the multi-link ADDBA Request **810** is transmitted by the multi-link originator **302** to the multi-link recipient **304**, if the multi-link TS setup **510** was for uplink traffic, the multi-link ADDBA Request would be transmitted by the multi-link recipient **304** to the multi-link originator **302**. Once the TS and BA have been setup in multi-link, the AP **102** can proceed to initiate the multi-link transmission **530** to the STA **104**, the multi-link transmission **530** involving simultaneous transmission of frames belonging to the same TS (TID/AC) to the multi-link recipient **304** over the three links.

[0063] FIG. **10** depicts an illustration **1000** of a multi-band capability element **1010** in accordance with various embodiments. If both the originator and recipient support multi-link TS and multi-link BA and have indicated the capability in the Multi-band TS and Block Ack field **1020** in the multi-band capability element **1010**, multi-band TS setup **510** (downlink traffic) and multi-band BA setup **520** for a particular TID applicable for multi-links may be performed using a single frame exchange on, for example, channels in the primary link. The Multi-band TS and Block Ack field **1020** also indicates whether the AP **102** and the STA **104** support the multi-link TS and the multi-link BA feature and a Supported Bands field **1030** indicates the frequency bands supported by the AP **102** and the STA **104**. It is also possible that the capabilities for the multi-link TS feature and multi-link BA feature are signaled separately in different fields.

[0064] FIG. **11** depicts an illustration of a multi-link BlockAckReq frame **1100** and a multi-link BlockAck frame **1150** in accordance with various embodiments. Upon

completion of the multi-link transmission **530**, the multi-link originator **302** may transmit a multi-band BlockAckReq frame **1100** to the multi-link recipient **304** on any of the links (e.g., on the primary link) to solicit a multi-link BlockAck frame **1150**. The multi-link BlockAck frame **1150** includes a consolidated BA bitmap in a BA information field **1152**, acknowledging the frames received on the three links. A multi-band field **1110** and a multi-band field **1160** differentiate the multi-link BlockAckReq frame **1100** and the multi-link BlockAck frame **1150** from a prior art single link BlockAckReq frame and a prior art single link BlockAck frame, respectively.

[0065] The consolidated BA bitmap in the multi-link BlockAck frame **1150** indicates that the Recipient failed to receive the QoS Data A-MPDU **536***c* transmitted on the 2.4 GHz band. In order to improve the success rate of retransmission by using frequency diversity, the multi-link originator **302** may choose to retransmit the QoS Data A-MPDU **538** on the 6 GHz band instead of the 2.4 GHz band used for the original transmission.

[0066] The multi-link originator **302** subsequently transmits the multi-link BlockAckReq frame **1100** to the multi-link recipient **304** on a different link (e.g., on the primary link) to solicit the multi-link BlockAck frame **1150** which carries the consolidated BA bitmap acknowledging the frames received on the 6 GHz band.

[0067] The Receiver Address (RA) and the Transmitter Address (TA) fields are set as the MAC address of the wireless radio interface of each link. However, regardless of the content of the RA and TA fields, if the Multi-band field **1110** is set to "1", the BlockAckReq frame **1100** is interpreted as soliciting a multi-link BlockAck frame acknowledging the frames belong to the TID indicated in a TID_INFO field **1112** regardless of the link on which the frames are received. Similarly, regardless of the content of the RA and TA fields, if the Multi-band fields **1160** is set to "1", the multi-link BlockAck frame **1150** carries a consolidated BA bitmap in the BA Information field **1152** acknowledging the frames belong to the TID indicated in the TID_INFO field **1162** regardless of the link on which the frames are received.

[0068] Thus, in accordance with present embodiments, traffic belonging to a same TID may be split over multiple bands. In addition, Block Acks for multiple bands may be consolidated and transmitted on another band. This capability is provided in accordance with present embodiments for the existing Block Ack Request types such as Compressed, Multi-TID, Multi-STA, and GroupCast with Retries (GC R) Block Ack Request types.

[0069] FIG. **12**A depicts an illustration **1200** of a Traffic Stream and Block Ack architecture in accordance with various embodiments. The MAC layers **318**, **320**, **322**, **324**, **326**, **328** are split into band-agnostic unified Upper MAC (UMAC) layers **1202**, **1204** and band specific Lower MAC (LMAC) layers **1206**, **1208**, **1210**, **1212**, **1214**, **1216**. In this architecture, the LMAC/PHY layers of different links are tightly coupled together with the UMAC coordinating the operations of each link specific LMCAC/PHY layers. Such architecture may be appropriate when an MLD is implemented as a single piece of silicon hardware. The Multi-link Traffic Stream agreements **1220**, **1222**, **1224** and the Multi-link Block Ack agreements **1230**, **1232**, **1234** for a TID are setup between the respective MAC layers of each link.

[0070] The Upper Layers **330**, **336** and the LLC layers **332**, **334** only need to deal with the unified UMAC layers **1202** and **1204** respectively. At the transmitter **302** side, the unified UMAC layer **1202** performs multi-link aggregation of the TS data (i.e., frames belonging to a particular Traffic Stream (TS) may be aggregated over different links) over three TS data paths **1240**, **1242**, **1244** and makes the decision of which link(s) to use for transmissions as well as retransmissions. The actual link used for the transmissions may be transparent to the upper layers. The multi-link recipient **304** unified UMAC **1204** is responsible for multi-link de-aggregation (i.e., reordering of frames belonging to a particular Traffic Stream (TS) received from different links) and recording the reception in a consolidate Block Ack Scoreboard.

[0071] The multi-link recipient **304** unified UMAC **1204** is also responsible for Multi-link Block Ack generation and transmission of the Multi-link Block Ack (BA) along a Multi-link BA path **1250** on a selected link (in this example, 2.4 GHz). The multi-link originator **302** may solicit Multi-link BA on any link by transmitting a Multi-link Block Ack Request. The recipient **304** generates and transmits the Multi-link Block Ack in response to reception of a Multi-link Block Ack Request frame or upon an implicit request to generate a multi-link BlockAck frame. The multi-link BlockAck frame is transmitted on the same link on which the respective request was received.

[0072] FIG. **12**B depicts an illustration **1260** of a Traffic Stream and Block Ack architecture purpose defined to take care of Multi-link transmission and Multi-link Block Ack in accordance with present embodiments. In this architecture, an MLD may be viewed as a collection of one or more affiliated STAs, each STA operating on one link at a time. All affiliated STAs may share a common MAC Service Access Point (SAP) to the upper layers and a unique MAC Address may be assigned to represent the MLD. Each affiliated STA has its own MAC/PHY layers and each MAC layer may have a unique MAC address assigned to it. The MAC address of the MLD may be same as one of the affiliated STA's MAC address, or they may be different. The MLD coordinates the operations of each link specific affiliated STA. For example, the originator MLD **302** has three affiliated STAs **1280**, **1282** and **1284** that operate on the 2.4 GHz link, the 5 GHz link and the 6 GHz link respectively. Similarly the recipient MLD **304** has three affiliated STAs **1286**, **1288** and **1290** that operate on the 2.4 GHz link, the 5 GHz link and the 6 GHz link respectively. The STA **1280** has its own MAC layer **1266** with the MAC address TA-**2** and PHY layer **317**, the STA **1282** has its own MAC layer **1268** with the MAC address TA-**5** and PHY layer **319**, the STA **1284** has its own MAC layer **1270** with the MAC address TA-**6** and PHY layer **321**, the STA **1286** has its own MAC layer **1272** with the MAC address RA-**2** and PHY layer **323**, the STA **1288** has its own MAC layer **1274** with the MAC address RA-**5** and PH Y layer **325**, and the STA **1290** has its own MAC layer **1276** with the MAC address RA-**6** and PHY layer **327**. The MAC address of MLD **302** may be the same as that of STA **1280** i.e. TA-**2**, while the MAC address of MLD **304** may be the same as that of STA **1286** i.e. RA-**2**. This architecture may be appropriate when each affiliated STA is implemented as an independent silicon, plurality of which may be housed together in a module to form an MLD, in which case the MLD may be seen as a logical collection of STAs. Of course, it is also possible that with the advance of the silicon technology, the entire MLD is implemented as a single piece of silicon hardware. It will

be appreciated that a variety of architectures for MLDs are possible. In this example, the Multi-link Traffic Stream **1224** and Multi-link Block Ack agreement **1230** for a TID are setup between the respective MLDs **302** and **304** and are link-agnostic and hence much simpler to manage. The Multi-link Traffic Stream **1224** and Multi-link Block Ack agreements **1230** may be identified by the TID and the MAC addresses of the MLDs and not by the link specific MAC addresses.

[0073] At the originator MLD **302**, the MLD receives TS data from upper layer through the common MAC SAP and performs multi-link aggregation of the TS data over three TS data paths **1240**, **1242**, **1244** and makes the decision of which link(s) to use for transmissions as well as re-transmissions and passes the TS data to the respective STA for transmission on the link. Similarly the recipient MLD **304** is responsible for multi-link de-aggregation of the TS data received from each of the affiliated STAs (and also for reordering the frames belonging to the TS received on the three TS data paths **1240**, **1242**, **1244**) before passing the TS to the upper layers via the shared MAC SAP.

[0074] FIG. **13** depicts an illustration **1300** of an exemplary multi-link transmission in accordance with various embodiments showing transmissions on a first link **1302** in a first frequency band (e.g. 2.4 GHz), a second link **1304** in a second frequency band (e.g. 5 GHz) and a third link **1306** in a third frequency band **1306** (e.g. 6 GHz) and assumes that the TS and BA setup for a TID has been completed on the concerned links. The bandwidth of the channels on each link **1302**, **1304**, **1306** may vary depending on channel conditions and availability (e.g. 20 MHz on the 2.4 GHz band **1302**, 80 MHz on the 5 GHz band **1304** and 160 MHz on the 6 GHz band **1306**). In some deployments Link One **1302** (e.g., the 2.4 GHz band) may be primarily used to exchange management and control frames such as the Multi-link Block Ack Request frames **1308** and the Multi-link BlockAck frames **1310** and may be known as a Primary link, while Link Two **1304** (e.g., the 5 GHz band) and Link Three **1306** (e.g., the 6 GHz band) may be primarily used to exchange Data frames **1312** (e.g., downlink (DL) PPDUs) and may be known as secondary links or supplementary links. Whereas in other deployments, there may not be any restrictions on the types of frames that may be transmitted on any links and there may not be such primary/secondary link distinctions.

[0075] After gaining access to the channel on each link, the AP **102** initiates the multi-link transmission **1300** which is made up of downlink PPDU **1312***a* on Link Three **1306**, downlink PPDU **1312***b* on Link Two **1304** and downlink PPDU **1312***c* on Link One **1302**. Each PPDU may carry aggregated MPDUs (A-MPDU), each with a number of frames.

[0076] The AP **102** sets the Ack policy in a QoS Control field of each frame to Block Ack to indicate that there should be no immediate ack in each link and assigns the transmission of the BAR and BA on a low rate link (e.g., the 2.4 GHz band **1302**) to free up the high rate links (e.g., Link 2 **1304** and Link 3 **1306**) for data transmissions. In addition, the same sequence number counter is used for each non-AP MCD, TID pair across multiple links to ensure that the Sequence Number (SN) of transmitted frames do not repeat across links. In this example frames with SN **1**, **2** and **3** are transmitted in the PPDU **1312***c* on Link One **1302**, frames with SN **4**, **5** and **6** are transmitted in the PPDU **1312***b* on Link Two **1304** and frames with SN **7**, **8** and **9** are transmitted in the PPDU **1312***a* on Link Three **1306**. The STA **104** (i.e., the Recipient) maintains a separate BlockAck Bitmap for each link at a Network Interface (NIC), but consolidates it into a single BlockAck Bitmap **1314** upon receiving a Multi-link BlockAckReq frame. The Multi-link BA frames **1310** carry the consolidated bitmaps **1314** acknowledging the frames received on the three links—a bit set to "1" indicates successful frame reception of the frame with SN corresponding to that bit and a "0" indicates failed frame reception of the frame with SN corresponding to that bit.

[0077] In the exemplary transmission **1300**, the multi-link aggregated DL PPDU frame transmission comprises frame **1312***a* transmitted on Link Three **1306**, frame **1312***b* transmitted on Link Two **1304** and frame **1312***c* on Link One **1302** and transmission of frame with SN **2** on Link One **1302** and frames with SN **5** and **6** on Link Two **1304** fails. Upon completion of the multi-link transmission, the AP **102** transmits the Multi-link BlockAckReq frame **1308***a* to solicit a Multi-link BA acknowledging the frame transmitted on the three links **1302**, **1304**, **1306**. The Multi-link BA **1310***a* consolidates the BlockAck bitmaps from the three links into the consolidated BlockAck bitmap **1314***a*. Bits **2**, **5** and **6** corresponding to SN **2**, **5** and **6** are set to "0" in the consolidated BlockAck bitmap **1314***a* indicating the failed reception of frames with SN **2**, **5** and **6** while the rest of the bits are set to 1 to indicate successful reception. Since there were failed transmissions on Link Two **1304** and Link One **1302** but not on Link Three **1306**, the AP **102** may decide that channel conditions on Link Three are better and choose to consolidate the failed frames and re-transmit them on Link Three **1306** in PPDU **1312***d*. Subsequently, the Multi-Link BlockAckReq frame **1308***b* is transmitted on Link One **1302** to solicit the Multi-Link BA **1310***b* carrying acknowledgements for the frames carried in the PPDU **1312***d* transmitted on Link Three **1306**. This time all three re-transmitted frames are successfully received and the STA **104** transmits the Multi-link BA **1310***b* with the corresponding bits in the BA bitmap set to 1.

[0078] FIG. **14** depicts an illustration **1400** of an exemplary reference model for Multi-link Block Ack implementation in accordance with various embodiments. In a wireless communication device, the Radio Interface (I/F), the PHY layers and time critical MAC functions of each link may be implemented as independent module and may be considered part of an independent affiliated STA (e.g., **1410**, **1420**, **1430** for the 2.4 GHz band, the 5 GHz band and 6 GHz band, respectively, such as the transceivers **230**, **232**, **234** (FIG. **2**)). All of the modules/STAs **1410**, **1420**, **1430** are all connected to a host system **1405** which may be a CPU. The Physical Layer (PH Y) modules (e.g., **323**, **325**, **327** (FIG. **12**A, FIG. **12**B)) as well as time critical MAC functions in the lower MAC layers **1402** (e.g., **1212**, **1214**, **1216** (FIG. **12**A) and **1272**, **1274**, **1276** (FIG. **12**B)) may be implemented on the Radio I/Fs **216**, **218**, **220** each of which may be part of independent affiliated STAs (e.g. **1286**, **1288**, **1290** in FIG. **12**B), while the rest of the MAC functions (i.e., the upper MAC layer **1404** (e.g., **1202** (FIG. **12**A)) may be implemented in the host system **1405**. The whole system **1400** may constitute an MLD.

[0079] Due to the low latency required to produce a BA in response to a BAR (within the Short Interframe Space (SIF S) from the end of the BAR), the Block Ack Scoreboard for

a particular band is implemented using fast but expensive on-chip memory in each radio I/F. However, maintaining the BA Scoreboard that persists for an entire duration of all active Block Ack sessions (known as a full state Block Ack) increases the memory requirement burden for a receiver implementation. Hence, most implementations reuse the on-chip memory for more than one Block Ack session, with the memory serving as a cache for storing the state of the most recently active Block Ack session (which is referred to as a partial state Block Ack). The In-band BA Scoreboard **1412**, **1422**, **1432** are examples of on-chip memories used as BA scoreboards to record the reception status of frames received on the 2.4 GHz, 5 GHz and 6 GHz bands, respectively. The In-band BA Scoreboards may also be known as per-link BA Scoreboard or per-link Scoreboard in short. Partial state Block Ack saves memory but increases the risk that the Block Ack Scoreboard may be overwritten by another Block Ack session in a next Transmission Opportunity (TXOP) and hence requires special handling to prevent loss of data.

[0080] To realize multi-link Block Ack operation, a Multi-link BA Scoreboard **1406** is maintained in the host system **1405**. Since memory on the host system **1405** is generally cheaper, the Multi-link BA Scoreboard **1406** may be implemented as a full state Block Ack Scoreboard, i.e., the Scoreboard persists for the entire duration of a Multi-link Block Ack session.

[0081] In accordance with the present embodiments and as shown in the illustration **1400**, the frames received in each link are parsed by the Rx Parsers **1414**, **1424**, **1434** and handled according to the frame type. Data frames **1415**, **1425**, **1435** that are correctly received and addressed to the recipient are recorded according to their sequence number (SN) in the In-band BA Scoreboard **1412**, **1422**, **1432** before being passed up to the Receive Buffer **1408**. The content of the Receive Buffer **1408** may be re-ordered according to the data frame SN at regular intervals.

[0082] In conventional single link Block Ack operation, upon the completion of the TXOP (for implicit Block Ack) or upon receiving a legacy BlockAck Request (BAR) frame (for explicit Block Ack), the lower MAC copies the BA bitmap from the In-band BA Scoreboard and generates the BlockAck frame for immediate transmission. However, for Multi-link Block Ack operation, explicit Block Ack may be used and upon completion of the TXOP on each band, the multi-link BA Scoreboard **1406** is updated with the content of the In-band Scoreboard **1412**, **1422**, **1432** from the respective radio I/F. By the end of a multi-link transmission opportunity (TXOP), the multi-link BA Scoreboard **1406** would have consolidated the BA bitmaps of all the In-band BA Scoreboards **1412**, **1422**, **1432**.

[0083] Finally, upon receiving the multi-link BAR frame **1416** on any of the links, the upper MAC **1404** copies the BA bitmap from the multi-link BA Scoreboard **1406** and generates **1407** the multi-link BlockAck frame for transmission. At the same time, the reception of the multi-link BAR frame **1416** also triggers the upper MAC to reassemble the complete MSDUs from the frames in the Receive Buffer **1408** (all complete MSDUs with SN lower than the Starting Sequence Number (SSN) carried in the multi-link BAR frame **1416**) and forward them in order to the upper layers. Although in the illustration **1400**, the reception of the multi-link BAR frame **1416** and the transmission of the multi-link BA frame **1820** are shown in the 2.4 GHz band, it is to be understood that the process is the same for other frequency bands as well.

[0084] In accordance with FIGS. **1-14**, a single block ack agreement may be negotiated between two MLD s for a TID that may be transmitted over one or more links. The block ack agreement may be represented by the tuple of {an Originator MLD MAC address, a Recipient MLD MAC address and a TID}. Further, a multi-link block ack agreement may be negotiated by exchanging a single pair of ADDBA Request/Response frames over any one of the enabled links between two MLDs. Even further, sequence numbers may be assigned from a common sequence number space shared across multiple links of a MLD, for MSDUs of a TID that may be transmitted to a peer MLD over one or more links.

[0085] However, potential issues may arise during multi-link transmissions when frames of the same TID are transmitted over different links at the same time, such as when one or more of the per-link Scoreboard contexts at the recipient MLD gets out of range. Referring to FIG. **15**A, an originator MLD may transmit MPDUs with SNs **1-15** on a Link-**1** (as shown in Link-**1** Transmit window **1502**) and MPDUs with SNs **16-30** on a Link-**2** (as shown in Link-**2** Transmit window **1504**) to a recipient MLD. The SN in Link-**1** Transmit window is controlled by the Link-**1** Transmit Control that starts at WS_O=1 (i.e. WS_O refers to the start of the Transmit window WinStart_O) and ends at **15** (assuming a Transmit window size of 15 was negotiated during the Multi-link BA agreement for both links), while the SN in Link-**2** Transmit window starts at WS_O=16 and ends at 30. Due to, for example, poor quality of Link 1 transmission, the recipient MLD may fail to receive MPDUs with SNs **3** and **5** to **15**. This can be seen in Link-**1** scoreboard **1512** where SNs **3** and **5** to **15** have a zero value. On the other hand, Link-**2** Scoreboard **1514** indicates that all the MPDUs with SN **16** to **30** are successfully received by the recipient MLD. At this time the Link-**2** scoreboard has shifted to the right (from initial WS_R=0) and now starts at WS_R=16 and ends at WE_R=30. (i.e. WS_R and WS_E refers to the starting SN WinStart_R and ending SN WinEnd_R of the Scoreboard context respectively). These MPDUs are consolidated in a re-order buffer **1516** where the MPDUs with the smallest value of consecutively running SNs i.e. SNs **1** and **2** are then forwarded to the next MAC process. However, the MPDUs with SNs **4** onwards that are successfully received by the recipient MLD cannot be forwarded to the next MAC process because MPDU with SN **3** has not been correctly received i.e. the forwarding has to be in sequential order. As a result, the SN of the frames in the re-order buffer **1516** now begins from **3** (i.e. WS_B=3; WS_B refers to the start of the receive reorder buffer WinStart_B)), with a gap at SN=3 and 5 to 15 as these MPDUs are not received by the recipient MLD.

[0086] Referring to FIG. **15**B, the Originator MLD may receive per-link BlockAck frames in each link, or a Multi-link BlockAck frame in one of the links and come to know of the transmission status of the MPDUs. As a next step, the failed MPDUs on Link 1 may be re-transmitted on Link 2 to the recipient MLD to take advantage of the better link. However, since the Scoreboard context on Link 2 has already shifted to the right and therefore out of range of the re-transmitted smaller SNs, the MPDUs with smaller SNs re-transmitted on Link 2 will be discarded, even though they

were all received in good order. This is in accordance with IEEE 802.11REVmd_D3.0, 10.25.6.3—Scoreboard context control during full-state operation i.e. If $WinStart_R + 2^{11} \leq SN < WinStart_R$, make no changes to the Scoreboard record. Here SN refers to the SN of the received frame and $WinStart_R$ refers to the starting SN of the Scoreboard context. The above is just one example to illustrate the potential issue of Scoreboard contexts of different links going out of each other's range, risking the failure of MPDUs re-transmitted on another link. As can be appreciated, the problem will get worse if the different links have different bandwidths, and consequently different Scoreboard context sizes. The Scoreboard context of the links with higher bandwidth can be expected to be shifted to the right much faster compared to the links with lower bandwidth, increase the risk of the Scoreboard contexts of different links going out of each other's range.

[0087] Alternatively, a receive reordering buffer overflow issue may also occur. Referring to FIG. **15**C, the MPDUs with SNs **3** and **5** to **15** that previously failed on be transmitted on Link 1 may be retransmitted on Link 1 to the recipient MLD. Further, following the successful transmission of MPDUs with SNs **16** to **30** as shown in FIG. **15**A, new MPDUs with SNs **31** to **45** may be transmitted on Link 2 to the recipient MLD. However, the MPDUs with SNs **3** and **5** to **15** may again fail to be received on Link 1 and MPDU with SN **31** may fail to be received on Link 2. As a result, the re-order buffer now has MPDUs with SNs starting from **16** up to 45 with a gap at SN=31. H ere, we assume the size of the receive reorder buffer $WinSize_B$=30 (sum of buffer sizes of link-**1** and link-**2**). As per the rules for the operation of receive reorder buffer, upon receiving a MPDU with SN greater than the end of the receive buffer, the end of the receiver reorder buffer is shifted to accommodate the new MPDU (i.e. WS_R=16 and WE_B=45; WE_B refers to the end of the receive reorder buffer $WinStart_B$)), and the contents of the buffer with SN less than the new start of the buffer WS_R (e.g. MPDU with SN **4**) are passed up to the next MAC process when if gaps exist in the SNs of the MPDUs. Further, MPDUs with SNs **16** to **30** previously received on Link 2 are forwarded to the next MAC process but MPDUs with SN **31** and above cannot be forwarded due to the gap caused by the transmission failure of MPDU with SN **31** (i.e. WS_R=31 and WE_B=60).

[0088] Referring to FIG. **15**D, the failed MPDUs with SNs **3** and **5** to **15** on Link 1 are once again re-transmitted on Link 1 to the recipient MLD. This time, all these MPDUs are successfully received and their receipt are recorded on the Link-**1** scoreboard. However, even though the re-transmitted MPDUs are correctly received on Link 1, they cannot be recorded in the receive reordering buffer and will be discarded at the recipient MLD, because the receive reordering buffer **1516** has already shifted to the right. This issue will be more common when there is a big difference in bandwidth/throughput among links i.e. the faster link will dominate the receive reordering buffer. As MPDUs with higher SN (beyond the current value of $WinEnd_B$) are received over the faster links, the receive reorder buffer will shift to the right (i.e. value of $WinStart_B$ and $WinEnd_B$ will get higher) and thereby increasing the risk of overflowing receiver reordering buffer.

[0089] In order to solve the above issues, a two-tiered block ack architecture is proposed for multi-link transmissions as shown in FIG. **16**. Essentially, originator MLD comprises a transmit buffer control per MLD-RA/TID **1604** with a starting SN equal to $WinStart_T$ and of size $WinSize_T$ for a common Transmit buffer **1602***a* shared among all links (or all affiliated STA assuming one affiliated STA per link if MLD architecture in FIG. **12**B is followed) that enables flexible re-transmissions across links and also prevents receive reordering buffer overruns at the recipient MLD. On the other hand, recipient MLD comprises a receive reordering buffer control per MLD-TA/TID **1614** with a starting SN equal to $WinStart_T$ and of size $WinSize_T$ for a common receive reordering buffer **1612** to ensure the MPDUs are forwarded in correct SN to a next MAC process. Here MLD-RA and MLD-TA refers to the MAC address of the Recipient MLD and the Originator MLD respectively. In order words the originator MLD maintains a Transmit Buffer and a Transmit Buffer Control for every TID of a Multi-link Block Ack agreement. The originator MLD also comprises transmit buffer control per L**1**-RA/TID **1606***a* with a starting SN $WinStart_O$ and of size $WinSize_O$, a transmit buffer **1602***a*, block ack state per L**1**-RA/TID **1608***a* and aggregation control L**1** **1610***a* for a Link 1, as well as transmit buffer control per L**2**-RA/TID **1606***b* with a starting SN $WinStart_O$ and of size $WinSize_O$, a transmit buffer **1602***c*, block ack state per L**2**-RA/TID **1608***b* and aggregation control L**2** **1610***b* for a Link 2. Here L**1**-RA and L**2**-RA refers to the MAC address of the affiliated STAs of the Recipient MLD operating on Link-**1** and Link-**2** respectively. In order words each affiliated STA of the originator MLD also maintains a per-link Transmit Buffer Control for every TID of a Multi-link Block Ack agreement, if that link is part of the Multi-link Block Ack agreement. Each affiliated STA of the originator MLD may also maintain a per-link Transmit Buffer for every TID of a Multi-link Block Ack agreement, if that link is part of the Multi-link Block Ack agreement. Advantageously, the per-link transmit buffer control **1606***a* and **1606***b* prevents overflow of a block acknowledgment record (Scoreboard context) maintained by each STA or station affiliated with the recipient MLD, that may be caused due to transmission of the frames over one or more links as illustrated in FIG. **15**A to **15**D. Advantageously, the common Transmit Buffer shared among all links enables flexible re-transmissions across links and also prevents Receive Reordering Buffer overruns at Recipient. However, having the same MPDU stored in two different Transmit Buffers require additional rules to ensure the two Transmit Buffers stay in synchronization. E.g. an MPDU already being transmitted on one link shouldn't be transmitted on another link prior to receiving transmit status on the original link. Only upon receiving feedback of a transmission failure on one link, an MPDU should be re-transmitted on another link, and the MPDU should be deleted from the per-link Transmit Buffer of the link of the original transmission. Upon receiving feedback of successful transmission over any link, or upon expiry of the MSDU Lifetime of the MSDU carried in the MPDU, the MPDU should be deleted from both the per-link Transmit Buffer as well as the common Transmit Buffer. The size of the block acknowledgement record for each STA or station is negotiated independently during the Multi-link Block ack negotiation as will be explained later. It will be appreciated that the STAs affiliated with the originator MLD or recipient MLD may also be termed as stations. The block ack states are used by the originator MLD to keep track of the status of the transmitted MPDUs and are updated upon receiving Block Ack frames from the

recipient MLD. The role of the Aggregation Control is to construct A-MPDUs for transmission by aggregating two or more MPDUs.

[0090] On the other hand, the recipient MLD further comprises a scoreboard context control L**1** with a starting SN $WinStart_R$ and of size $WinSize_R$ **1616***a* and a deaggregation control L**1** **1618***a* for Link 1, as well as a scoreboard context control L**2** with a starting SN $WinStart_R$ and of size $WinSize_R$ **1616***b* and a deaggregation control L**1** **1618***b* for Link 2. Scoreboard context may also be known as block acknowledgment records and they keep a record of the reception status of MPDUs. The role of the deaggregation control is to de-construct a received A-MPDU into two or more MPDUs. The Recipient MLD also maintain a common receive reordering buffer (or receive buffer in short) for each TID of a Multi-link BlockAck agreement. The main role of the receiver reordering buffer is to ensure MPDUs are forwarded in the correct SN order to the next MAC process. Having a common receiver reordering buffer shared among affiliated STAs (links) ensures that the MPDUs received over different links are passed to the next MAC process in the correct order. It will be appreciated that the number of sets of transmit buffer control per RA/TID, block ack state per RA/TID, aggregation control, scoreboard context control and deaggregation control can be expanded to include 3 or more links. With this architecture, the originator MLD maintains a two-tier Transmit buffer control structure: a common transmit buffer control shared across multiple links, and a separate transmit buffer control for each link.

[0091] The Multi-link extension of the HT-immediate block ack mechanism may be known as Multi-link block ack and is negotiated separately for each direction between two MLDs for a particular TID. The MLD whose affiliated STAs send data using the Multi-link block ack agreement is referred to as originator MLD, and the MLD whose affiliated STAs are receiver of the data is referred to as recipient MLD. The Multi-link block ack agreement is uniquely identified by a tuple of {originator MLD MAC address, recipient MLD MAC address, TID}.

[0092] Under the architecture as shown in FIG. **16**, the originator MLD contains a common transmit buffer control per {Recipient MLD MAC address, TID} that is shared among the affiliated STAs or stations that use the Multi-link block ack agreement, and uses $WinStart_T$ and $WinSize_T$ to submit MPDUs for transmission and release transmit buffers upon receiving BlockAck frames. $WinStart_T$ is the starting sequence number of the common transmit window across all links of the Multi-link block ack agreement and $WinSize_T$ is the size of the total Transmit window and is equal to the receive reordering buffer maintained by the recipient MLD. $WinSize_T$ is equal to the size of receive reorder buffer negotiated during block ack agreement. The size of receive reorder buffer may be negotiated independently or may be calculated based on the size of the per-link scoreboard contexts. The common transmit buffer is used as to store MSDUs or A-MSDUs until they are reported as successfully received or they exceed their lifetime (e.g. MSDU Lifetime).

[0093] Each affiliated STA of the originator MLD contains a per-link Transmit Buffer Control and a per-link block ack state per {peer affiliated STA MAC address, TID} and an Aggregation control. Each affiliated STA also maintains a per-link transmit buffer valid for a short period e.g. a single transmission opportunity (TXOP) and may be used for per-link retransmissions i.e. retransmission within the same TXOP.

[0094] The recipient MLD contains a common receive reordering buffer control per {Originator MLD MAC address, TID} and is responsible for recording and reordering the MSDUs/A-MSDUs arriving from each of the affiliated STAs, as well as identifying and discarding duplicate frames.

[0095] Further, each affiliated STA of the recipient MLD contains a per-link Scoreboard context control per {peer affiliated STA MAC address, TID} and a deaggregation control. Each per-link scoreboard context control contains an acknowledgement bitmap control containing the current reception status of MSDUs or A-MSDUs received over the associated link, and may use either full-state or partial-state operation.

[0096] In operation, the originator MLD may store transmitted frames in the common transmit buffer until they are acknowledged by the recipient MLD as successfully received or until they are discarded at the end of a MAC Service Data Unit (MSDU) lifetime. On the other hand, the stations affiliated with the originator MLD may store frames in the per-link transmit buffer only for the duration of a transmit opportunity (TXOP). In other words, frames are stored for a longer duration in the common transmit buffer compared to the per-link transmit buffer.

[0097] FIG. **17**A shows a Block Ack Parameter Set (i.e. a field in ADDBA request frame **810** as shown in FIG. **8**) and FIG. **17**B shows a Multi-band element (i.e. a field in ADDBA response frame **820** as shown in FIG. **8**) in accordance with the block ack architecture **1600** as illustrated in FIG. **16**. Block Ack Parameter set **1700** includes a buffer size field **1702** which in the ADDBA response frame indicates the size of the Scoreboard context control (i.e. $WinSize_R$) of the link on which the ADDBA Response frame is transmitted. Multi-band element **1710** now includes a buffer size field **1712** which in the ADDBA response frame indicates the size of the Scoreboard context control ($WinSize_R$) of the link represented by the Multi-band element **1710**. In accordance with the architecture as illustrated in FIG. **16**, the size of the receive reordering buffer $WinSize_B$=$WinSize_T$=sum of $WinSize_R$ across all links of the multi-link block ack agreement. Alternatively, buffer size field **1702** in the ADDBA response frame may represent $WinSize_B$ and $WinSize_R$ of the link on which the ADDBA response frame was transmitted=$WinSize_B$−value of the buffer size field **1712** in Multi-band element (i.e. the $WinSize_R$ of the link on which the ADDBA response frame was transmitted is indirectly signalled).

[0098] FIG. **18** shows a format of an enhanced BlockAck Request (eBAR) frame in accordance with the architecture as illustrated in FIG. **16**. As per existing HT-immediate block ack rules, a BAR frame may be used to shift forward the value of $WinStart_R$, but a BAR with Starting Sequence N umber (SSN) value less than $WinStart_R$ is discarded, so it is not possible to shift back the value of $WinStart_R$. Therefore, enhanced BAR (eBAR) frame **1800** can explicitly allow this. For example, if the bit in Shift $WinStart_R$ field **1802** is set, recipient MLD shall replace the value of $WinStart_R$ of the Scoreboard Context (of the link on which the enhance BAR frame was received) with the value of the Starting Sequence Number (SSN) sub-field of the BAR information field. If the bit is not set, $WinStart_R$ is updated

only if $WinStart_R$<SSN≤$MinStart_R$+2^{11}. Further, if the bit in Shift $WinStart_B$ field **1804** is set, recipient MLD shall replace the value of $WinStart_B$ with the value of the Starting Sequence Number sub-field of the BAR information field. If the bit is not set, recipient shall not update based on the value of SSN in BAR frames. Further, transmission of the eBAR frame **1800** on a link also replaces $WinStart_O$ of the link on the originator side with the value of SSN.

[0099] Alternatively, if a protected block ack agreement has been successfully negotiated, a robust ADDBA Request frame may also be used to achieve the same effect as the eBAR frame **1800**. Accordingly, a BlockAck Request frame may be configured to indicate whether or nota starting point of a block acknowledgment record maintained by a station should be replaced with a value of a Starting Sequence Number (SSN) carried in the BlockAck Request frame.

[0100] FIG. **19** shows how eBAR resolves the issue of scoreboard context out of range as previously illustrated in FIG. **15**A. Since the value of $WinStart_R$ for the scoreboard **1512** on Link 2=WS_R=16 after the initial transmission, if the originator MLD were to retransmit the failed MPDUs (that were originally transmitted on Link 1) on Link 2, since the SNs are less than 16, they will be discarded by the recipient MLD. To avoid this, the originator MLD transmits an eBAR **1800** with SSN=3, which is the smallest SN to be re-transmitted. The "shift $WinStart_R$" bit is set in the eBAR, hence recipient MLD shall replace the value of $WinStart_R$ for the scoreboard **1902** on Link 2 with the value of the Starting Sequence Number (SSN) sub-field of the BAR information field. Thereafter, the failed MPDUs on Link 1 may be re-transmitted on Link 2 as illustrated in **1900** without causing the scoreboard context control to become out of range. Advantageously, eBAR solves the issue of Scoreboard context control being out of range and facilitates cross-link re-transmissions.

[0101] Alternatively, if the originator MLD decides to disable Link 1 due to repeated transmission failure, it may transmit a signal to the recipient MLD to disable Link 1. Upon reception of the signal to disable Link 1, the recipient MLD may shift the Scoreboard Context Control to the left (such that $WinStart_R$=smallest SN not yet successfully received) in anticipation of the retransmission of the failed MPDUs on Link 1.

[0102] Having a common Transmit buffer control across all links of Multi-link block ack agreement, as illustrated in the BlockAck architecture of FIG. **16**, will advantageously prevent the issue of Receive reordering buffer overflow (i.e. as previously shown in FIGS. **15**A, **15**C and **15**D) at the recipient. ($WinStart_T$+$WinSize_T$) acts as an upper bound on the SN of the MPDU transmitted over individual links, such that Highest SN transmitted on any link $WinStart_T$+$WinSize_T$.

[0103] M FIG. **20** illustrates how the common transmit buffer control prevents the receive reordering buffer overflow issue as shown in FIGS. **15**A, **15**C and **15**D. Here, $WinStart_T$ refers to the starting of the transmit window (i.e. WS_T) and is equal to the smallest SN that is yet to be acknowledged by the recipient MLD as successfully received. As seen in common transmission buffer control **2000**, MPDUs that previously failed transmission on Link 1 (i.e. MPDUs with SNs **3** and **5** to **15**) are re-transmitted on Link 1. The highest SN that can be safely transmitted across all links is capped by the common transmit window size ($WinSize_T$): Highest SN=$WinStart_T$+$WinSize_T$−1=32.

[0104] $WinSize_T$ is set to the buffer size value of the Receive Reorder Buffer control **2004** and hence having the above rule ensures that the MPDUs transmitted by the originator MLD will never overflow the Receive Reorder Buffer at the recipient MLD. Now if the failed MPDUs on Link-**1** are retransmitted on Link-**1** as shown in FIG. **15**D, they can be safely received at the recipient side. If the originator MLD gives up on transmission of MPDUs (for example due to repeated transmission failures or due to expiry of the MPDU lifetime), the originator MLD may shift the transmit window to the right by transmitting a BlockAck Request frame with the SSN set to the value of the next MPDU to be transmitted. This causes $WinStart_T$ and $WinStart_O$ of the link to be set to SSN at the originator MLD, and also causes the recipient MLD to shift both the scoreboard and the receive window to the right by setting $WinStart_R$ (i.e. WS_R) and $WinStart_B$ (i.e. WS_B) to SSN. Subsequently, the transmission of MPDUs with higher SN may be resumed. Advantageously, cross-link re-transmissions are possible without overflowing the receive buffer.

[0105] In accordance with another embodiment, if the recipient MLD supports consolidated block ack across multiple links, a common Multi-link scoreboard context control may be used to combine the scoreboard context controls of individual links. FIG. **21** illustrates a block ack architecture **2100** in accordance with this embodiment which is a variation of the block ack architecture **1600** illustrated in FIG. **16**. While the two architectures are mostly the same, a main difference is that the recipient MLD in architecture **2100** now comprises a multi-link scoreboard context control **2120** of a size ($ML\_WinStart_R$,$ML\_WinSize_R$). $ML\_WinStart_R$ is a minimum $WinStart_R$ across all links of a multi-link block ack agreement negotiated by the originator MLD and the recipient MLD, such that the $ML\_WinSize_R$≥sum of $WinSize_R$ across all links of the multi-link block ack agreement Another difference is that the originator MLD in architecture **2100** only maintains one common transmit buffer **2100** that is shared among all links.

[0106] Architecture **2100** is based on a premise that it is possible for the two-tier transmit buffer control to be performed without separate per-link transmit buffers such as the transmit buffers **1602***b* and **1602***c* for link 1 and link 2 respectively of the block ack architecture **1600**. For example, the buffer in architecture **2100** is only a common transmit buffer **2102** and the two-tier transmit buffer control is performed by address/pointers management.

[0107] The multi-link scoreboard context control **2120** may operate with the following rules for reception of data frames:

- If $ML\_WinStart_R$ <= SN <= ML_WinEnd_R : set to 1 the bit in position SN within the bitmap.
- If ML_WinEnd_R < SN < ML_WinEnd_R + 2^{11}:
1) set to 0 bits with SN values from ML_WinEnd_R + 1 to SN −1
2) ML_WinEnd_R = SN
3) $ML\_WinStart_R$ = SN − $ML\_WinSize_R$
4) set to 1 the bit at position SN in the bitmap.
- If ML_WinEnd_R + 2^{11} <= SN <= ML_WinEnd_R: make no change

[0108] Further, the multi-link scoreboard context control **2120** may operate with the following rules for reception of multi-link BlockAckReq (ML_BAR) frames:

- If $ML\_WinStart_R$ <= SSN <= ML_WinEnd_R:
1) $ML\_WinStart_R$ = SSN
2) set to 0 bits with SN values from ML_WinEnd_R+ 1 to $ML\_WinSize_R$−1
3) ML_WinEnd_R= $ML\_WinStart_R$+ $ML\_WinSize_R$ − 1
- If ML_WinEnd_R < SSN < ML_WinEnd_R + 2^{11}:
1) $ML\_WinStart_R$ = SSN
2) ML_WinEnd_R = $ML\_WinStart_R$ + $ML\_WinSize_R$ − 1
3) set to 0 bits with SN values from $ML\_WinStart_R$ to ML_WinEnd_R
- If ML_WinEnd_R + 2^{11} <= SSN <= ML_WinEnd_R: make no change

[0109] The rules for the update of Receive Reordering Buffer Control upon receipt of multi-link BAR (ML_BAR) frames are the same as receipt of BAR frames. Further, receipt of per-link BAR does not affect the ML_scoreboard, while receipt of ML_BAR does not affect the per-link scoreboard.

[0110] In both the architectures shown in FIG. **16** as well as the one in FIG. **21**, although it is advantageous to implement a separate Transmit Buffer Control **1604** or **2104**, it is also possible that instead of maintaining such a record ($WinStart_T$, $WinSize_T$) the Originator MLD performs control of the transmissions across multiple links by referring to the records of each per-link Transmit Buffer Controls prior to each transmission to ensure that the receive reorder buffer at the recipient is not overflowed. The Originator MLD ensures that the difference between the smallest $WinStart_T$ across all links and the largest value of ($WinStart_T$+$WinStart_T$) across all links is not larger than $WinSize_B$. In summary, the purpose of having the common Transmit Buffer Control is to ensure that the transmissions of MPDUs across different links do not cause issues for the recipient MLD, for example overflow of receive reorder buffer.

[0111] FIG. **22**A shows a Block Ack Parameter Set (i.e. a field in ADDBA request frame **810** as shown in FIG. **8**) and FIG. **22**B shows a Multi-band element (i.e. a field in ADDBA response frame **820** as shown in FIG. **8**) in accordance with the block ack architecture **2100** as illustrated in FIG. **21**. Block Ack Parameter set **2200** includes a buffer size field **2202** which in the ADDBA response frame indicates the size of the receive reordering buffer (i.e. $WinSize_B$). ADDBA Request/Response frames carry one Multi-band element for each link of the Multi-link block ack agreement (including the link on which the frames are transmitted). Multi-band element **2210** now includes a buffer size field **2212** which in the ADDBA response frame indicates the size of the scoreboard context control ($WinSize_R$) of the link represented by the Multi-band element **2210**. Each Multi-band element **2210** identifies one link of the multi-link block ack agreement.

[0112] In accordance with the architecture **2100** as illustrated in FIG. **21**, $WinSize_T$=$WinSize_B$≥sum of $WinSize_R$ across all links of the multi-link block ack agreement negotiated by the originator MLD and the recipient MLD. A receive reordering buffer size bigger than the sum of the receive buffer across all links may be negotiated to account for differences in the link throughputs. Further, the size of the receive reorder buffer may be negotiated independent of the size of the per-link scoreboard. Such implementation may help to reduce the chances of the receive reorder buffer overflows due to the differences in the link bandwidths etc. as explained earlier by being able to accommodate more MPDUs received over fast links without overflowing while still being able to receive MPDUs from slower links. However, it has to be appreciated that even though the bigger size of the receive reordering buffer may help to mitigate some cases of overflow of receive reordering buffer, it alone cannot completely avoid the risk of overflow of receive reordering buffer and regardless of the size of the receive reordering buffer negotiated during the multi-link Block Ack agreement, some sort of central control of the transmissions across different links at the originator side will be necessary.

[0113] In accordance with yet another embodiment, ADDBA Request and Response frames may carry a Multi-link element that specify the parameters related to all the links of the Multi-link block ack agreement negotiated between the originator MLD and the recipient MLD. Referring to FIGS. **23**A, **23**B and **23**C, ADDBA request frame **2304** and ADDBA response frame **2306** may comprise a Block Ack Parameter Set field **2300** that contains a buffer size field **2302**. The buffer size field **2302** indicates the size of the receive reordering buffer ($WinSize_B$). ADDBA request frame **2304** and ADDBA response frame **2306** may also comprise a Multi-link element field **2310** that contains one or more Link Parameters field **2312**. The one or more Link Parameters field may each comprise a Link ID field **2314**, a Scoreboard Size field **2316** and an optional MAC Address field **2318**. The Link ID field **2314** identifies the associated link, where the Link ID may be assigned during multi-link setup/association or during a separate link setup procedure after association. The Scoreboard Size field **2316** in M ti-link element **2310** in the ADDBA response frame **2306** indicates the size of the Scoreboard context control ($WinSize_R$) of the link represented by the associated Link ID as identified in the Link ID field **2314**. In the current embodiment, $WinSize_T$=$WinSize_B$≥sum of $WinSize_R$ across all links of the multi-link block ack agreement.

[0114] FIG. **24** shows a schematic of an originator MLD **2400** in accordance with various embodiments. The originator MLD comprises a common transmit buffer control **2406** with a common transmit buffer **2404** (i.e. the common transmit buffer control **1604** with common transmit buffer **1602***a* in originator MLD of architecture **1600**, as well as common transmit buffer control **2104** with common transmit buffer **2102** in originator MLD of architecture **2100**) and a MAC-SAP **2402** for performing distribution service (DS). The originator MLD **2400** comprises two affiliated STAs or stations, STA **1** **2408***a* and STA **2** **2408***b*. STA **1** **2408***a* comprises at MAC layer a per-link Transmit Buffer Control **2414***a*, a Block ack state **2416***a* and an Aggregation Control **2418***a* (i.e. similar to transmit buffer control **1606***a*, block ack state **1608***a* and aggregation control **1610***a* in architecture **1600**, and transmit buffer control **2106***a*, block ack state **2108***a* and aggregation control **2110***a* in architecture **2100**). Likewise, STA **2** **2408***b* comprises at MAC layer a per-link Transmit Buffer Control **2414***b*, a Block ack state **2416***b* and an Aggregation Control **2418***b* (i.e. similar to transmit buffer control **1606***b*, block ack state **1608***b* and aggregation control **1610***b* in architecture **1600**, and transmit buffer control **2106***b*, block ack state **2108***b* and aggregation control **2110***b* in architecture **2100**). Both STAs comprise a PHY layer from which transmission via Link 1 (for STA **12408***a*) and Link 2 (for STA **2** **2408***b*) occurs. It will be appreciated that the number of links and affiliated STAs or stations may be further expanded.

[0115] FIG. **25** shows a schematic of a recipient MLD **2500** in accordance with various embodiments. The recipient MLD comprises a receive reorder buffer control **2506** with a receive reorder buffer **2504** (i.e. the receive reorder

buffer control **1614** with receive reorder buffer **1612** in recipient MLD of architecture **1600**, as well as receive reorder buffer control **2114** with receive reorder buffer **2112** in recipient MLD of architecture **2100**) and a MAC-SAP **2502** for performing distribution service (DS). The recipient MLD **2500** comprises two affiliated STAs or stations, STA **1 2508***a* and STA **2 2508***b*. STA **1 2508***a* comprises at MAC layer a Scoreboard Context control **2516***a* and a Deaggregation Control **2518***a* (i.e. similar to scoreboard context control **1616***a* and deaggregation control **1618***a* in architecture **1600**, and scoreboard context control **2116***a* and deaggregation control **2118***a* in architecture **2100**). Likewise, STA **2 2508***b* comprises at MAC layer a Scoreboard Context Control **2516***b* and a Deaggregation Control **2518***b* (i.e. similar to scoreboard context control **1616***b* and aggregation control **1618***b* in architecture **1600**, and scoreboard context control **2116***b* and aggregation control **2118***b* in architecture **2100**). Both STAs comprise a PHY layer from which transmission via Link 1 (i.e. between STA **1 2508***a* and STA **1 2408***a* at the originator MLD **2400**) and Link 2 (i.e. between STA **2 2508***b* and STA **2 2408***b* at the originator MLD **2400**) occurs. It will be appreciated that the number of links and affiliated STAs or stations may be further expanded.

[0116] FIG. **26** shows a flow diagram **2600** illustrating a method for multi-link communication according to various embodiments. In step **2602**, setup is initiated, at a first multi-link device, of a block acknowledgement agreement with a second multi-link device that is configured to operate with a second plurality of stations, the first multi-link device being configured to operate with a first plurality of stations, wherein a link has been established between each station of the first plurality of stations and a corresponding station of the second plurality of stations. In step **2604**, frames of a Traffic Identifier (TID) are transmitted on one or more links to the second multi-link device based on the block acknowledgement agreement, wherein the first plurality of stations are configured to share a common transmit buffer that stores the frames of the TID to be transmitted to the second multi-link device and a common transmit buffer control to manage the transmission of the frames over the one or more links, and wherein each of the first plurality of stations is configured to maintain a per-link transmit buffer control to manage the transmission of the frames on a corresponding one of the one or more links.

[0117] FIG. **27** shows a schematic, partially sectioned view of a multi-link device **2700** that can be implemented for multilink communication in accordance with various embodiments as shown in FIGS. **1** to **26**. The multi-link device **2700** may be implemented as an AP MLD or non-AP MLD, and comprising one or more affiliated stations or STAs according to various embodiments.

[0118] Various functions and operations of the multi-link device **2700** are arranged into layers in accordance with a hierarchical model. In the model, lower layers report to higher layers and receive instructions therefrom in accordance with IEEE specifications. For the sake of simplicity, details of the hierarchical model are not discussed in the present disclosure.

[0119] As shown in FIG. **27**, the multi-link device **2700** may include circuitry **2714**, at least one radio transmitter **2702**, at least one radio receiver **2704** and multiple antennas **2712** (for the sake of simplicity, only one antenna is depicted in FIG. **27** for illustration purposes). The circuitry may include at least one controller **2706** for use in software and hardware aided execution of tasks it is designed to perform, including control of communications with one or more other multi-link devices in a M IMO wireless network. The at least one controller **2706** may control at least one transmission signal generator **2708** for generating ADDBA action frames such as ADDBA request frames and/or ADDBA response frames to be sent through the at least one radio transmitter **2702** to one or more other multi-link devices and at least one receive signal processor **2710** for processing ADDBA action frames such as ADDBA request frames and/or ADDBA response frames received through the at least one radio receiver **2704** from the one or more other multi-link devices. The at least one transmission signal generator **2708** and the at least one receive signal processor **2710** may be standalone modules of the multi-link device **2700** that communicate with the at least one controller **2706** for the above-mentioned functions. Alternatively, the at least one transmission signal generator **2708** and the at least one receive signal processor **2710** may be included in the at least one controller **2706**. It is appreciable to those skilled in the art that the arrangement of these functional modules is flexible and may vary depending on the practical needs and/or requirements. The data processing, storage and other relevant control apparatus can be provided on an appropriate circuit board and/or in chipsets. In various embodiments, when in operation, the at least one radio transmitter **2702**, at least one radio receiver **2704**, and at least one antenna **2712** may be controlled by the at least one controller **2706**. Furthermore, while only one radio transmitter **2702** is shown, it will be appreciated that there can be more than one of such transmitters i.e. one transmitter for each affiliated station or STA of the multi-link device **2700**.

[0120] As shown in FIG. **27**, the at least one radio receiver **2704**, together with the at least one receive signal processor **2710**, forms a receiver of the multi-link device **2700**. The receiver of the multi-link device **2700**, when in operation, provides functions required for multi-link communication. While only one radio receiver **2704** is shown, it will be appreciated that there can be more than one of such receivers i.e. one receiver for each affiliated station or STA of the multi-link device **2700**.

[0121] The multi-link device **2700**, when in operation, provides functions required for multi-link communication. For example, the multi-link device **2700** may be a first multi-link device configured to operate with a first plurality of affiliated stations. The circuitry **2714** may, in operation, initiate setup of a block acknowledgement agreement with a second multi-link device that is configured to operate with a second plurality of affiliated stations, wherein a link has been established between each station of the first plurality of stations and a corresponding station of the second plurality of stations. The transmitter **2702** may, in operation, transmit frames of a Traffic Identifier (TID) on one or more links to the second multi-link device based on the block acknowledgement agreement, wherein the first plurality of stations are configured to share a common transmit buffer that stores the frames of the TID to be transmitted to the second multi-link device and a common transmit buffer control to manage the transmission of the frames over the one or more links, and wherein each of the first plurality of stations is configured to maintain a per-link transmit buffer control to manage the transmission of the frames on a corresponding one of the one or more links.

[0122] Each of the first plurality of stations may be configured to maintain a separate per-link transmit buffer to store the frames to be transmitted on the corresponding one of the one or more links. The circuitry **2714** may be configured to store the frames in the common transmit buffer until they are acknowledged by the second multi-link device as successfully received or until they are discarded at the end of a MAC Service Data Unit (MSDU) lifetime, the first plurality of stations storing frames in the per-link transmit buffer only for the duration of a transmit opportunity (TXOP).

[0123] The common transmit buffer control may be used to prevent overflow of a receive reordering buffer that is maintained by the second multi-link device due to a transmission of frames over the one or more links; the per-link transmit buffer control being used to prevent overflow of a block acknowledgment record maintained by each of the second plurality of stations due to transmission of the frames over the one of the one or more links. Further, a size of the received reordering buffer that is managed by the second multi-link device may be negotiated independently.

[0124] The circuitry **2714** may be configured to negotiate the block acknowledgement agreement with the second multi-link device by exchanging ADDBA action frames over the one of the one or more links, wherein a size of a block acknowledgment record maintained by each station of the second plurality of stations is independently negotiated.

[0125] Further, the circuitry may be configured to transmit a BlockAckReq frame to the second multi-link device on the one of the one or more links to solicit a BlockAck frame, wherein the BlockAckReq frame is configured to indicate whether or not a starting point of a block acknowledgment record maintained by one of the second plurality of stations should be replaced with a value of a Starting Sequence Number (SSN) carried in the BlockAckReq frame.

[0126] FIG. **28** depicts a detailed block diagram **2800** of a multi-link device **2802** in accordance with the present embodiments. Each of a plurality of Wireless I/Fs **2810**, **2820**, **2830** implement both a respective one of the Physical layer (PHY) processing modules **2816**, **2826**, **2836** and a respective one of Lower MAC function modules **2812**, **2822**, **2832**. The function of the W ireless I/Fs **2810**, **2820**, **2830** may be the same as that of affiliated STAs **1280**, **1282**, **1284**, **1286**, **1288** and **1290** in FIG. **12**B if such an architecture is implemented. The Upper MAC functions may be implemented as software within a central processing unit (CPU) **2840** which, in operation, may be coupled to a memory **2842** that may be used to store the multi-band BA scoreboard, a secondary storage **2844** and a wired communication I/F **2846** for communicating with external networks, other APs **102** or other MLDs. A power source **2848** provides power for the AP **2802**. If the architecture as shown in FIG. **12**B is implemented, the Upper MAC functions are fulfilled by the MLD.

[0127] The present disclosure can be realized by software, hardware, or software in cooperation with hardware. Each functional block used in the description of each embodiment described above can be partly or entirely realized by an LSI such as an integrated circuit, and each process described in the each embodiment may be controlled partly or entirely by the same LSI or a combination of LSIs. The LSI may be individually formed as chips, or one chip may be formed so as to include a part or all of the functional blocks. The LSI may include a data input and output coupled thereto. The LSI here may be referred to as an IC, a system LSI, a super LSI, or an ultra LSI depending on a difference in the degree of integration. However, the technique of implementing an integrated circuit is not limited to the LSI and may be realized by using a dedicated circuit, a general-purpose processor, or a special-purpose processor. In addition, a FPGA (Field Programmable Gate Array) that can be programmed after the manufacture of the LSI or a reconfigurable processor in which the connections and the settings of circuit cells disposed inside the LSI can be reconfigured may be used. The present disclosure can be realized as digital processing or analogue processing. If future integrated circuit technology replaces LSIs as a result of the advancement of semiconductor technology or other derivative technology, the functional blocks could be integrated using the future integrated circuit technology. Biotechnology can also be applied.

[0128] The present disclosure can be realized by any kind of apparatus, device or system having a function of communication, which is referred as a communication device.

[0129] The communication apparatus may comprise a transceiver and processing/control circuitry. The transceiver may comprise and/or function as a receiver and a transmitter. The transceiver, as the transmitter and receiver, may include an RF (radio frequency) module including amplifiers, RF modulators/demodulators and the like, and one or more antennas.

[0130] Some non-limiting examples of such communication device include a phone (e.g., cellular (cell) phone, smart phone), a tablet, a personal computer (PC) (e.g., laptop, desktop, netbook), a camera (e.g., digital still/video camera), a digital player (digital audio/video player), a wearable device (e.g., wearable camera, smart watch, tracking device), a game console, a digital book reader, a telehealth/telemedicine (remote health and medicine) device, and a vehicle providing communication functionality (e.g., automotive, airplane, ship), and various combinations thereof.

[0131] The communication device is not limited to be portable or movable, and may also include any kind of apparatus, device or system being non-portable or stationary, such as a smart home device (e.g., an appliance, lighting, smart meter, control panel), a vending machine, and any other "things" in a network of an "Internet of Things (IoT)".

[0132] The communication may include exchanging data through, for example, a cellular system, a wireless LAN system, a satellite system, etc., and various combinations thereof.

[0133] The communication device may comprise an apparatus such as a controller or a sensor which is coupled to a communication apparatus performing a function of communication described in the present disclosure. For example, the communication device may comprise a controller or a sensor that generates control signals or data signals which are used by a communication apparatus performing a communication function of the communication device.

[0134] The communication device also may include an infrastructure facility, such as a base station, an access point, and any other apparatus, device or system that communicates with or controls apparatuses such as those in the above non-limiting examples.

[0135] As a non-limiting example of an architecture (for example, the architectures as illustrated in FIGS. **12**A, **12**B, **16** **21** and **28**), the MLD of the present disclosure can be

logical and realized by a plurality of separated communication apparatuses sharing a common MAC data service interface to an upper layer.

[0136] A non-limiting example of a station may be one included in a first plurality of stations affiliated with a multi-link station logical entity (i.e. such as an MLD), wherein as a part of the first plurality of stations affiliated with the multi-link station logical entity, stations of the first plurality of stations share a common medium access control (MAC) data service interface to an upper layer, wherein the common MAC data service interface is associated with a common MAC address or a Traffic Identifier (TID). The station may comprise circuitry, which in operation, initiates setup of a block acknowledgement agreement with a second multi-link device that is configured to operate with a second plurality of affiliated stations, wherein a link has been established between each station of the first plurality of stations and a corresponding station of the second plurality of stations; and a transmitter, which in operation, transmits frames of the TID on one or more links to the second multi-link device based on the block acknowledgement agreement, wherein the first plurality of stations are configured to share a common transmit buffer that stores the frames of the TID to be transmitted to the second multi-link device and a common transmit buffer control to manage the transmission of the frames over the one or more links, and wherein each of the first plurality of stations is configured to maintain a per-link transmit buffer control to manage the transmission of the frames on a corresponding one of the one or more links.

[0137] Thus, it can be seen that the present embodiments provide communication devices and methods for operation over multiple links in order to fully realize the throughput gains of multi-link communication.

[0138] While exemplary embodiments have been presented in the foregoing detailed description of the present embodiments, it should be appreciated that a vast number of variations exist. It should further be appreciated that the exemplary embodiments are examples, and are not intended to limit the scope, applicability, operation, or configuration of this disclosure in any way. Rather, the foregoing detailed description will provide those skilled in the art with a convenient road map for implementing exemplary embodiments, it being understood that various changes may be made in the function and arrangement of steps and method of operation described in the exemplary embodiments and modules and structures of devices described in the exemplary embodiments without departing from the scope of the subject matter as set forth in the appended claims.

1. A recipient multi-link device (MLD) comprising:

circuitry which, in operation, establishes on a first link a multi-link Block Ack agreement for a plurality of links with an originator MLD;

a receiver which, in operation, receives from the originator MLD a plurality of MAC layer Protocol Data Units (MPDUs) with a common Traffic Identifier (TID) on one or more links among the plurality of links; and

a transmitter which, in operation, transmits a multi-link Block Ack agreement to the originator MLD and, in operation, transmits one or more per-link Block Acks to the originator MLD, each of the one or more per-link Block Acks indicating reception status of a subset of the plurality of MPDU s, the subset being received on one of the one or more links.

2. The recipient MLD according to claim **1**, wherein the one or more per-link Block Acks are consolidated to a Multi-link Block Ack scoreboard.

3. The recipient MLD according to claim **2**, wherein the Multi-link Block Ack scoreboard comprises a bitmap comprising a plurality of bits, each bit indicating whether a corresponding MPDU is successfully received.

4. The recipient MLD according to claim **1**, wherein the multi-link Block Ack agreement is established per TID by:

receiving an Add Block Ack (ADDBA) Request frame on an enabled link; and

transmitting an Add Block Ack (ADDBA) Response frame on the enabled link.

5. The recipient MLD according to claim **1**, wherein the circuitry, in operation, maintains a single common receive reordering buffer to reorder the plurality of MPDUs received across the one or more links.

6. A reception method by a recipient multi-link device (MLD), the reception method comprising:

establishing on a first link a multi-link Block Ack agreement for a plurality of links with an originator MLD;

receiving from the originator MLD a plurality of MAC layer Protocol Data Units (MPDUs) with a common Traffic Identifier (TID) on one or more links among the plurality of links;

transmitting a multi-link Block Ack agreement to the originator MLD; and

transmitting one or more per-link Block Acks to the originator MLD, each of the one or more per-link Block Acks indicating reception status of a subset of the plurality of MPDU s, the subset being received on one of the one or more links.

7. The reception method according to claim **6**, comprising:

consolidating the one or more per-link Block Acks to a Multi-link Block Ack scoreboard.

8. The reception method according to claim **7**, wherein the Multi-link Block Ack scoreboard comprises a bitmap comprising a plurality of bits, each bit indicating whether a corresponding MPDU is successfully received.

9. The reception method according to claim **6**, wherein the multi-link Block Ack agreement is established per TID by:

receiving an Add Block Ack (ADDBA) Request frame on an enabled link; and

transmitting an Add Block Ack (ADDBA) Response frame on the enabled link.

10. The reception method according to claim **6**, comprising:

maintaining a single common receive reordering buffer to reorder the plurality of MPDUs received across the one or more links.

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