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Re:	IEEE P802.16-REVd/D4-2003
Abstract	This contribution introduces AAS enhancements for OFDMA PHY as an optional feature
Purpose	Adopt into P802.16d/D5 draft.
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1   Introduction

Adaptive array systems (AAS) can extend cell coverage by improving the system link budget. Link budget gain is realized by an AAS through the coherent combining of signals received or transmitted from multiple antenna elements, as well as by the increase in diversity order offered by the antenna array. At the same time, AAS can increase base station capacity by enabling the use of higher order modulation through interference reduction and by enabling spectral reuse within the cell.

In order to enable effective AAS processing, several issues must be resolved, some of which require additional capabilities in the BS or SS. This document describes these new AAS capabilities, including support for new control signal structures, which are compatible with the OFDMA PHY.

Examples of AAS control signals include antenna array training and bandwidth request signals that are able to function in a co-channel RF environment.   The current OFDMA standard is silent on the definition of these signals. To ensure compatibility across different base stations and SSs, the control signals must be defined. Accordingly, a compact set of AAS control signals, is proposed in this submission. The use of these controls is only required for systems using the optional AAS mode. Non-AAS systems are not required to use these signals, and therefore bear no inefficiency.

2   Problem Definition

2.1   Broadcast Control Messages and Range

Coherent beamforming with a base station antenna array can effectively increase the transmission range of the uni-cast channels, since there exists an optimum beamforming solution to serve the intended SS, but it cannot directly increase the range of broadcast messages on broadcast channels – most crucially, broadcast MAP bursts do not enjoy the extended range. An SS who cannot receive the broadcast DL-MAP is cut-off from receiving other downlink traffic intended for it even though enough link budget on a beamformed transmission exists. The same problem occurs on the uplink – any SS that cannot receive the broadcast UL-MAP will not be able to transmit, even though the base station can use coherent combining gain to close the link.

The present OFDMA standard attempts to resolve this problem in the AAS mode with the active AAS DL scan (Section 8.4.4.7), which broadcasts on a sequence of different transmit beams, references to private DL-MAP allocations transmitted on the relevant transmit beam.

We present two new AAS modes, the Diversity Map Signaling method, which is a superset of the current active AAS DL scan, and the Direct Signaling method. These methods will replace the current active AAS DL scan definition. Both methods are optional AAS modes.

2.2   Interference on Control Messages

AAS system that employ adaptive arrays for the purpose of increasing base station capacity do so by aggressive reuse of frequency – often by re-using frequencies within the cell several times. In such an RF environment, the control messages are buried by interference, not only from interference generated by adjacent cells, but by interference generated from multiple users within the same cell. Thus, it becomes imperative to protect control signaling that opens data flows between various SS and the serving base station from this interference. This implies that control signaling be structured to enable interference mitigation using either in time, frequency, spatial and/or coding dimensions.

2.3   Proposed Solution

The proposed solution introduces low overhead control symbols and signaling that can be overlaid onto the OFDMA PHY framing structure. This control signaling is specifically designed for the AAS mode and may be selectively removed in non-AAS modes. Specially, the control signaling is designed so that base stations that employ adaptive antenna arrays can use spatial or spatial/spectral filtering to isolate this critical signaling and maintain the link budget advantages described above.

3   AAS Control Signaling Overview Solution

The following paragraphs provide an overview of the physical layer control signaling supporting the optional AAS mode. The signaling mechanisms described herein have been rationalized and integrated with the OFDMA frame structure.

An outline of this section is as follows: First is a definition of an AAS-DLFP that carries broadcast information and is transmitted with beam-pattern diversity and carries a minimal set of compressed DL-MAPs and UL-MAPs. This approach, or the Diversity-Map Method, is described in section 3.1 below. This method is effectively augmenting the functionality of the current Active DL AAS scan (8.4.4.7). Method 2 is the Direct-Signaling Method, and includes the definition of special symbols to support paging and access requests, and is described in section 3.2 below.

The Diversity-Map Method has the benefits of:

- Increased link budget for broadcast information

- High spectral efficiency

- High base station capacity

- Uses existing MAC messaging for flexible BW allocations

- No significant additional processing requirements on the SS

Method #2, the Direct-Signaling Method, also defines an AAS-DLFP2 that carries broadcast information and is transmitted with beam-pattern and frequency diversity. AAS-DLFP2 carries the minimal set information needed to set up base station

beamforming so that Map allocations and other broadcast information can be transferred with adequate link budget. Once the UL-Maps and DL-Map have transferred the data flow CIDs, burst parameters and map regions, PHY layer control signaling is used to page subscriber stations and to train the adaptive arrays in the co-channel environment. Method 2 applies only to the AMC sub-channel region and enables the following attributes (analysis for PUSC on going):

- Higher in-cell frequency reuse and higher base station capacity

- Reduced overhead & higher spectral efficiency

- Higher number of BW allocation/request opportunities per frame

- Supports lower-latency bandwidth allocations for multiple users

- Scalable, K logical BW allocation/access channels per 1 physical channel where K is proportional to the number of antennas M.

3.1   AAS Method 1 – Diversity-Map Signaling

The purpose of the AAS-DLFP is to provide a robust transmission of the required base station parameters to enable SS initial ranging and access requests, as well as SS paging and access allocation. This is achieved through using the most robust form of modulation and coding (namely QPSK-1/2 rate, 2 repetitions) together with redundant transmission that exploits beamforming diversity.

The AAS-DLFP supports the ability to transmit MAP IE's that carry compressed DL or UL allocations. These allocation messages can be used to "page" an SS who cannot receive the normal DL-MAP or UL-MAP. Once the initial allocations are provided to the user, private DL-MAPs and UL-MAPs can be sent on a beamformed transmission to the user at the highest modulation and lowest coding rate that can be supported by the link. The uplink initial ranging allocation for AAS subscribers can be indicated by the compressed UL MAP IEs.

3.1.1   Proposed Text Changes

[Delete section 6.3.2.3.41 "AAS Beam Select Message" in IEEE802.16-REVd/D4.]

[Replace Section 8.4.4.7 "Optional Active DL AAS Scan" in IEEE802.16-REVd/D4 with the following section.]

8.4.4.7 AAS frame structure

The two highest numbered subchannels of the downlink frame may be dedicated at the discretion of the base station for AAS diversity map zone. When these subchannels are used for this purpose, they should not be allocated in the normal DL MAP message and shall be used only on the AAS portion of the downlink subframe. These subchannels will be used to transmit the AAS-DLFP in the AAS Diversity Map Zone as shown in Figure 1. The AAS-DLFP is transmitted with a known modulation and coding, namely QPSK ½-rate with 2 repetitions.

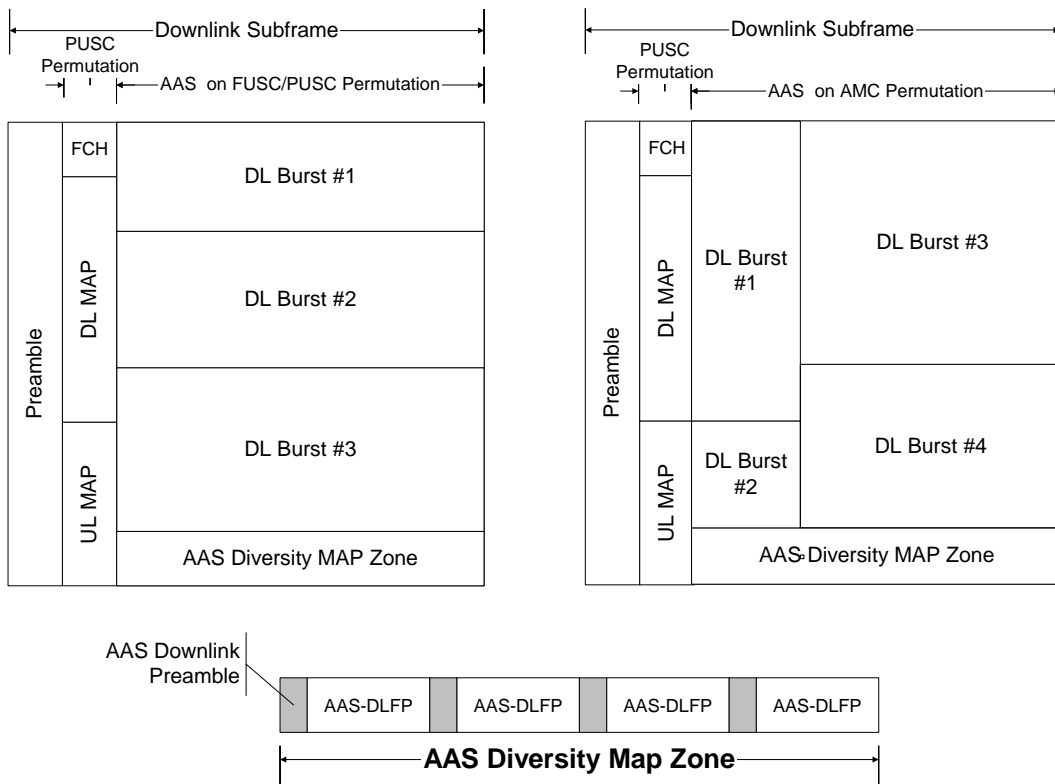Figure 1 below shows the DL subframe for these two variations.

Figure 1: AAS Diversity Map Frame Structures

The AAS Diversity Map Zone shown in Figure 1 will carry repeated transmissions of the AAS downlink preamble and the AAS-DLFP. The AAS-DLFP carries information on the frame number, UCD, DCD, and other AAS specific parameters. It also carries two compressed AAS map IEs, either uplink or downlink maps. Table 1 provides the AAS-DLFP structure. The compressed map IEs can point to broadcast allocations that carry information such as the DCD or UCD messages, normal DL MAP or UL MAP messages, or UL allocations for initial ranging, or initial bandwidth allocations for specific CIDs.

Table 1. AAS-DLFP Structure, Diversity-Map Signaling

Syntax	Size	Notes
AAS-DLFP() {		
BSID	4 bits	Lowest 4 bits
Frame_Number	4 bits	4 LSBs of Frame Number field as specified in Table 246
UCD_Configuration_Change_Count	1 bits	LSB of UCD Change Count value as specified in 6.4.2.3.3
DCD_Configuration_Change_Count	1 bits	LSB of DCD Change Count value as specified in 6.4.2.3.1
AAS beam direction index	6 bits	This index shall correspond to the direction the AAS beam is pointing at, if such a direction can be defined. The range of angles of the AAS element should be linearly covered by the range 0-63 of this field.
AAS_Comp_IE()	52 bits	
AAS_Comp_IE()	52 bits	
HCS	8 bits	An 8-bit Header Check Sequence
}		
Total	16 bytes	

Table 2. Structure of AAS_COMP_IE ()

AAS_COMP_IE() {		
Dir	1 bit	Allocation direction: Dir = '1' means DL
If (Dir == '1'){		
AAS_COMP_DL_IE()	51 bits	Compressed DL Map
} else {		
AAS_COMP_UL_IE()	51 bits	Compressed UL Map
}		

}		

Table 3. Structure of AAS_COMP_DL/UL_IE ()

AAS_COMP_DL/UL_IE() {		
CID	16 bits	
DIUC/UIUC	4 bits	DIUC for DL and UIUC for UL
OFDMA Symbol Offset	10 bits	
Subchannel offset	6 bits	
No of OFDMA Symbols	8 bits	
No of Subchannels	6 bits	
Preamble presence	1 bit	0 = No preambles precede the AAS burst allocation 1 = A preamble precedes the AAS burst allocation
Total	51 bits	
}		

8.4.4.7.1 AAS Downlink Preamble

The AAS-DLFP is preceded by a preamble. This preamble is as described in Section 8.4.6.1.1. In addition, the "Preamble Presence" bit of the AAS_COMP_DL_IE indicates the presence of a preamble on any downlink allocation made by the DLFP. The preamble in this case will be as defined in section 8.4.6.1.1.

8.4.4.7.2 AAS Uplink Preamble

The "Preamble Presence" bit of the AAS_COMP_UL_IE indicates the presence of a preamble on any uplink bandwidth allocation made by the DLFP. The preamble in this case will be as defined in section 8.4.6.1.1.

[Modify the following DL and UL MAP definitions to include the specification of additional uplink or downlink preambles]

[In section 8.4.5.3, add the following entry following the "No. Subchannels" field to Table 248, together with the descriptive text]

Preamble presence	1 bit	0 - no preamble 1 - preamble present

Preamble presence
        Indicates the presence of a preamble at the beginning of the DL burst described by this allocation. This preamble is as defined in section 8.4.4.7.1.

[In section 8.4.5.4, add the following entry following the "UIUC" field in Table 256 together with the descriptive text]

Preamble presence	1 bit	0 - no preamble
		1 - preamble present

Preamble presence
      Indicates that the SS should send a preamble at the beginning of the UL burst. This value must be set to zero for UIUCs not equal to 1-10.

[Modify the table in section 11.8.3.7.2 and 11.8.3.7.3 as follows to support definition of the two AAS modes]

11.8.3.7.2 OFDMA SS demodulator
This field indicates the different demodulator options supported by a WirelessMAN-OFDMA PHY SS for downlink reception. This field is not used for other PHY specifications. A bit value of 0 indicates "not supported" while 1 indicates "supported."

Type	Length	Value	Scope
151	1	Bit #0: 64-QAM Bit #1: BTC Bit #2: CTC Bit #3: STC Bit #4: AAS Diversity Map Signaling Bit #5: AAS Direct Signaling Bit #6-7: *Reserved*	SBC-REQ (see 6.3.2.3.23) SBC-RSP (see 6.3.2.3.24)

11.8.3.7.3 OFDMA SS modulator

This field indicates the different modulator options supported by a WirelessMAN-OFDMA PHY SS for uplink transmission. This field is not used for other PHY specifications. A bit value of 0 indicates "not supported"while 1 indicates "supported."

Type	Length	Value	Scope
152	1	Bit #0: 64-QAM Bit #1: BTC Bit #2: CTC Bit #3: AAS Diversity Map Signaling Bit #4: AAS Direct Signaling Bit #5-7: *Reserved*	SBC-REQ (see 6.3.2.3.23) SBC-RSP (see 6.3.2.3.24)

3.2   AAS Method 2 – Direct Signaling Method

[Add this text as sec 8.4.4.8]

The purpose of the AAS-DLFP2 using the direct signaling method is to provide a robust transmission of the basic base station parameters to enable AAS SS initial ranging and access requests. Once initial ranging is successful, the SS is provisioned with AAS signaling and training codes that provide the mechanism to adapt the antenna arrays at the base station (and SS). The SS can then receive compressed DL-Map and UL-Map messages from the base station with the required antenna array gain. Additionally, Method 2 provides multi-user beamforming in K spatial channels (where K < M antennas) that transport private access requests and private bandwidth allocations.

The AAS-DLFP2 message is sent in the BW allocation/access channel. This channel is constructed by using paired partitions in the frame. A partition is defined as a region that is 1 bin x J symbol slots where J is the number of symbol slots in a frame and an AMC bin is 9 adjacent subcarriers as defined in Figure 227. Only the transfer of basic base station parameters is conducted without beamforming using the most robust form of modulation and coding (namely QPSK-1/2 rate) together with redundant transmission that exploits spatial/spectral beam diversity.

Method 2 supports the ability to transmit UL and DL MAPs simultaneously to multiple users on the BW allocation/access channel and to provide lower latency, direct AAS paging method described in the following text once these maps are received. The direct method provides the capability to start multiple data flows per frame in multiple regions of the frame over K spatial channels per region.

3.2.1   Method 2 Framing

[Add this text as sec 8.4.4.8.1]

At least one BW allocation/access (BWAA) channel is allocated in the TDD AAS frame for network entry, ranging, bandwidth request, and AAS MAP communications. One BWAA channel is shown in Figure 3. Up to 4 of these channels may be provisioned as indicated in AAS-DLFP2. The location is identified in the UL-MAP as Initial-Ranging (UIUC=12), but shall be marked by an AAS initial ranging CID to ensure that no non-AAS subscribers use this region for initial ranging. The channel is formed using the first and last partition in the frame to improve channel reliability and SINR through beamforming and diversity combining methods. In the case that multiple BW allocation/access channels are specified, the first channel shall be constructed from the first partition and the partition indexed by P-(Nac-1) where P is the number of partitions and Nac is the number of BW allocation/access channels provisioned. AAS with FDHC (section 8.4.8.3) is used as the combining method on the BWAA channel. The channel is power boosted.

At least one BW allocation/access channel is provisioned per RF channel. In addition, sectorized base stations provision at least one BWAA channel per sector. For the case where the RF band has been divided into sub-bands, at least one BWAA channel is provisioned per sub-band.

The BW allocation/access channel is contention based. If collisions occur, SSs use the random back-off algorithm to randomize retry timing per section 6.3.8. By using the

signaling methods described below, an AAS base station is able to spatially separate K subscriber stations on the BWAA channel.   This minimizes contention and linearly increases the number of logical BW allocation/access channels in proportion to the number of antennas used in the antenna array.
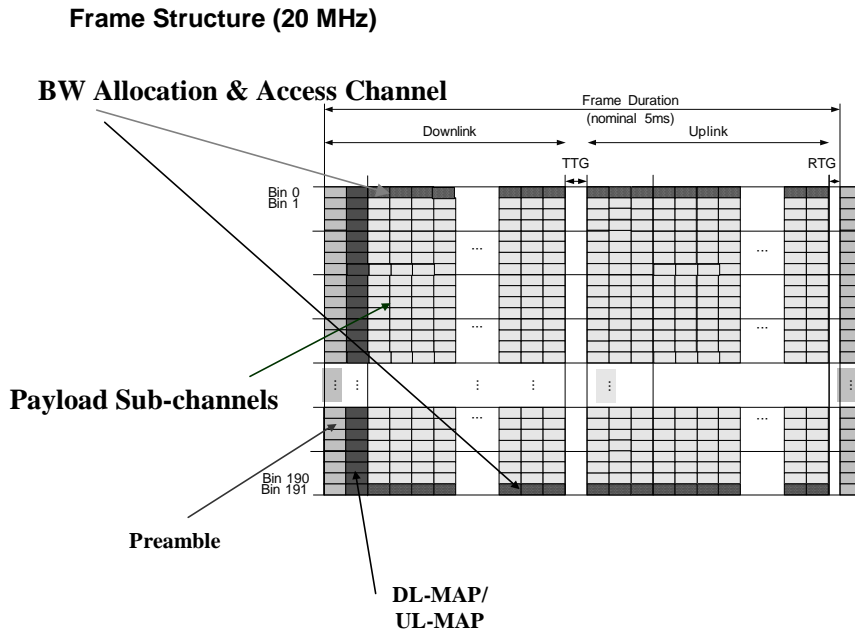

Figure 3   Frame Layout in the AAS Region

The structure of the BW allocation/access channel is illustrated in Figure 4.   In this figure, the two partitions forming the BW allocation/access channel are shown.   This channel immediately follows the FUSC/PUSC DL and UL Map region in the downlink frame and is identified uniquely by the AAS AMC preamble.   The channel shows a DLFP zone using 4th-order beam-pattern diversity and a payload region of 6 sub-channels for the frame duration illustrated by this example. Two AAS control signals are also shown (FLI and FLT) which will be described the text below.   Table 4 provides the AAS-DLFP2 data structure.   This six byte data structure is repeated four times.   It provides the necessary information for initial ranging and for reception of the initial ranging response messages to included the basic CID.   This CID maps one-to-one into the Reverse Link Training (RLT) sequence index.   The RLT is transmitted by the SS and is used to adapt the base station array.   The data sub-channels shown in Figure 4 support the compressed DL_MAP and UL_MAP messages per the format in Table 1, 2 and 3 above.
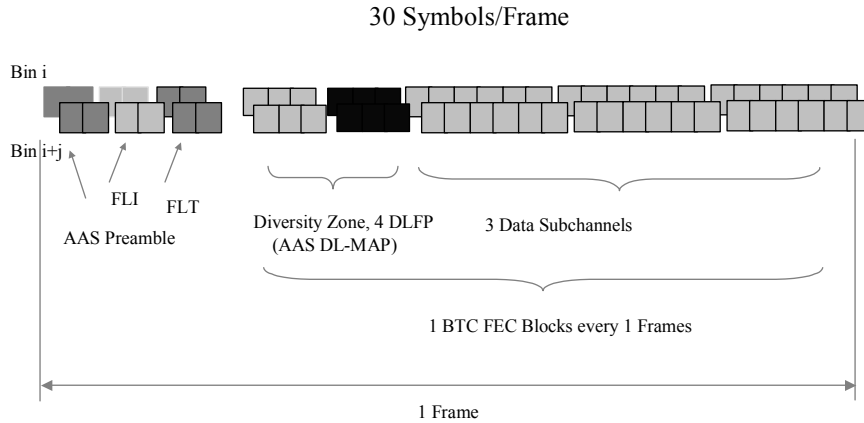
Access/SICH Partition

30 Symbols/Frame

Figure 4   Downlink BW Allocation/Access Channel

Table 4   AAS-DLFP2 Structure, Directed Signaling

Syntax	Size	Notes
AAS-DLFP2 () {		
Frame_Number	4 bits	4 LSBs of Frame Number field as specified in Table 200
Base Station ID	4 bits	4 LSBs
Multi-Frame	2 bits	00 = 1 frame per multi-frame 01 = 2 frames per multi-frame 10 = 4 frames per multi-frame 11 = reserved
Uplink_Training_Config	2 bits	00 – 1x4 Training sequence 01 – 2x2 Training sequence 10 – 2x4 Training sequence 11 – 1x8 Training sequence
Downlink_Paging _Config		0x – 1-FLI Paging sequence 1x – 2-FLI Paging sequence
AMC Subchannel Definition		x0 – 1 bin x 6 slots sub-channel x1 – 2 bins x 3 slots sub-channel
Number of Access/DLFP Channels	2 bits	00 – 1 Channels 01 – 2 Channels 10 – 3 Channels 11 – 4 Channels
Initial Access Codes	4 bits	

Syntax	Size	Notes
BS_EIRP+ EIRxP$_{Irmax}$	2 bytes	
BW Allocation	1 bit	0 = UL/DL map only 1 = UL/DL map w/ direct signaling
HCS	1 byte	
Spare	5 bits	
}		
Total	6 bytes	1 subchannel, QPSK rate 1/2

3.2.2 TDD Framing

[Add this text as sec 8.4.4.8.2]

In the informative text that follows which describes this signaling, the example AAS system a frame duration of 5 milliseconds and 48 OFDMA symbols per frame. The frame contains 192 bins x 48 symbols slots for the 20 MHz RF channel described here. It is assumed for illustration purposes that 33 symbols are allocated to the forward link and 15 symbols are allocated to the reverse link resulting in 2 to 1 asymmetry (as determined by the base station) in the forward and reverse link rates. An AAS sub-channel is defined as six consecutive bins in time (1 bin x 6 symbol slots). An alternate AAS sub-channel defined as a 2 bins x 3 symbols cluster is also supported as defined in the AAS-DLFP2. Mandatory CC coding and optional BTC or CTC FEC is supported by this frame structure. Figure 3 illustrates an AAS frame comprised of a forward and reverse link data area, the downlink preamble, map area and dedicated BW allocation/access channel.

3.2.3 Reverse Link AAS Control Signals

[Add this text as sec 8.4.4.8.3]

The reverse link partition in the TDD RL sub-frame is shown in Figure 5 for one of P (P=192 for 20 MHz) partitions. The reverse link in this example provides 15 symbol slots and is organized as two AAS sub-channels. One of the 2 AAS sub-channels contains one AAS reverse link control signal that is transmitted once every multi-frame. A multi-frame is 1, 2, or 4 frames.

Two physical layer control signals are defined for the reverse link. The first is a reverse link training (RLT) signal, which allows a SS to send an AAS training signal to the base for a given sub-channel. The RLT provides the time-bandwidth product necessary to adapt up to 12 antennas at the base station. The RLT signal shall occur at the beginning of the reverse link frame as shown in Figure 5 and is sent alternately every frame, every other frame or every fourth frame as provisioned by the "multi-frame parameter" in the AAS-DLFP2. MAC messages or traffic data are sent after the RLT in the first data sub-channel and in subsequent sub-channels thereafter also shown in Figure 5. The RLT occupies a maximum of 8 symbol slots per partition providing 64 QPSK symbols for base station training. When used with fewer antennas, the RLT may be set to 32 QPSK symbols spanning 4 symbol slots to minimize training overhead. In addition, the RLT symbol sequence may span two adjacent bins. Accordingly, supported RLT cluster configurations are 1 x 8, 1 x 4, 2 x 4, and 2 x 2 (bins x symbol slots).

Reserved for Future Use

RLI (8 Symbols)
w/ Ranging

1 Subchannel

2 Subchannels

1 Frame

1 BTC FEC Block or 3 RS-CC FEC Blocks per 2 Frames
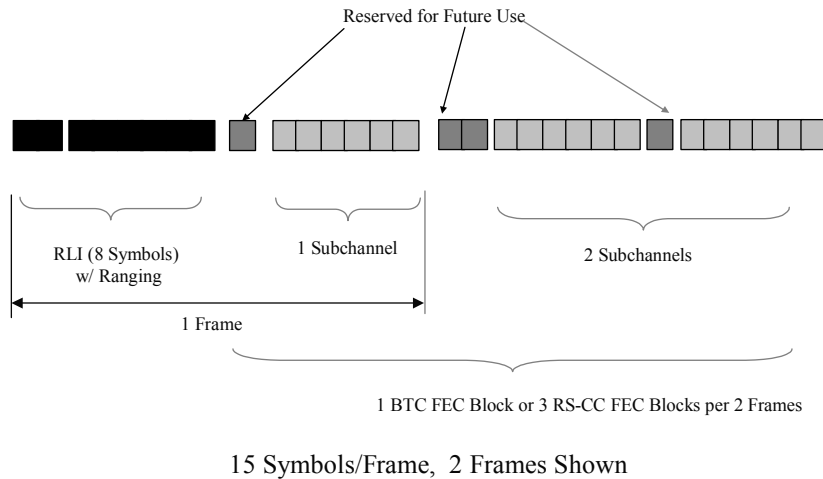
15 Symbols/Frame, 2 Frames Shown

Figure 5   Reverse Link AAS Sub-Frame Structure Showing RLT Signaling

The second control signal is the reverse link access (RLA) signal. The SS uses the RLA to train the base station antenna array on the BWAA channel. The RLA is sent ahead of the BW request message to inform the base that it has information to send on the uplink. The reverse link access partition is identical to the traffic partition shown in Figure 5 and the RLA sequence is identical to the RLT. The base in turn, with coordination through its scheduling mechanism, sets up traffic sub-channels using map allocations followed by direct forward link control signaling as described below if enabled.

3.2.4   Forward Link AAS Control Signals

[Add this text as sec 8.4.4.8.4]

The forward link partition is shown in Figure 6 for one of 192 partitions. The forward link partition in this example provides 33 symbol slots and is organized as five AAS sub-channels. One of the 5 AAS sub-channels contains three forward link control signals of two types applied once every multi-frame.

There are two types of AAS control signals used by the forward link. The first is the forward link initiation (FLI) signal. The FLI signals to the SS to initiate communications on traffic sub-channels. This "paging" and "link initiation" signal is shown for the downlink frame structure shown in Figure 6 and has coding unique to a SS. One or two FLI signals are provisioned per AAS signaling sub-channel in every multiframe frame. Each FLI signal modulates 16 tones (1 bin x 2 symbol slots) with 16 QPSK symbols. The FLI provides 12 dB (or 15 dB with soft combining) of processing gain to signal subscriber stations without directed beam steering knowledge.
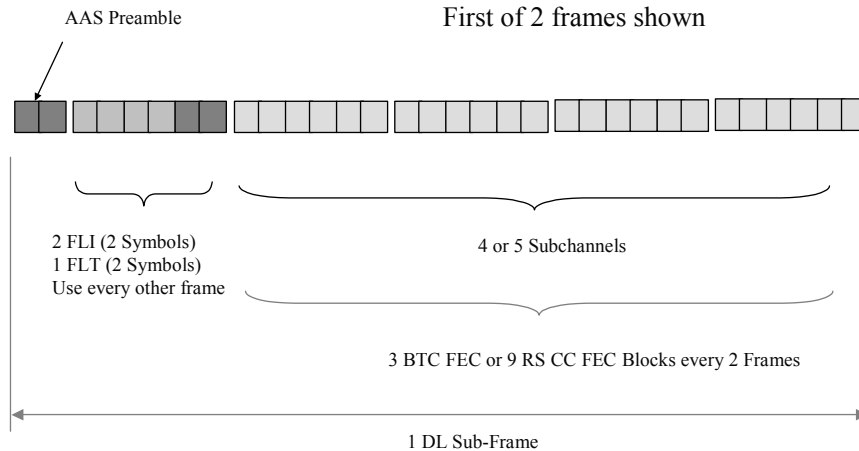
Figure 6   Forward Link Sub-Frame Structure showing FLI and FLT Signaling

The forward link training (FLT) signal opportunity occupies the 2 bins located after the two FLI opportunities. The FLT transmits a known training sequence unique to the SS so that an SS can estimate and update the vector channel response. The FLT is sent in TDD systems with full beamforming gain. Multiple SSs may be trained on the same sub-channel during the same time slot.

3.2.5   Forward and Reverse Link Bandwidth Request/Grant, Ranging

[Add this text as sec 8.4.4.8.5]

If the RU is not yet ranged with the base station and hence, does not know the proper timing for reverse link transmissions, it randomly chooses an initial ranging access code, sends a RLA signal, detects a FLI response from the base, then adjusts its delay and transmit power based iteratively until an FLI is detected with maximum strength. This process is repeated until the best delay and transmit power have been identified. Once this has been accomplished, other periodic ranging mechanisms manage the transmit window time. The RU uses the RSS derived from forward link preamble measurements and the Base Station EIRP to set its initial transmit power level during initial ranging.

3.2.6   PHY Layer Control Signal Sequencing

[Add this text as sec 8.4.4.8.6]

Having defined the control signaling above, the controlling sequences can now be described. The AAS physical layer is controlled via the signaling sequences described below. Table 5 provides a list of sequence actions keyed to the sequence diagram shown in Figure 7. For the first case, we consider a base station initiated data flows subsequent to the receipt of the DL_MAP and UL_MAP.

Table 5   Base Initiated Data Flows

The base station uses the assigned SS access code to open sub-channel(s) to a SS:

1. Base station sends the FLI of the SS being addressed in the intended sub-channel(s).

2. SS looks for its assigned FLI in all sub-channels. When it receives a FLI in a sub-channel , it starts transmitting its RLT in the next reverse link time slot, followed by data in the sub-channel.

3. When base station receives the RLT, it performs the necessary training for both RL and FL directions. A beam is formed and the link is established.

4. Base station transmits FLT in forward link time slot and user data in the subsequent sub-channel

5. The (RLT+Data, FLT+Data) exchange continues as long as the sub-channel is open. The absence of the FLT terminates the exchange.

6. When the exchange stops, the SS stops transmitting RLT.   -

The diagram on the left side of Figure 7 also illustrates the directed SS initiated connection. In this case an RLA at step 0 is sent to the base station. The base station responds with a map allocation on the BWAA channel and FLIs and data in the appropriate data regions. The control sequence then is identical to the base initiated connection.
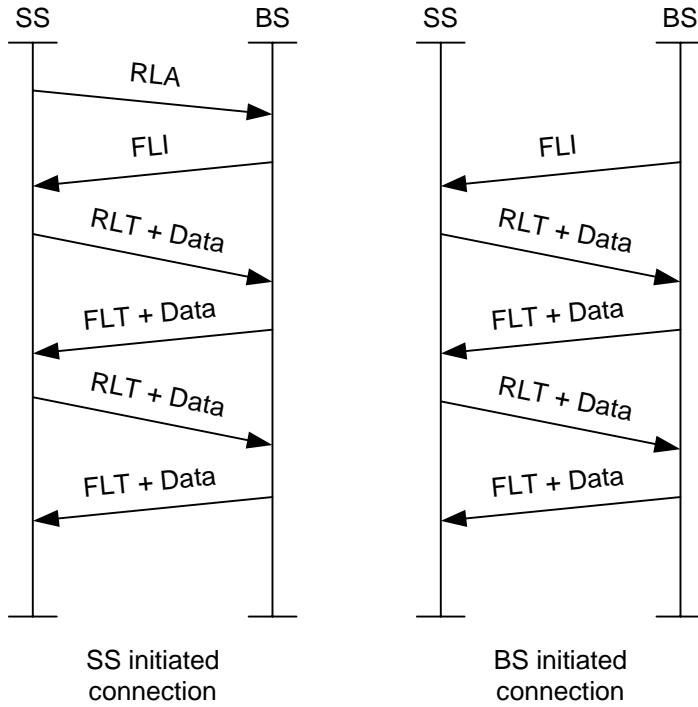
Figure 7   PHY Control Signal Sequence Diagrams

3.2.7   Granularity

[Add this text as sec 8.4.4.8.7]

In the illustrated multi-frame structure, a SS is allocated a continuous set of AAS sub-channels spanning 2 frames (10 msec). The following table tabulates the granularity of bandwidth allocation in this scenario with forward and reverse link asymmetry parameter set to 50%.

Table 7 Bandwidth Granularity with AAS and AMC sub-channels

Modulation Scheme	Bytes/Sub-Channel	Bytes/10 msec (50% asymmetry)
QPSK ½	6	36
QPSK ¾	9	54
16QAM ½	12	72
16QAM ¾	18	108
64QAM ½	18	108
64QAM 2/3	24	144
64QAM ¾	27	162

3.2.8   AMC Sub-channel Definition

[Add this text as sec 8.4.4.8.8]

The AMC sub-channel shall be defined as a region of 1 bin x 6 symbol slots or 2 bins x 3 symbol slots as configured in the AAS-DLFP2. The UL-MAP and DL-MAP IEs shall specify 192 (8 bits) bin locations in the frequency domain.

3.2.9   PHY Control Signaling and Coding Structure

[Add this text as sec 8.4.4.8.9]

The following paragraphs described the details of the AAS control signals.

3.2.9.1   RLT and RLA code properties

The properties of these signals are as follows:

- Provides a spatial training sequence for up to 12 antennas with the appropriate time bandwidth product

- Provides unique SS identification at the base station. Both signals are detected with beamforming gain

- Provides a fine ranging structure within the symbol modulation

- 8064 codes are available based on 64 symbols

- High probability of detection, low false alarm rate consistent with modest cross-correlation properties between assigned codes at various code delays

- The same codes may be re-used multiple times at the base station if sectors or sub-bands are used

- Robust code reuse factor of 4 between base stations. Further code de-correlation occurs for distance base stations due to base station to base station range differences

- The base station can separate multiple SS on the access sub-channel using different RLAs

3.2.9.2   RLT and RLA code construction

The RLT and RLA PHY control signals shall be based upon a compact 64 QPSK symbol message constructed from Hadamard sequences. The RLT and RLA shall be sent in the first symbol slots of the reverse link sub-frame. Each SS registered to a base is assigned a unique training & access code (RLT or RLA). The code index shall have a one-to-one mapping with the basic CID. The RLT and RLA code construction is identical. The RLT/RLAs shall be inserted into AAS partitions only at the start of the multi-frame in the zeroth frame number of the zeroth partition and in the first frame of

the first partition, etc. until the pattern repeats. The Multi-frame is defined in the AAS-DLFP2.

The access code may be reused from sub-band to sub-band or reused from sector to sector. Thus, within a given sub-band or sector, each SS has its own unique access code. There are a maximum of 8064 access codes. The access codes, $a = 2016t + c$, are divided into four equal sets; $0 \leq t < 4$, where t is the base descriptor code. Each set of 2016 access codes are divided into three types with each type allocated a certain number of access codes: there are 2000 traffic access codes, c, for assigned SSs: $0 \leq c \leq 1999$, there are 8 access codes, c, for SS initial registration: $2000 \leq c \leq 2007$, and there are 8 access codes, c, for SS initial ranging: $2008 \leq c \leq 2015$.

RLT and RLA codewords are based on Hadamard basis functions. RLTs and RLAs are described by an access index, a, $0 \leq a < 8064$. A codeword, $\mathbf{p}_{i_1 i_0}$, contains 64 QPSK symbols and has in-phase and quadrature components taken from the columns of a 64 by 64 Hadamard matrix,

$$\mathbf{p}_{i_1 i_0} = A\mathbf{F}_1\mathbf{h}_{i_1} + jA\mathbf{F}_1\mathbf{h}_{i_0}, \quad i_1 \neq i_0$$

$$\mathbf{p}_{i_3 i_2} = A\mathbf{F}_2\mathbf{h}_{i_1} + jA\mathbf{F}_2\mathbf{h}_{i_0}, \quad i_3 \neq i_2$$

where,

$\mathbf{h}_{i_1}$ and $\mathbf{h}_{i_0}$ are different columns from the Hadamard matrix, A is an amplitude scaling factor and $\mathbf{F}_1$ and $\mathbf{F}_2$ are toggling matrices. The indices i_3, i_2, i_1 and i_0 select a particular RLT code. For a given access index, a, the zero-based column indices are,

$$i_1 = \mathrm{mod}(a, 64)$$

$$i_0 = \mathrm{mod}\left(\lfloor a/64 \rfloor + i_1 + 1, 64\right).$$

For two given column indices, the access code is,

$$a = 64\,\mathrm{mod}\left(i_0 - i_1 + 63, 64\right) + i_1.$$

3.2.9.3   FLI and FLT code properties

The FLI and FLT control signals are based upon a compact 16 QPSK tones (8 tones/symbols, 2 symbols) message constructed from Kronecker products. The properties of these signals are as follows:

- The FLT provides a vector channel training sequence for up to 4 degrees of freedom with the appropriate time bandwidth product.

- The FLT are multi-user directed transmissions and benefit from beamforming gain

- The FLT and FLI are uniquely coded and assigned to the SS by the base station.

- 8064 codes are available based on 16 tones (8 tones/symbol, 2 symbols)

- High probability of detection, low false alarm rate consistent with modest cross-correlation properties between assigned codes at various code delays

- The same codes may be re-used multiple times at base station if sectors or sub-bands are used

- Robust code reuse factor of 4 between base stations. Code de-correlation occurs for distance base stations due to base station to base station range differences

- The FLI does identify which base is sending the FLI via recognition of the base descriptor code.

3.2.9.4   FLI and FLT code construction

Each SS registered with a base is assigned a unique link initiation and training code (FLI or FLT). Coding is the same for the FLI and FLT. There is a one-to-one mapping between the basic CID and FLI/FLT index. One or two FLI opportunities, as specified in the AAS-DLFP2, shall follow the AAS preamble in each partition. The FLT opportunity shall follow the last FLI. The FLI/FLTs shall be inserted into AAS partitions only at the start of the multiframe in the zero indexed frame number of the zero indexed partition and in the first indexed frame of the first indexed partition, etc. until the pattern repeats. The Multi-frame is defined in the AAS-DLFP2.

The modulation on each tone of a FLI message is QPSK and thus can be represented by two bits of information. Each FLI message is described in a compact format by 32 bits: 16 tones by 2 bits per tone. A table can be used to represent these compact codewords. Table 8 lists Matlab that can be used to convert a compact codeword into an FLI modulation sequence.

Table 8. Matlab code to generate forward link codewords.

```
In the FLI codeword directory:

fli_new_codes.m   makes   the   compact   codeword   and   outputs   it   to
   fli_new_codes_cx_results.m.   This takes about 28 hours to find a compatible
   set of codewords.
fli_new_sort.m orders the codewords so that the best set consists of those with
   a   small   access   code.    The   sorted   compact   codeword   table   is
   fli_new_codes_cx_sorted.m
make_fli_new.m is a matlab routine that returns a specific FLI codeword vector
   from an existing compact codeword table, fli_new_codes_cx_sorted.m
```

A compact HEX file of FLI codewords will be attached here generated by the MATLAB script supplied here.

3.2.9.5   AAS preamble

The AAS preamble defines the AAS sub-region of the downlink sub-frame and shall be inserted as the first two symbol slots of the AAS partition as shown in Figure 4. The AAS preambles are based upon a compact 16 BPSK data symbol modulating the subcarriers in two adjacent AMC bins and is constructed by adaptively optimizing sequences based on the properties listed below:

- The AAS preamble provides a preamble structure permitting SSs to rapidly acquire frequency, time, and frame, and multi-frame synchronization with the base station

- The AAS preamble shall be placed at the beginning of the AAS region

- The AAS preamble codewords are selected so as to maximize the probability that the SS would lock onto the correct base, at the correct multi-frame sequence, and the correct frequency.

- The AAS preamble provides a preamble sequence with up to K ($4 <= K <= 8$) degrees of freedom to enhance SINR and reduce interference via adaptive combining.

- The pattern of AAS preamble codewords is unique within a multi-frame, and repeats from multi-frame to multi-frame.

- The AAS preamble transmission uses a random space/frequency weight vector. Each AAS preamble coding cluster, defined as a 2 x 2 cluster of adjacent bins uses a different weight vector in the same time epoch.

- 12 unique AAS preamble sequences indexed by base ID code are available

- Robust code reuse factor of 12 between base stations.

3.2.9.6   AAS preamble construction

The AAS preamble is a constant modulus BPSK code unique to a given base station defining the AAS region of the frame. The code uses nonlinear phase construction and is uncorrelated to the codes used by the other bases.   Furthermore, the codeword in the second AAS preamble symbol slot does not resemble a complex scalar multiplying the codeword in the first AAS preamble symbol slot. The code is split into two codewords for the two AAS symbol slots in a forward link. Each length 16 codewords modulates the data subcarriers in two adjacent bins (a bin pair).

The 32-element vector containing the code is multiplied by a pseudo random complex scalar for each of the K spread AAS preamble bin pairs. For each AAS preamble bin pair, the resulting 32 complex gain elements are split between the consecutive AAS symbol slots. The AAS preamble of the first symbol slot has the first 16 complex

elements and the AAS preamble of the second symbol slot has the second 16 complex elements. The base then transmits the code over the assigned AAS preamble bins pairs.

An AAS base selects random transmit weight vectors for AAS preambles for each bin pair and spreading location. Each element of each transmit weight vector has the same amplitude and a randomly selected phase. The random number generator use at one base is not be correlated with or have the same repeat period as the generator of another bin pair of any base with a different base offset code.

Every base uses a particular set of AAS codewords. The base offset code associated with the base forms part of the AAS codewords used by that base. AAS codeword sequences, like the base offset codes, may be reused every 12 cells.

The table and matlab script below generate the AAS preamble.

```
function AAS = make_AAS(base, superframe)
% function AAS = make_AAS(base, superframe)
% Synthesize a scaled 16 by 1 AAS codeword.
% base is the base offset code and varies from 0 to 11
% superframe is the slot sequence number and varies from 0 to 11

AAS_super_results_12 % read in the codeword descriptor array

t = zeros(Nt,1);
for jj=1:Nt
   t(jj) = 2^(jj-1); % form a vector of walking ones
end

cw = codeword(base+1, superframe+1); % select codeword descriptor
bv = (bitand(cw,t) ~= 0) * 2 - 1; % make BPSK vector
    AAS = (15 + 15j) * bv; % scale the BPSK vector


% AAS_super_results_12.m
% Lower 12 bits are the base tones, upper 4 bits are the superframe tones.
% First index (row) is the base, second (column) is the superframe
codeword = [ ...
 52053 43861 11093 56149 19285  6997 47957 31573 23381 35669 27477 39765; ...
 52217 11257 15353  7161 23545 60409 39929 35833 31737 44025 27641 48121; ...
 38245 42341 13669 62821 21861 54629  9573 30053  5477 34149 50533 46437; ...
 13817 30201 26105 38393 46585 22009 54777 50681 62969 42489  5625 58873; ...
 42709 14037 30421 54997 22229 18133 59093 34517 38613  5845 50901 46805; ...
 22917 10629 59781  6533  2437 43397 51589 47493 27013 55685 39301 18821; ...
 60749 27981 56653 44365 11597 64845 48461 15693 36173 40269 32077 52557; ...
 7481 60729 48441 27961  3385 19769 52537 64825 23865 44345 56633 32057; ...
 47825 56017  2769 60113 10961 23249 51921 19153 35537  6865 39633 43729; ...
 11955 24243 32435 36531 52915 40627 57011 16051  7859 61107 48819 28339; ...
```

```
 37517 53901  4749 45709 21133  8845 33421 62093 41613 49805 12941 57997; ...
 21029 61989 12837  8741 37413 16933 57893 41509 25125 49701 45605 29221; ...
];

%  CB55 AB55 2B55 DB55 4B55 1B55 BB55 7B55 5B55 8B55 6B55 9B55
%  CBF9 2BF9 3BF9 1BF9 5BF9 EBF9 9BF9 8BF9 7BF9 ABF9 6BF9 BBF9
%  9565 A565 3565 F565 5565 D565 2565 7565 1565 8565 C565 B565
%  35F9 75F9 65F9 95F9 B5F9 55F9 D5F9 C5F9 F5F9 A5F9 15F9 E5F9
%  A6D5 36D5 76D5 D6D5 56D5 46D5 E6D5 86D5 96D5 16D5 C6D5 B6D5
%  5985 2985 E985 1985 0985 A985 C985 B985 6985 D985 9985 4985
%  ED4D 6D4D DD4D AD4D 2D4D FD4D BD4D 3D4D 8D4D 9D4D 7D4D CD4D
%  1D39 ED39 BD39 6D39 0D39 4D39 CD39 FD39 5D39 AD39 DD39 7D39
%  BAD1 DAD1 0AD1 EAD1 2AD1 5AD1 CAD1 4AD1 8AD1 1AD1 9AD1 AAD1
%  2EB3 5EB3 7EB3 8EB3 CEB3 9EB3 DEB3 3EB3 1EB3 EEB3 BEB3 6EB3
%  928D D28D 128D B28D 528D 228D 828D F28D A28D C28D 328D E28D
%  5225 F225 3225 2225 9225 4225 E225 A225 6225 C225 B225 7225
%
% Iteration 9
Nb = 12; % Number of tones in base
Ns =  4; % Number of tones in superframe sequence
Nt = 16; % Total number of tones
```