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Title	**AAS enhancements for OFDMA PHY**
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Re:	IEEE P802.16-REVd/D3-2003
Abstract	This contribution introduces AAS enhancements for OFDMA PHY as an optional feature
Purpose	Adopt into P802.16d/D4 draft.
Notice	
Release	
Patent Policy and Procedures	

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 1X scalable 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. With the introduction of the OFDMA-1X scalable PHY (IEEE C802.16d-04_50), this mechanism needs to be redefined. We present a new definition that offers significant improvements.

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 1x scalable 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 1x scalable frame structure.

An outline of this section is as follows: First is a definition of an AAS-SICH 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. 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
- Uses existing private map allocation definitions

Method #2, Direct-Signaling Method, uses the AAS-SICH to receive basic SICH overhead information and BW requests. "In band" AAS control signaling is used to page subscriber stations and to grant bandwidth. Method 2, with some requirements of additional SS processing, can provide the additional benefits of:

- Reduced overhead & higher spectral efficiency
- Supports low-latency allocations for multiple users

- Additional physical access channels are not required with growing in-cell frequency – linear scalability in number of users.

3.1 AAS Method 1 – Diversity-Map Signaling

The purpose of the AAS-SICH 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) together with redundant transmission that exploits beamforming diversity.

The AAS SICH 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.

3.1.1 Proposed Text Changes

[Add the following text to Section 8.4.3.3 to 802.16-Revd/D3]

8.4.3.3 AAS frame structure
AMC subchannels are used for uplink and downlink traffic bursts in the AAS mode. The downlink sub-frame has four dedicated bins to carry AAS-SICH. The uplink frame structure can be divided into ranging and traffic bursts. Figure 1 illustrates the AAS frame structure.

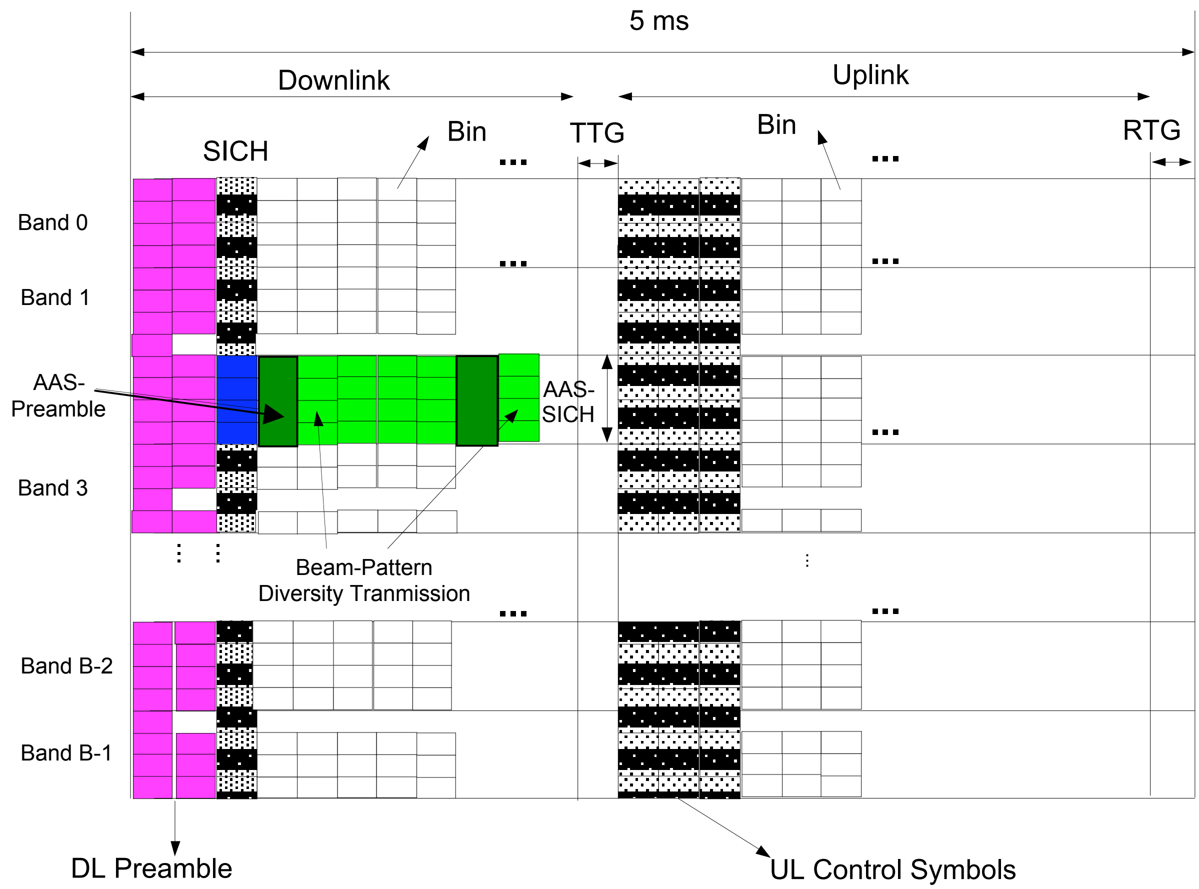


Figure 1 – Frame Structure for AAS, Diversity-Map Signaling

The downlink sub frame has the downlink preamble followed by the AAS preamble marking the start of the AAS-SICH. The downlink sub frame carries compressed UL & DL Maps. Maps are repeatedly transmitted using beam-pattern diversity throughout the downlink frame. The structure of the AAS-SICH is illustrated in Figure 2 showing a beam-pattern diversity order of 4.

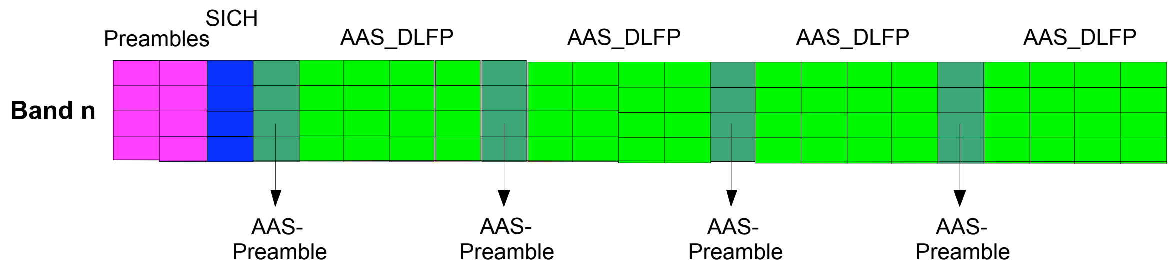


Figure 2 – Structure of AAS-SICH

[Insert a new Section 8.4.3.3.1 to 802.16-Revd/D3]

8.4.3.3.1 AAS Diversity Zone

AAS-SICH has an AAS preamble followed by the AAS-DLFP. AAS-DLFP carries information on the frame number, UCD, DCD, and other AAS specific parameters. It also carries two AAS map IEs, either uplink or downlink maps. The segment of preamble and AAS-DLFP is repeated in time to form the AAS diversity zone. Table 1 provides the AAS-DLFP structure.

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 200
UCD_Configuration_Change_Count	3 bits	3 LSBs of UCD Change Count value as specified in 6.4.2.3.3
DCD_Configuration_Change_Count	3 bits	3 LSBs of DCD Change Count value as specified in 6.4.2.3.1
Uplink_Training_Config	2 bits	00 – 2x2 Training sequence 01 – 6x1 Training sequence 10 – 2x4 Training sequence 11 – 1x8 Training sequence
Downlink_Training_Config	1 bit	0 – 1-slot preamble 1 – 2-slot preamble
Reserved	1 bit	
AAS_Comp_Map_IE()	47 bits	
AAS_Comp_Map_IE()	47 bits	
HCS	8 bits	An 8-bit Header Check Sequence
}		

Syntax	Size	Notes
Total	16 bytes	(including the tail byte)

Table 2. Structure of AAS_COMP_IE ()

AAS_COMP_IE() {		
Dir	1 bit	Allocation direction: Dir = ‘1’ means UL
If (Dir == ‘1’){		
AAS_COMP_DL_IE()	46 bits	Compressed DL Map
} else {		
AAS_COMP_UL_IE()	46 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
Allocation Start	10 bits	Allocation start in symbols with reference to the AAS preamble. The symbol after the AAS preamble is numbered #1.
Duration	8 bits	
Subchannel index	8 bits	
Total	46 bits	
}		

[Insert a new Section 8.4.3.3.2 to 802.16-Revd/D3]

8.4.3.3.2 AAS Preamble

The AAS preamble is constructed by appropriately puncturing the preamble definition given in 8.4.5.1.1 of C802.16d-04_50, using the lowest 4 LSBs of the BSID as the ID_{cell} and the parameter s=0.

8.4.3.3.3 AAS Burst Preambles

The preambles in the AAS mode for downlink bursts are the same as for non-AAS mode, concatenated in the case when the Downlink_Training_Config transmitted in the AAS_SICH specifies 2-slot preambles.

The preambles for the AAS mode in uplink can be configured to be in multiple formats, specified as **n** x **m**, where **n** is the number of bins and **m** is the number of slots. The configurations supported are 2 x 2, 6 x 1, 2 x 4, and 1 x 8.

The relevant preamble for the particular cell ID defined in C802.16d-04_50 forms a **basis** preamble to be used to specify the AAS uplink preamble. This **basis** preamble is used to fill up tones first in sequential bin order and then by slots in the AAS preamble. The extended AAS preambles (2 x 4, 1 x 8) are formed by concatenating and appropriately terminating the **basis** preamble.

3.2 AAS Method 2 – Direct Signaling Method

The purpose of the AAS-SICH using the direct signaling method is to provide a robust transmission of the basic base station parameters to enable SS initial ranging and access requests. Ranging, access requests and grants all benefit from multi-user beamforming. 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 beamforming diversity and optional frequency diversity.

This AAS SICH supports the ability to transmit UL and DL MAPs simultaneously to multiple users or to provide additional low latency, direct entry method described in the following text. The direct method provides the capability to start multiple data flows per frame.

3.2.1 Access/AAS-SICH Framing, Directed Signaling Method

[Add this text as sub-section 8.4.15.2.1 under "8.4.15 AAS Control Signaling Structure"]

At least one access/AAS-SICH partition is allocated in the TDD frame for network entry, ranging, bandwidth request, and AAS SICH communications. The access partition, shown in Figure 3, occupies one or more partitions in the frame. The location is identified by a special AAS preamble. Here, it is shown in the first bin location in the frame structure. A second partition that occupies the last bin location may be paired with the first to improve channel reliability and SINR through diversity combining methods. Either 2x spreading/despreading or space-frequency coding (SFC) maybe used as the diversity combining method. As shown, the partitions are spaced at the extremes of the RF channel to maximize the spectral diversity. The access partitions may be power boosted.

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

The access partition is contention based. If collisions occur, SSs use the random back-off algorithm to randomize retry timing. By using the coding methods described later in this document, AAS base stations are able to spatially separate subscriber stations on the access partition. This minimizes contention and linearly increases the number of logical access partitions in proportion to the number of antennas used in the AAS array.

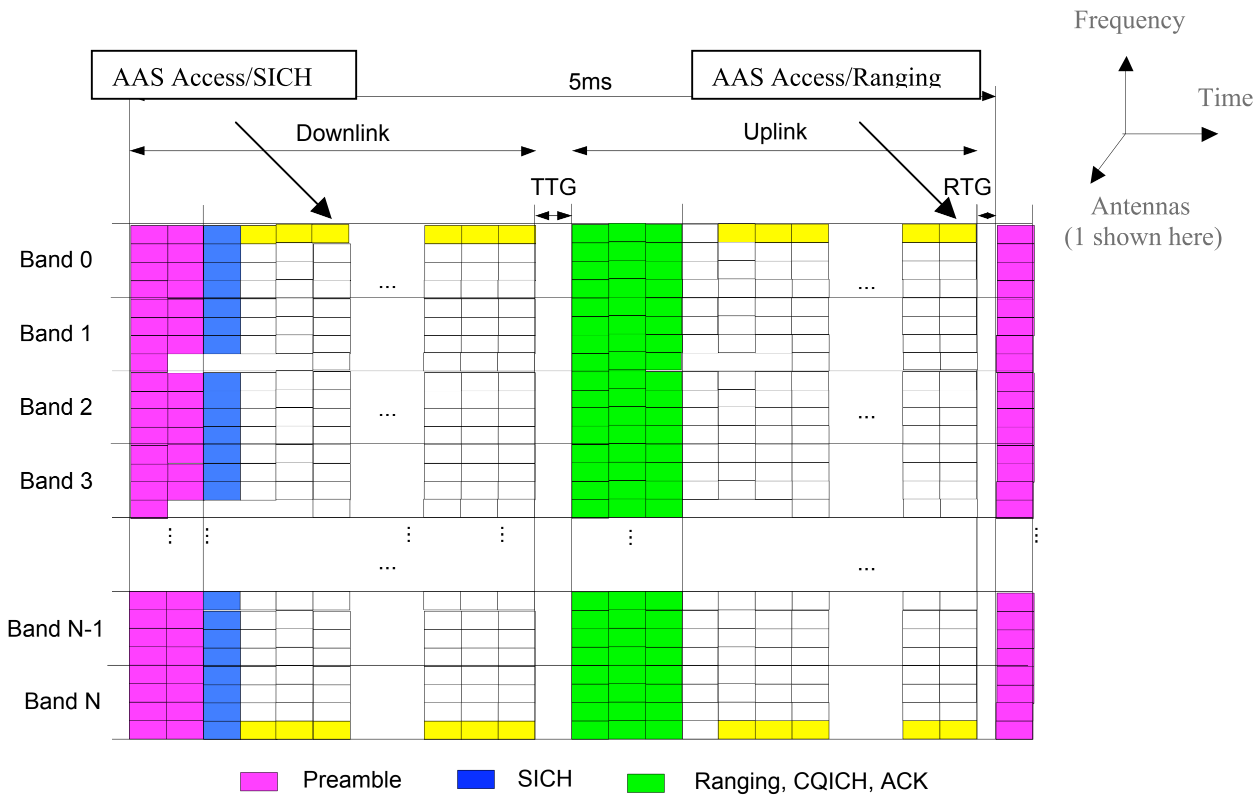


Figure 3 1x Scalable Frame Layout w/ AAS Overlay

The downlink sub-frame has the downlink preamble followed by the AAS preamble that identifies the AAS-SICH partition(s). The structure of AAS-SICH is illustrated in Figure 4. In this example, the AAS-SICH channel uses optional 2x spreading/despreading. In addition, a DLFP zone using 3rd-order beam-pattern diversity follows the AAS preamble. Table 2 provides the AAS-DLFP structure. This structure requires 2 bytes of information and is repeated efficiently using beam diversity. Two AAS control signals are also shown which will be described in subsequent paragraphs. Data transport sub-channels is also shown for maps and other information.

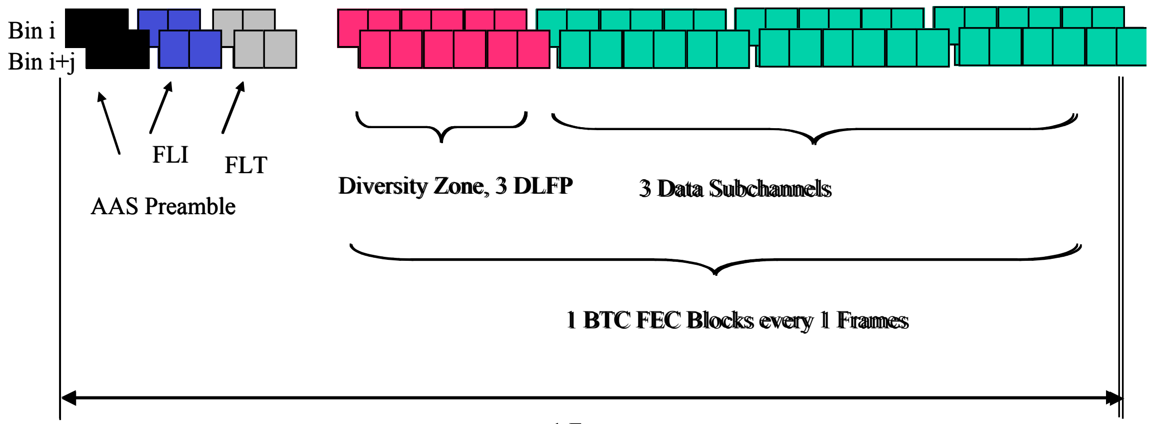


Figure 4 Downlink Access/SICH Partition

Table 4 AAS-DLFP Structure, Directed Signaling

Syntax	Size	Notes
AAS-DLFP () {		
Frame_Number	4 bits	4 LSBs of Frame Number field as specified in Table 200
Base Station ID	4 bits	4 LSBs
Uplink_Training_Config	2 bits	00 – 1x4 Training sequence 01 – 2x2 Training sequence 10 – 2x4 Training sequence 11 – 1x8 Training sequence
Downlink_Training_Config	1 bit	0 – 1-slot preamble 1 – 2-slot preamble
Access/SICH Diversity	1 bits	0 – No diversity 1 – Frequency Diversity
Number of Access/SICH Channels	2 bits	00 – 1 Channels 01 – 2 Channels 10 – 3 Channels 11 – 4 Channels
Reserved	2 bits	
}		
Total	2 bytes	

[Add a new section to IEEE P802.16-REVd/D3-2004 “8.4.15 AAS Control Signaling Structure”. Add the following text in the sub-sections provided below. An outline of this section 8.4.15 is provided here].

3.2.2 TDD Framing

[Add this text as sub-section 8.4.15.2.2 under "8.4.15 AAS Control Signaling Structure"]

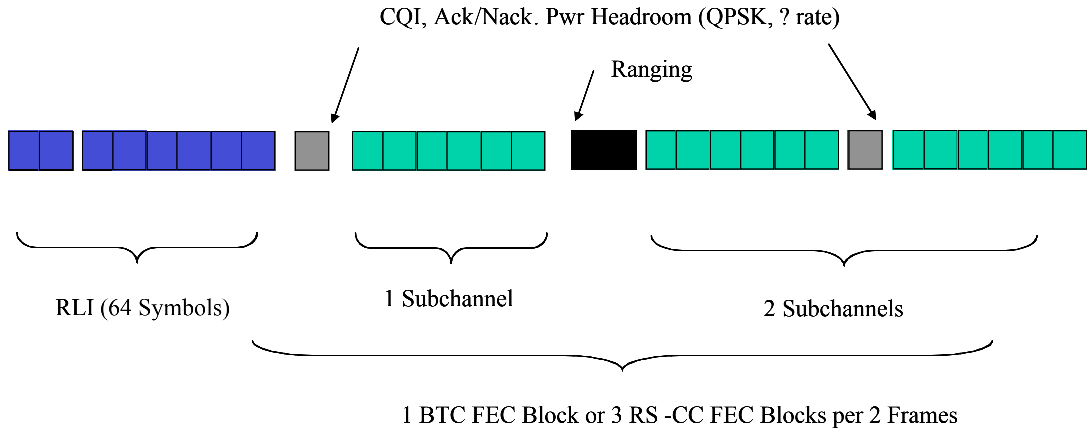
In the informative text that follows which describes this signaling, the target AAS system uses time division duplexing (TDD). The 1x scalable frame layout uses a frame time of 5 milliseconds and 48 OFDMA symbols per frame. The frame contains 84 bins x 48 symbols slots for the 10 MHz channel described here. For clarity throughout this document, a new term "partition" is used. A partition is defined as 1 bin by 48 symbol slots. It is assumed for illustration purposes that 32 symbols are allocated to the forward link and 15 symbols are allocated to the reverse link resulting in 2 to 1 asymmetry (provisioned) 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 bin x 3 symbol cluster is also supported. Mandatory CC coding and optional BTC or CTC FEC is supported by this frame structure. Figure 3 illustrates a complete frame comprised of a forward and reverse link data area, the downlink preamble, uplink control area and dedicated access partition.

3.2.3 Reverse Link AAS Control Signals

[Add this text as sub-section 8.4.15.2.3 under "8.4.15 AAS Control Signaling Structure"]

The reverse link partition in the TDD frame is shown in Figure 5 for one of K (K=84 for 10 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 signals transmitted once every multi-frame. A multi-frame is 1, 2, or 4 frames. Non-AAS systems do not send this AAS control signal.

There are two physical layer control signals for the reverse link. The first is a reverse link initialization (RLI) signal, which allows a SS to send an AAS training signal to the base for a given sub-channel. The RLI provides the time-bandwidth product necessary to adapt up to 12 antennas at the base station. The RLI signal occurs at the beginning of the reverse link frame as shown in Figure 1 and is sent alternately every frame, every other frame or every fourth frame as provisioned by the "multi-frame parameter". Map and traffic data are sent after the RLI in the first sub-channel and in subsequent sub-channels thereafter also shown in Figure 1. The RLI occupies a maximum of 8 bins by 8 tones (9 tones with pilot) per bin providing 64 QPSK symbols for base station training. When used with fewer antennas, the RLI may be set to 32 QPSK symbols and 4 bins to minimize training overhead. In addition, the RLI symbol sequence may span two adjacent bins. Accordingly, supported RLI cluster configurations are 1 x 8, 1 x 4, 2 x 4, and 2 x 2. When adjacent RLI bins are provisioned, user data in following sub-channels shall span the longest training interval (8 symbol slots).



15 Symbols/Frame, 2 Frames Shown

Figure 5 Reverse Link AAS Frame Structure Showing RLI Signaling

The second control signal is the reverse link access (RLA) signal. The SS uses the RLA 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 1. SSs use the RLA signal mechanism for sending supervisory messages such as bandwidth requests and signaling for initial ranging. The base in turn, with coordination through its scheduling mechanism, sets up traffic sub-channels using forward link control signaling, either an FLI or FLA as described below.

3.2.4 Forward Link AAS Control Signals

[Add this text as sub-section 8.4.15.2.4 under “8.4.15 AAS Control Signaling Structure”]

The forward link partition is shown in Figure 3 for one of 84 bins. The forward link partition in this example provides 33 or 32 symbol slots and is organized as five AAS sub-channels. One of the 5 AAS sub-channels contains three forward link control signals once every multi-frame.

There are three 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 3 and has coding unique to a SS. One or two FLI signals are provisioned per AAS signaling sub-channel in every other or every forth frame. Each FLI signal modulates 16 tones (1 bin x 2 symbol times) with 16 QPSK symbols. The FLI provides 12 dB of processing gain to signal subscriber stations through all antennas without directed beam steering knowledge.

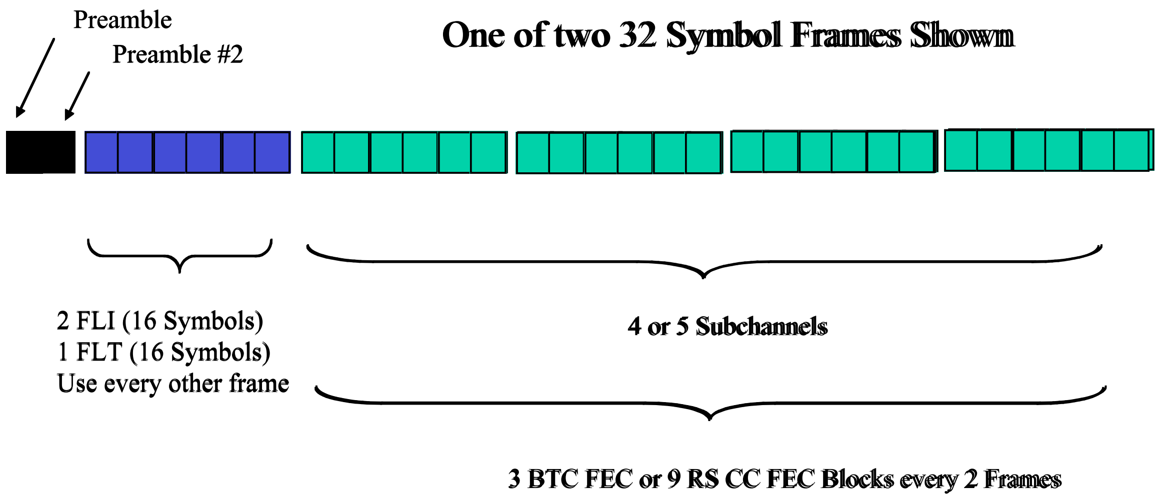


Figure 6 Forward Link Frame Structure showing FLI and FLT

The forward link training (FLT) signal occupies the 2 bins located after the two FLI signals. 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. The FLT signal may be provisioned with 8 QPSK symbols occupying 1 bin. This configuration providing higher efficiency reduced training time and a smaller user addressing space.

The third PHY layer control signal is the forward link access (FLA) signal. The base uses the FLA signal followed by the user code number (identifies which RLI and FLI codes to recognize) and map data to direct SSs to start traffic flows. Flows start by transmitting RLI signals in the specified sub-channels. The FLA is transmitted with full beamforming gain and interference cancellation. Moreover, since the FLA is sent in response to an RLA, an estimate of channel quality derived from the RLA is available at the base. Thus, the FLA frame may be used to convey initial modulation burst parameters in the uplink. Similar information is conveyed in the RLA message. In this case, initial channel quality parameters are derived from the forward link synchronization (FLS) preamble.

3.2.5 Forward and Reverse Link Bandwidth Request/Grant, Ranging

[Add this text as sub-section 8.4.15.2.5 under “8.4.15 AAS Control Signaling Structure”]

If the RU is not yet registered with the base station and hence, does not know the proper timing for reverse link transmissions, it randomly chooses a ranging access code, sends a RLA message, detects a FLA response from the base, then adjusts its delay and transmit power based iteratively until an FLA 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 average power level derived from forward link preamble measurements to set its initial transmit power level during initial ranging.

3.2.6 PHY Layer Control Signal Sequencing

[Add this text as sub-section 8.4.15.2.6 under "8.4.15 AAS Control Signaling Structure"]

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.

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 RLI in the next reverse link time slot, followed by data in the sub-channel.
3. When base station receives the RLI, 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 (RLI+Data, FLT+Data) exchange continues as long as the sub-channel is open. A field in the FL frame header lets the base station tell he SS to maintain or close a partition.
6. When told to close a sub-channel , SS stops transmitting RLI+Data, and turns on FLI detect for that sub-channel.

The diagram on the right side of Figure also illustrates the SS initiated connection. In this case an RLA at step 0 is sent to the base station. The control sequence then is identical to the base initiated connection. The base station has the option of sending an FLA at step 1 instead of the FLI(s) if burst parameters need to be updated.

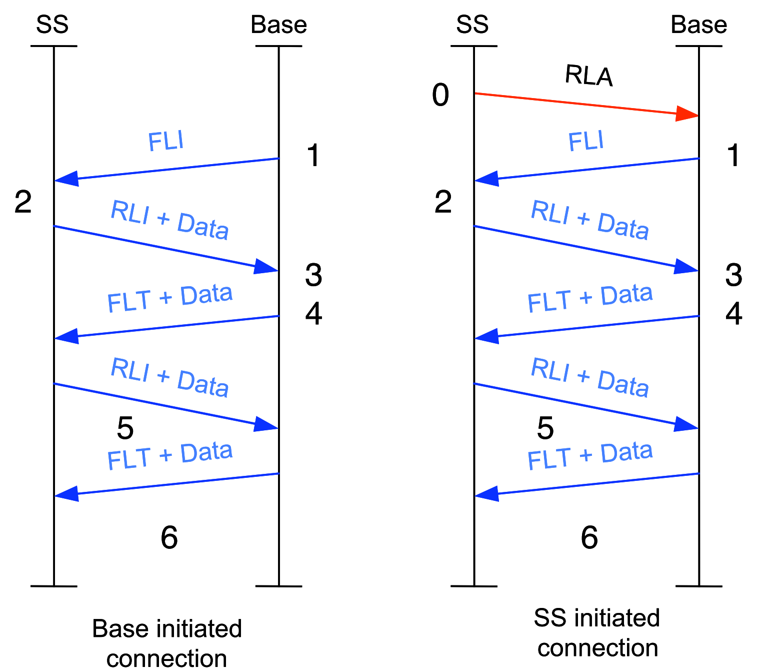


Figure 7 PHY Control Signal Sequence Diagrams

3.2.7 Granularity

[Add this text as sub-section 8.4.15.2.7 under “8.4.15 AAS Control Signaling Structure”]

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

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

3.2.8 Use of PHY Channel Signaling along with existing DL-MAP/UL-MAP

[Add this text as sub-section 8.4.15.2.8 under "8.4.15 AAS Control Signaling Structure"]

AAS PHY signaling proposed here are for training the SS and BS. Allocation of BW is still done using DL-MAP/UL-MAP mechanism currently exists in standards. Also, use of mini MAP proposed in 1x Scalable PHY is proposed here in unicast mode to communicate to an individual SS.

3.2.9 PHY Control Signaling and Coding Structure

[Add this text as sub-section 8.4.15.2.9 under "8.4.15 AAS Control Signaling Structure"]

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

3.2.9.1 RLI and RLA code properties

The RLI and RLA PHY control signals are based upon a compact 64 QPSK symbol message constructed from Hadamard sequences. 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 RLI and RLA code construction

Each SS registered to a base is assigned a unique traffic access code (RLI or RLA). The access code may be reused from sub-band to sub-band or reused from sector to sector. A database in maintained which binds the access code with the SS identification number. 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; $0 \le t < 4$, 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: $0 \le c \le 1999$, there are 8 access codes, c, for SS initial registration: $2000 \le c \le 2007$, and there are 8 access codes, c, for SS initial ranging: $2008 \le c \le 2015$.

RLI and RLA codewords are based on Hadamard basis functions. RLIs are described by an access code, a, $0 \le a < 8064$. A RLI 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,

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

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

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 RLI code. For a given access code, 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, FLA and FLT code properties

The FLI, FLT and FLA 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 and FLA are directed transmissions and benefit from beamforming
- The FLI transmission uses random beam diversity principles
- The FLT, FLA 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, FLT and FLA code construction

Each SS registered with a base is assigned a unique link initiation and training code (FLI, FLT or FLA). Coding is the same for the FLI, FLT, and FLA.

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
```

fli_new_make_c.m converts the compact codeword table into "c" files.