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Title	**AAS enhancements for 1x Scalable PHY**
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Re:	IEEE P802.16-REVd/D3-2003
Abstract	This contribution introduces AAS enhancements for proposed 1x Scalable PHY as an optiona feature
Purpose	Adopt into P802.16d/D4 draft.
Notice	
Release	
Patent Policy and Procedures	

1 Introduction

AAS can extend cell coverage by improving the system link budget. Link budget gain is achieved through beamforming. Beamforming coherently combines the RF wavefront received from multiple antennas in an adaptive combiner while increasing the order of the diversity combining mechanism. At the same time, AAS can increase base station capacity by enabling the use of higher order modulation through interference reduction and by enabling M-fold spectral reuse within the cell. To gain these benefits, the adaptive arrays must be trained using a known set of training symbols. Furthermore, robust signaling methods are needed to page subscriber stations when the adaptive arrays provided no beamforming gain. These training, paging, and initialization signals are collectively called AAS control signals in this document.

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, compatible with the 1x Scalable OFDMA PHY, 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 current DL-MAP is cut-off from receiving other downlink traffic intended for it even though enough link budget is available. 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 patches this problem in the AAS mode be redefining several of the broadcast messages, in particular the MAP messages, to be received as a series of private uni-cast messages. However, the large increase in overhead, the increase in latency and the inability to send uni-cast messages to portable or inactive SSs were not considered adequately.

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 and closes 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. Reliance on extended uni-cast maps is reduced.

3 PHY 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. The control signaling consists of special symbols modulating OFDMA carriers within the 1x scalable bin and sub-channel structure. The AAS symbol structure minimizes overhead thus maintaining high airlink efficiency. The handshaking mechanisms described below provide reliable, low latency airlink control in co-channel interference environments.

3.1 TDD Framing

In the informative text that follows, 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 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 33 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 defined by a contiguous area of 1 bin x 6 symbol slots in length. Mandatory CC coding and optional BTC or CTC FEC is supported by this frame structure. Optional 2x spreading or SFC is used on the access channel for improved control channel reliability.

3.2 Reverse Link Signals

A reverse link partition in the TDD frame is shown in Figure 1 for one of 84 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.

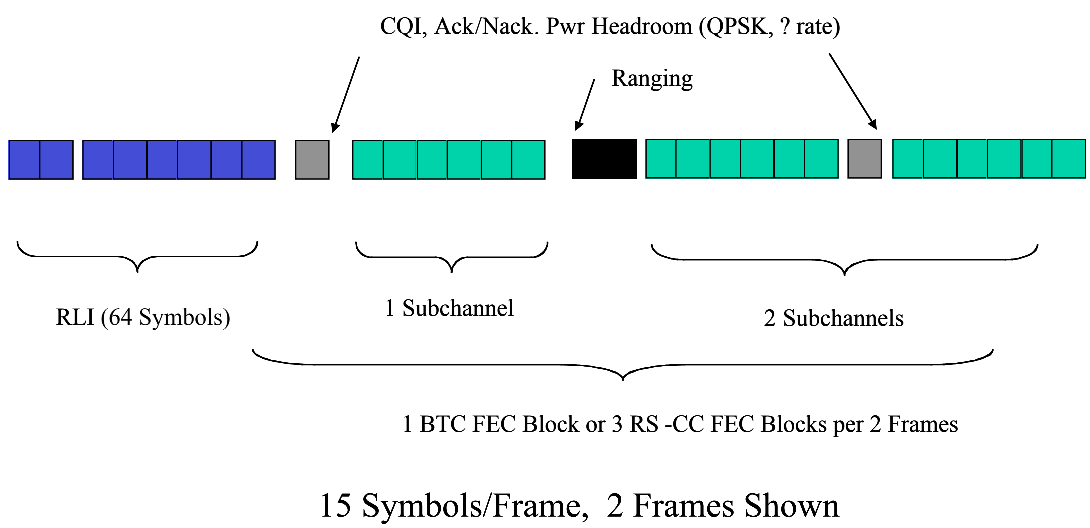


Figure 1 Reverse Link AAS Frame Structure Showing RLI Signaling

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.

At least one access partition is allocated in the TDD frame for network entry and ranging, bandwidth request, and auxiliary SICH communications. The access partition, shown in Figure 2, occupies the first bin location in the frame structure. A second partition that occupies the last bin location may be paired with

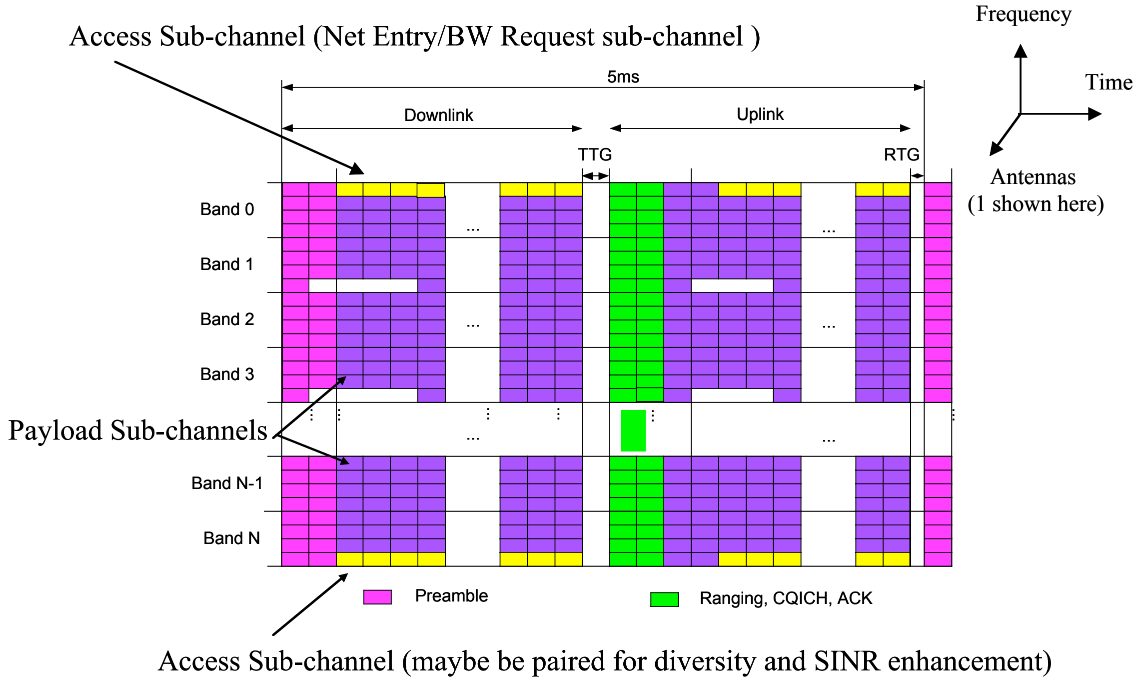


Figure 2 1x Scalable Frame Layout

the first to improve reliability and SINR through diversity combining methods. Either simple 2x spreading or space-frequency coding (SFC) maybe used as the diversity combining method. The partitions are spaced at the extremes of the RF channel to maximize the spectral diversity and may be power boosted.

3.3 Access Sub-Channels

At least one access partition is required for each 5 MHz 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 a random back-off algorithm to randomize retry timing. By using the coding methods described latter in this document, AAS base stations are able to spatially separate subscriber stations thus minimizing contention, and linearly increasing the number of logical access partitions in proportion to the number of spatially processed antennas.

3.4 Forward Link Signals

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.

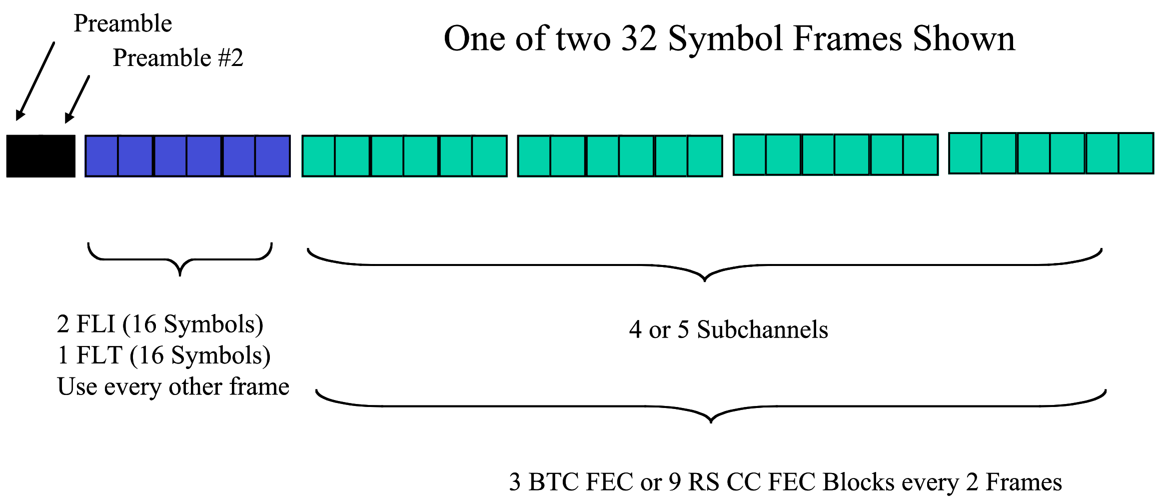


Figure 3 Forward Link Frame Structure showing FLI and FLT

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 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.

3.5 Initial Ranging, the RLA and FLA

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 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.

3.6 Forward Link Synchronization Preamble, the FLS

The base sends forward link synchronization (FLS) preambles that the SS uses for synchronization in time and frequency with the base. In addition, the SS also computes the average received signal strength of FLS preambles to determine the path loss between the base and SS. As shown in Figure 2, each forward link frame has FLS signals in the first and second time slot. Multiple FLS bursts from adjacent frames maybe used to increase synchronization accuracy.

The FLS symbols are spread in frequency by K times, where $4 \leq K \leq 8$, to provide a robust means to increase the time-bandwidth product of the signal and to remove competing interference from other base stations FLS preambles. The FLS can be used in cellularized layouts with a frequency re-use of 1 and maintain the requisite accuracy to support 64 QAM constellations. The FLS is unique to a base station to within a conservative 12 to 1 frequency reuse pattern.

3.7 PHY Layer Control Signal Sequencing

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 1 provides a list of sequence actions keyed to the sequence diagram shown in Figure 4. For the first case, we consider a base station initiated data flows.

Table 1 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 4 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.

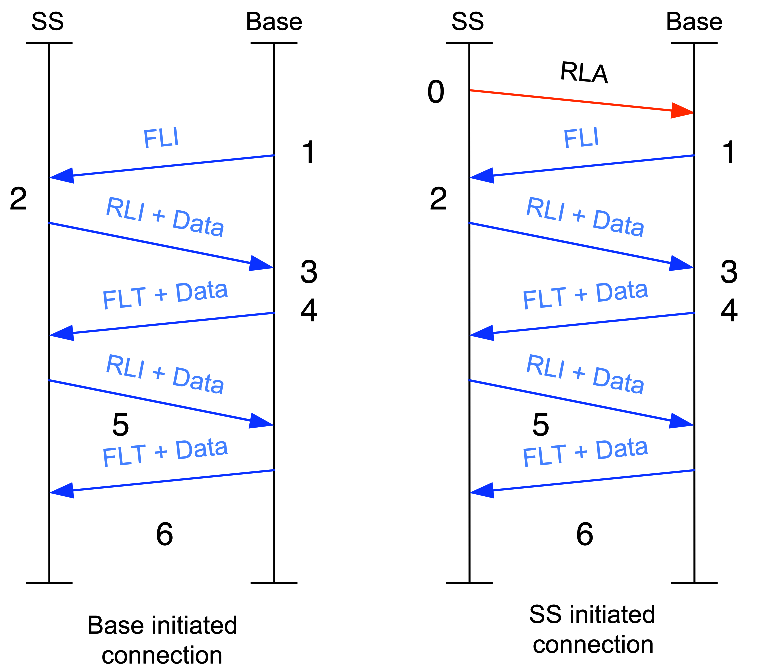


Figure 4 PHY Control Signal Sequence Diagrams

3.8 Granularity

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 2 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	

3.9 Information Elements

Add following information element in SICH for Forward and Reverse link framing in AAS Mode

Item	Size	Note
AAS Frame_Structure	2 bits	00 - DL: 32 Symbols, UL: 15 Symbols 01- DL: 24 Symbols, UL: 24 Symbols 02 - UL/DL frames are not separated and dynamically allocated (only non-AAS system) 03- Reserved

In this example, the location of access sub-channel is shown on 2 extreme frequencies. It is proposed to make it configurable parameter, which will be broadcasted in SICH. This allows BS select the location and number of access sub-channels.

Item	Size	Note
Number of Access Subchannels	2 bit	
Location of Access SubChan1 Group	8 bits	Location in frequency domain
Location of Access SubChan2 Group	8 bits	Location in frequency domain

The reverse link frame in Figure 1 shows 8 bins used for reverse link training and a multi-frame of 2. Following information element is sent along with SICH for other combinations.

Item	Size	Comment
No. Reverse Link Training Bins	2 bits	Bins used for reverse link training 2, 4, 6, 8
Number of FLI/frame	1 bits	0 one FLI/frame 1 two FLIs/frame
AAS Training Periodicity	2 bits	1, higher mobility, 2, fixed, portable, mobile 3, fixed wireless 4, reserved

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

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.

4 PHY Control Signaling and Coding Structure

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

4.1 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

4.2 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; $0 \leq t < 4$, 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: $2008 \leq c \leq 2015$.

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

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

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

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 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,

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

4.3 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.

4.4 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 2 lists Matlab that can be used to convert a compact codeword into an FLI modulation sequence.

Table 2. 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.
```

5 AAS Synchronization with Interference Cancellation

The following paragraphs describe the AAS synchronization preamble properties and construction.

5.1 Synchronization code properties

The FLS preambles are based upon a compact 32 BPSK symbol modulating a cluster of 2 bins by 2 symbol slots. The FLS sequence is constructed by adaptively optimizing sequences based on the following properties:

- The FLS provides a preamble structure permitting SSs to rapidly acquire frequency, time, and frame, and multi-frame synchronization with the base station
- The FLS codewords are selected so as to maximize the probability that the SS will lock onto the correct base, at the correct multi-frame sequence, and at the correct frequency.
- The FLS provides a preamble sequence with up to K degrees of freedom to enhance SINR and reduce cross-correlation interference via adaptive combining.
- The FLS is transmitted with constant power so that the SS can estimate path loss and reverse link transmit power.
- The pattern of FLS codewords is unique within a multi-frame and repeats from multi-frame to multi-frame.
- The FLS transmission uses beam diversity principles. Each FLS coding cluster, defined as a 2 x 2 cluster of adjacent bins uses a different beam position in the same time epoch.
- 12 unique FLS sequences indexed by base offset code are available. Reducing the number to 12 allows rapid handover for mobile users.
- The same FLS code is re-used multiple times at a base station if sectors or sub-bands are used
- Robust code reuse factor of 12 between base stations.

5.2 FLS code construction

The FLS preamble is a constant modulus BPSK code unique to a given base station. The code has nonlinear phase and is uncorrelated to the codes used by the other bases. Furthermore, the codeword in the second FLS burst does not resemble a complex scalar multiplying the codeword in the first FLS burst. For the 1x scalable configuration, a code of length 32 is sufficient. The code is split into two codewords for the two FLS bursts in a forward link preamble slot. Each length 16 codewords modulates 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 FLS bin pairs. For each FLS bin pair, the resulting 32 complex gain elements are split between the consecutive FLS bursts. The FLS of the first burst has the first 16 complex elements and the FLS of the second burst has the second 16 complex elements. The base then transmits the code over the assigned FLS bins pairs. The code is received at the SS in its corresponding FLS bin pairs with an unknown modulation frequency due to frequency offsets. For initial acquisition, a frequency offset is estimated by applying an objective function to frequency shifted and time shifted versions of the FLS data. Once the initial search is completed, a tracking frequency estimate is obtained by measuring the phase change between bursts.

An AAS base selects random transmit weight vectors for FLS messages 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 transmit weight vectors are used so that with high probability, at least one of them has a main lobe in the direction of each SS. 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 FLS codewords. The base offset code associated with the base forms part of the FLS codewords used by that base. Figure 5 gives an example of a hexagonal layout of N cells. The numeral in each cell is its base offset code. Figure 6 gives an example of a rectangular layout of N cells. FLS codeword sequences, like the base offset codes, may be reused every 12 cells.

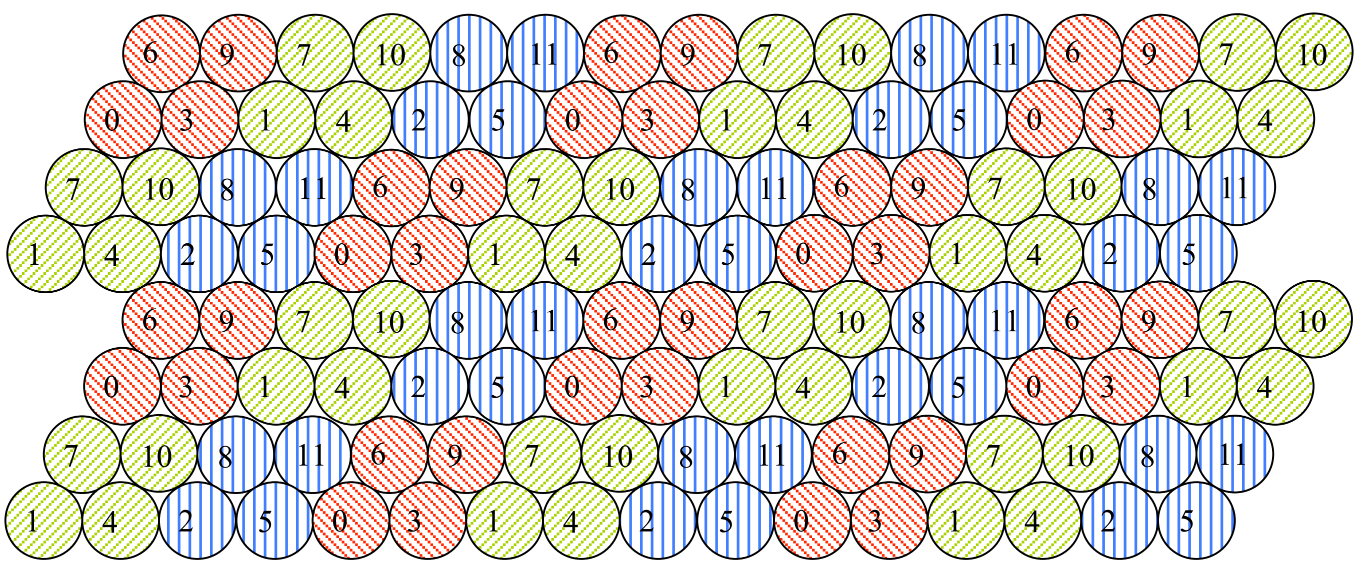
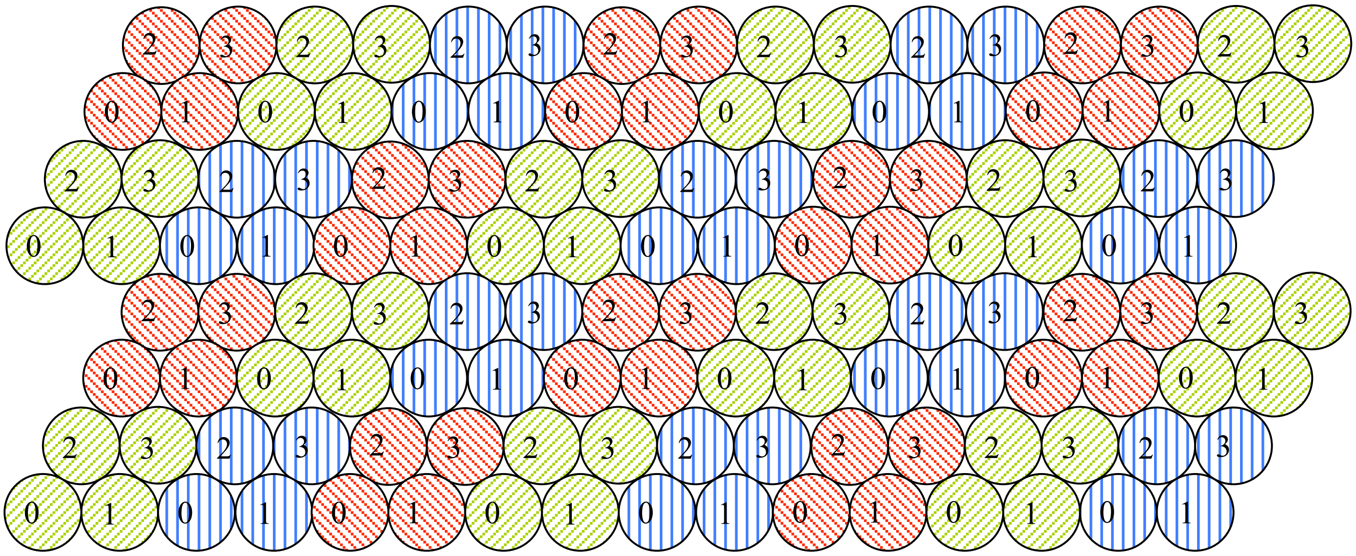


Figure 5. Base offset codes for a re-use factor of 12, hexagonal layout.



Base color codes: red , green , and blue .

Figure 6. Base descriptor codes have a repeat factor of 4.

FLS Codewords

Codes will be generated and provided for the 1x Scalable PHY

6 Text to be included in the standard

The AAS control signal overlay is coordinated with the 1X Scalable PHY definition. Text will be provided