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Re:	Call for Technical Proposals regarding IEEE Project P802.16j; See 802.16j-06/027	
Abstract	This document proposes modifications to the 802.16 OFDMA AAS zone structure in order to support high capacity MMR base stations.	
Purpose	This document provides a Technical Proposal for an AAS Signaling Methodology for consideration by the 802.16j Multi-hop Relay Task Group	
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AAS Direct Signaling Methodologies to Support High Capacity MMR-BS to RS Links

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Abstract

This document proposes modifications to the 802.16 OFDMA AAS zone structure, adds new AAS training sequences and modifies associated MAP IEs in order to achieve higher capacity and spectral efficiency for MMR-base stations in realistic propagation environments.

Introduction

The term AAS (adaptive antenna system) refers to an 802.16 system adaptively exploiting more than one antenna to improve the coverage and the system capacity[1]. Multi-user AAS[2] refers to the ability to support multiple user links simultaneously on the same sub-channel in the same timeslot through the use of AAS techniques coupled with active interference cancellation. Multi-user AAS is also referred to as "space division multiple access" or "multi-beam adaptive beamforming and null-steering".

Multi-user AAS extends cell coverage by improving the system link budget. Link budget gain is realized through the coherent combining of signals received or transmitted from multiple antenna elements, as well as by the increase in diversity provided by a multi-element antenna array. At the same time, multi-user AAS increases base station capacity by enabling the use of higher order modulation and reuse of spectral resources within the same cell.

This document proposes modifications to the 802.16 OFDMA AAS zone structure, adds new AAS training sequences and modifies associated MAP IEs in order to achieve higher spectral efficiency of MMR-base stations in realistic propagation environments and enable the use of multi-user AAS on the MMR-BS – RS link. Moreover, modifications are proposed to increase capacity on the bandwidth request signaling channel so that bandwidth requests and grant allocations scale linearly with higher capacity.

This proposal affects only the MMR-BS to RS link and the proposed modifications affect an optional AAS mode of the proposed 802.16j standard. This optional mode is fully compatible with legacy 802.16 airlink frame structures and will allow an MMR-BS to support AAS and non-AAS users in the same channel.

Multi-user AAS is the preferred method for addressing requirement O9 (Multiple Antenna Support) of IEEE 802.16j-06/016r1 (Technical Requirements Guideline for Relay TG).

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[1] IEEE Std. 802.16-2004 – Part 3 – Definitions.

[2] "Multi-user AAS" is also referred to as "multi-user beamforming" in this contribution.

New Requirements Imposed by MMR-BS to Relay Link

The MMR architecture is particularly well suited to dense urban-core deployments where the highest user density will prevail. This high density coupled with high user activity will stress the MMR base station capacity and its contention-based bandwidth request mechanism.

The multihop relay architecture imposes new requirements on the capacity of the MMR-BS. In cost effective architectures, the MMR-BS must have the capacity to concentrate the traffic of multiple Relay Stations (RS) and to directly serve mobile stations (MS) within its own coverage footprint. Relay stations themselves aggregate mobile station traffic either through direct connection to mobile stations or via relay from other RS nodes in the network. Typical RS nodes may range from low capacity devices to moderately-sized base stations. Accordingly, 5 to 50 relay stations maybe serviced by a high capacity MMR-BS in typical deployment scenarios.

Capacity & Spectral Efficiency Requirement of the MMR-BS

The following example illustrates the capacity and spectral efficiency requirements imposed by the relay architecture. In this example, we assume the two hop architecture, whereby the MMR-BS services 18 intermediately-sized RS nodes, as shown in Figure 1. A total of 18 high capacity links must be statistically multiplexed with MS nodes directly connected to the MMR-BS.

The RS to MS cell radius is assumed to be 1 km. As a result, the MMR-BS to RS links are 3 to 3.5 km for exterior RS nodes, while the links to the interior RS cells are approximately 1.7 km. The MMR-BS direclty services MS traffic in the center cell. The additional range supported on the MMR-BS – RS links is a direct result of two factors:

Relay Stations are installed in a higher location than a typical MS
Relay Links to the Base Station achieve higher system gain

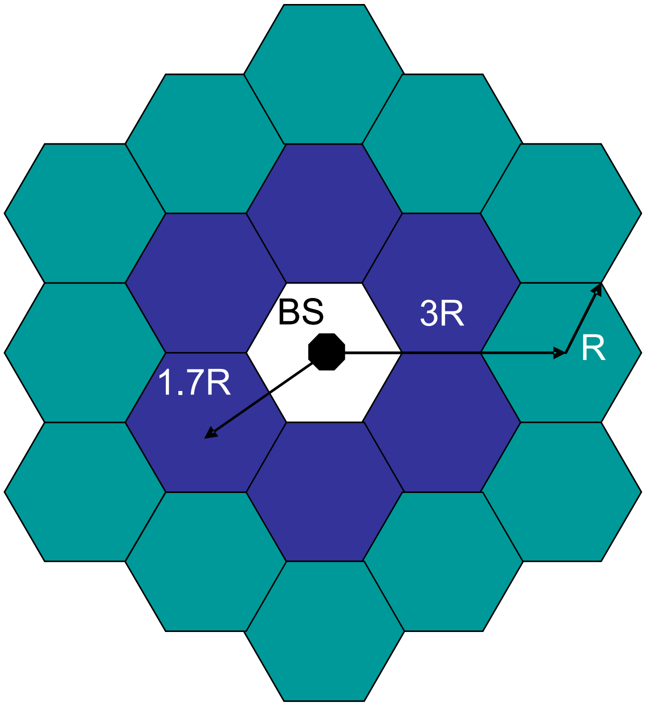

Figure 1. Mobile Multihop Basestation and Relay Station Architecture

In this example, it is assumed that each RS node has a downlink spectral efficiency of 1 bps/Hz and operates in 10 MHz of spectrum. A separate 10 MHz channel is dedicated to the MMR-BS to RS link to simplify the following analysis, although other configurations are possible. Table 1 tabulates the required capacity and spectral efficiency of the MMR- BS under this set of assumptions. In this case, the required spectral efficiency is 9 bps/Hz using a 50% trafffic load factor at each RS. Although the peak load factor at any RS may be significantly higher than 50%, the loading factor is averaged over all RS nodes with the MMR-BR coverage footprint for this analysis.

Table 1. MMR-BS Capacity and Spectral Efficiency Requirements

Parameter	**Value**	**Comments**
BS-RS Link Bandwidth (MHz)	10	RF Channel BW
RS-MS Bandwidth (MHz)	10	RF Channel BW
RS Spectral Efficiency (bps/Hz)	1	For the DL, K=1 reuse
RS Peak Capacity (Mbps)	10	At full capacity
Number of RS Cells	12	2nd Tier of cells
Number of Interior RS Cells	6	1st Tier of cells
Total RS Cells	18	
Total Peak Capacity (Mbps)	180	Total, at full peak capacity
Average MS Utilization (%)	50	Averaged over cell

Total Average Capacity (Mbps)	90	Total average capacity
BS Spectral Efficiency, bps/Hz	9.0	To service RS nodes only

The MMR-BS to RS Propagation Environment

The propagation environment for the MMR-BS to RS link will be predominately NLOS in many urban core deployments. But because the RS nodes tend to be elevated above street level and have high transmitter power, the cell radius of the MMR-BS to RS link will be 2 to 5 times greater than the cell radius of the RS to MS link under a broad set of conditions. While the maximum cell radius of the RS to MS link may range from 0.5 to 1.0 km, the range of the MMR-BS to RS link may range from 3 to 5 km. Accordingly, the multipath delay spread of these links will be higher (typically, 0.2 to 1 microseconds rms). Appropriate propagation models for these links are indicated by SUI 3 and SUI 4 [1]. The SUI 3 and SUI 4 have similar delay spread to the suburban and urban macro-cellular models derived for “beyond” 3GPP as described in [5].

The Erceg B path loss model is appropriate for well-elevated RS nodes, while Erceg A or Walfish-Ikegami may be indicated for RS nodes closer to street level in dense urban cores [2]. Erceg B has less diffraction loss when compared to Erceg A, hence the difference between well-elevated RS and street level RS nodes.

Higher multipath delay spread lowers the coherent bandwidth of the link [3]. This stresses wide bandwidth training strategies used in closed-loop AAS and MIMO feedback schemes as will be demonstrated through simulation below. An approximation of the delay spread mathematics suggests that the training bandwidth should be limited to less that 1/10th of the coherence bandwidth of the channel for accurate AAS training.

Proposed Improvements to the AAS Zone

The current IEEE 802.16-2005 standard supports advanced multi-antenna technologies such as MIMO and AAS in order to increase cell capacity and to enhance cell radius. It is generally accepted that a base station can achieve spectral efficiencies of up to 3 bps/Hz in a realistic propagation environment using the advanced methods currently in the standard.

However, AAS methods will generally achieve higher spectral efficiency than MIMO methods in the reduced multipath environment that is likely to apply to a large number of BS to RS links. Accordingly, this proposal focuses on improving the spectral efficiency of the AAS zone via multi-user AAS methods.

The current frame structure in the AAS zone should be enhanced in order to address new requirements imposed by the MMR-BS architecture. Among these requirements are:

Spectral efficiencies higher than supported by current AAS or MIMO methods through the support of high performance multi-user beamforming and interference cancellation

Longer uplink preambles to support training of larger BS antenna arrays in realistic propagation environments

A bandwidth request mechanism that can scale with an M-fold increase in the number of users afforded by multi-user beamforming

A mechanism to communicate MAP information to the edge-of-cell RS nodes, which improves upon the current AAS Diversity Zone method

The proposed solution:

Provides an optional UL preamble that has adequate time-frequency support for adequately training antenna arrays up to 16 antennas.

Increases the spectral efficiency of the MMR-BS to 9 bps/Hz via multi-user AAS processing.

Adds a bandwidth request and ranging channel that supports an M-fold increase in processing capacity by separating user requests on different spatial channels.

Reliably communicates MAP information to edge of cell AAS-RS nodes so that frame duration, subframe length, start time, DCD, and UCD information can be received.

A detail discussion of the solutions follows:

UL Link Preamble

This proposal increases the maximum number of AAS training preamble symbols to 8 and provides a maximum of 64 subcarriers for training. This is adequate to adapt an array of up to 16 antenna elements with low misadjustment loss within the frame. The preamble sequence length is programmable via the AAS OFDMA UL IE and is specified over the AMC subchannel permutation using either a 2 x 3 or 1 x 6 bin structure.

Selection of the bin structure and sequence length is dictated by the performance objectives of maximizing the post beamforming SINR while minimizing the preamble overhead. Performance loss is in part determined by the “difficulty” of the propagation environment and use case. RF channels with high frequency dispersion or high time dispersion are more difficult channels.

As a demonstration of this principle, Figure 2 provides Monte Carlo simulation of the downlink signal-to-interference and noise ratio (SINR) using a 16 element array and 12 RS nodes. All 12 RS nodes communicate simultaneously with the MMR-BS on 12 co-channel RF links. In this case, the selected channel model is the SUI-3 model using the moderate gain antenna model at the RS (30 degree azimuth beamwidth).

To adapt each link, each RS uses a unique preamble containing 64 subcarriers to train the array.

In the simulation, 1500 data subcarriers are used to determine the post-beamforming SINR. The SINR is used as the measure of performance as the bandwidth of the training is varied in this simulation. Over the Monte Carlo trials, the 90th percentile of the SINR is plotted in Figure 2. The preamble subcarriers were distributed in a contiguous frequency-symbol region according to the bandwidth parameter specified on the x-axis. The subcarriers were distributed across frequency from 10 kHz to 3500 kHz. In the former case, the frequency-symbol region is 1 subcarrier x 64 symbols. In the latter case (mode B), the frequency-symbol region is 64 subcarrier x 1 symbol evenly distributed across 3500 kHz.

Mode C in Figure 2 shows that training over a 1 x 6 AMC bin (100k) produces good results by using 8 preamble symbols (8 subcarriers + 1 pilot x 8 symbol times). By changing the preamble frequency support to the 2 x 3 AMC subchannel (200 kHz), the SINR falls 1.5 dB. However, the training overhead is reduced since only 4 preamble symbol times (16 subcarriers x 8 symbol times) are required. Note that broadband training strategies covering regions greater that 200 kHz results in a substantial loss of SINR, and while attractive from an efficiency standpoint, fail to perform adequately. The worse case is Mode B where the preamble is spread across the entire bandwidth. The SINR loss is 14 dB compared to the better preamble training strategy of Mode C. Clearly, the frequency dispersion of the channel does not permit broadband training. Moreover, relatively narrowband preamble training is preferred, particularly as the delay spread of the channel increases.

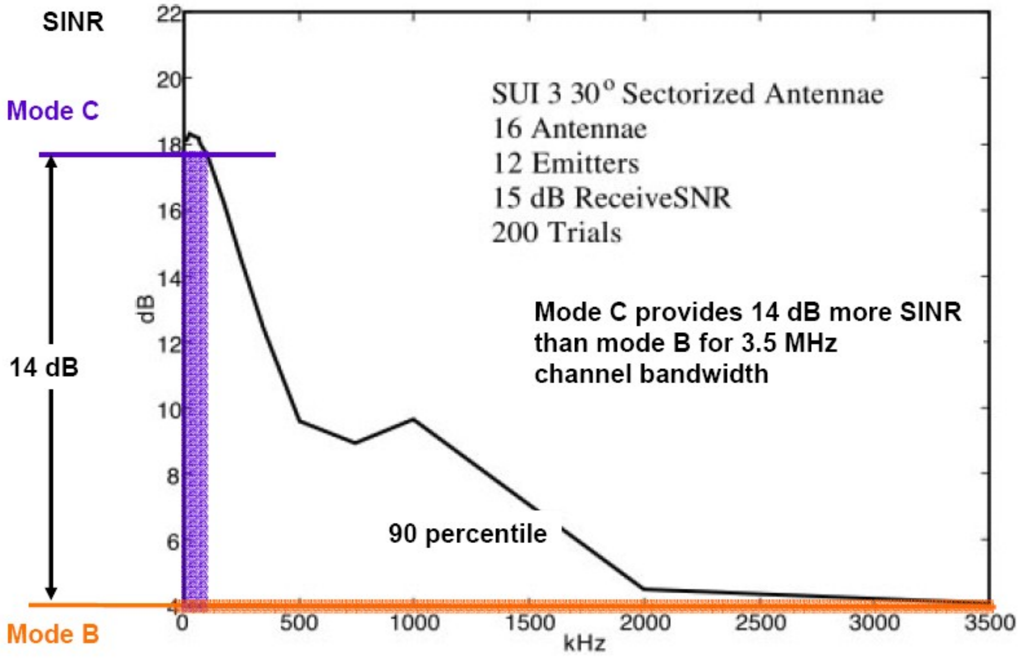

Figure 2. DL Output SINR vs. Preamble Bandwidth

Capacity

The uplink preambles are designed to support multiple co-channel users enabling multi-user beamforming. Construction of the UL preambles are based on Hadamard code words modulating a QPSK constellation. The modulation has favorable cross correlation properties with other Hadamard code words and this ensures accurate vector channel estimation in a multi-user MMR-BS scenario. To test the effectiveness of the approach, a simulation of 19 MMR-BS and 190 RS nodes was performed using the SUI-3 channel model. The model was extended as reported in [4] to include realistic angle spread and multipath delay using the ray-tracing geometrical elliptical model. This ensures that each multipath has a unique spatial signature, time delay, and complex reflection coefficient. The model is calibrated to produce the same K-factor and rms delay spread as the relevant SUI model. The model creates Doppler by moving the reflectors, by moving the RS/MS nodes or by moving both.

Since each multipath has a unique spatial signature and time delay, the effects of frequency dispersion (related to the coherence bandwidth and delay spread) and time dispersion (related to relative motion and Doppler) are accurately modeled.

Each MMR-BS in the simulation uses 16 antennas where 4 antennas are distributed in 4 sectors aligned to the rectangular street grid of an urban core. Each base station connects to 10 co-channel full-bandwidth RS nodes simultaneously. The cell-to-cell reuse factor corresponds to K=1. The simulation uses 1 x 6 AMC subchannels with 64 preamble training subcarriers. The location of each RS node is randomly selected from a uniform distribution on each Monte Carlo trial and the RS nodes are located 6 meters above street level. An RS location plot of a typical Monte Carlo run is shown in Figure 3 for reference.

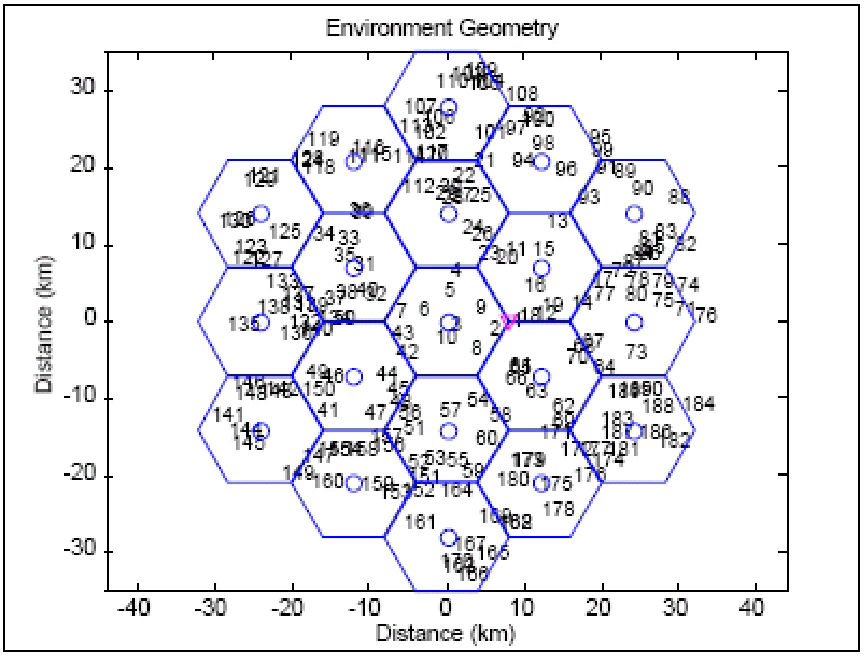

Figure 3. Capacity Test: 19 MMR-BS and 190 Co-Channel RS Nodes

Figure 4 shows the cumulative distribution of the output SINR on the uplink for the simulation parameters given above. Note that the multi-user AAS SINR of 17-20 dB supports most CC and

CTC 64QAM constellations of various code rates. For reference, a second curve is plotted for the same antenna array titled “sectored antennas”. In this case the simulation employed sectored antennas at the base station that pointed at each desired user. The beamforming was based on estimates of the antenna steering vector with power control but without directing nulls at interference. Thus, the antennas are electronically combined, albeit without interference cancellation, to achieve the best SINR.

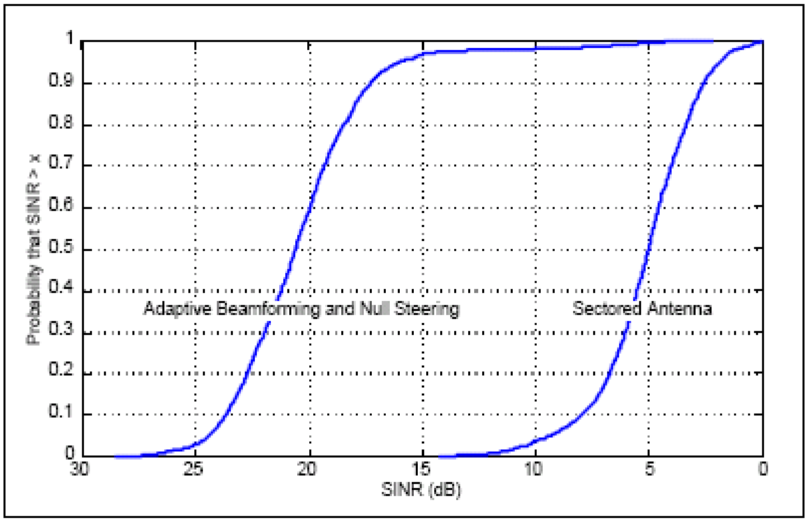

Figure 4. Capacity Test: Output SINR for Multi-user AAS and Sectorized Antennas

Figure 4 shows the quantitative difference between the two approaches and the benefits of multi-user AAS in a fully cellularized MMR-BS deployment where the frequency reuse factor is one. The Adaptive Beamforming and Null Steering method achieves an SINR of 17 dB for 95% of the RS link. This SINR supports the CTC 64QAM rate 3/4 modulation providing 4.5 information bits per subcarrier. The Sectored Antenna with beam-steering achieves 2.5 dB for 95% of the RS links. This supports the CTC QPSK rate ½ modulation providing 1 information bit per subcarrier.

Bandwidth Request and Periodic Ranging

Figure 4 indicates that substantial spectral efficiency gains are possible with multi-user AAS processing using the extended Hadamard preambles for training. In this case, ten spatial planes of traffic processing are supported with an SINR supporting 64QAM. However, this capacity can only be realized if traffic can be efficiently multiplexed onto multiple spatial planes via the bandwidth request and scheduling processes. In this case, the contention-based CDMA access mechanism may be overloaded, or conversely, so many CDMA slots are needed for access that the slots must be subtracted from the AAS zone. The latter case is particularly costly since lost slots must be multiplied by the Co-Channel Reuse Multiple (CCRM) to determine the payload loss in the AAS zone. In this example, the Co-Channel Reuse Multiple is 10-fold.

The solution to this problem is to effectively multiply the BW request/grant throughput, by the co-channel reuse multiple. This proposal achieves this goal by using multi-user AAS processing, frequency repetitions and the new preambles in an AAS-access zone. A new physical channel called the "AAS access channel" is proposed using the AMC subchannel permutation in the AAS zone. This channel effectively multiplies the number of access opportunities by the CCRM while using only a small number of AMC slots. In this case, the beamforming processing separates the access operations into multiple spatial planes via MMSE channel estimation techniques. Both spatial degrees of freedom and the frequency repetitions can be used to optimize the solution.

As an added benefit, the AAS access channel extends the system gain of the channel through beamforming gain, frequency repetitions and reduced interference. In addition, the AAS access channel can be used for ranging tasks including periodic and handover ranging.

Summary of Proposed Solution

The proposed solution defines changes in the AAS zone while being backward compatible to the AAS zone structure as described in IEEE 802.16-2005. The AAS zone is modified to include the AAS access channel(s) replacing the AAS-DLFP. In addition, extended preambles are defined. The proposed changes are signaled in the AAS_Relay_Downlink_IE and AAS_Relay_Uplink_IE.

Proposal

Insert this section in 8.4.4.8.x and renumber figures

MMR-BS to RS AAS Frame Structure

The AAS frame structure for MMR-BS to RS links is shown in Figure 5. The AAS zone uses the AMC subchannel permutation and either the 2 bin x 3 symbol or 1 bin x 6 symbol slot construction. The AAS access zone is defined to be 1 or more subchannels starting at subchannel 0 for both the uplink and downlink. Subchannel 0 is paired with subchannel n-1-k where n is the total number of subchannels and k is the number of subchannels designated in the AAS access zone. Two repetitions of the preamble and data are used in the subchannel pair to aid robust reception via diversity combining or other signal processing methods..

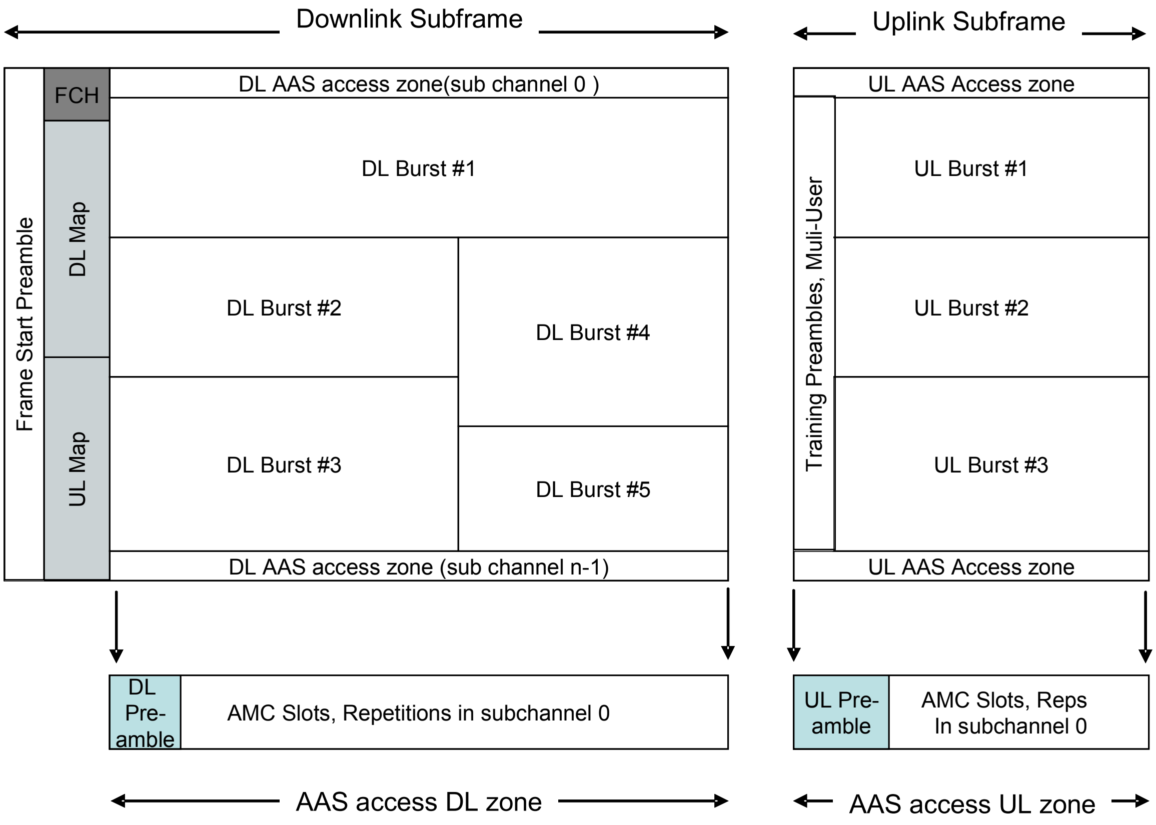

Figure 5. AAS Zone Frame Structure

The DL access zone begins with an AAS DL preamble and the UL access zone begins with the AAS UL preamble.

The AAS network entry utilizing the AAS-access zone involves the following procedure:

> The AAS-RS synchronizes frame timing and frequency to the frame-start DL preamble.
>
> Most AAS-RS receive and decode the broadcast DL-MAP and UL-MAP messages. These broadcast messages define the AAS zone via informational elements within the MAP including the AAS_Relay_Downlink_IE and AAS_Relay_Uplink_IE.
>
> For AAS-RS at the cell edge, which cannot decode the broadcast DL-MAP and UL-MAP messages, they will search for the AAS zone start preamble in the AAS Access Zone. Since the location of the access subchannels are known ahead of time, only a 1-D search across the symbol time axis is required.
>
> The cell edge AAS-RS receives the compact DL-MAP, UL-MAP, AAS_Relay_Downlink_IE and AAS_Relay_Uplink_IE in the DL AAS access zone with the benefit of scatter-cast beamforming and selection diversity enabled by the frequency repetitions. The DL_MAP starts immediately after the AAS zone start preamble. The

maps are transmitted using the well-known rate 1/2 QPSK modulation with 2 repetitions.

Most AAS-RS receive necessary messages such as the DCD and UCD using standard allocations pointed to by IEs in the DL-MAP.

The cell edge RS nodes receive DCD and UCD messages in the AAS-access zone via allocations pointed to by IEs contained in the DL-MAP repeated in the AAS-access zone.

Once the AAS- RS decodes the DCD and UCD, it performs initial ranging in the UL preamble allocation using the initial ranging codewords defined below. The preamble location is specified in the AAS_Relay_Uplink_IE.

When initial ranging code is successfully detected, the base station is able to compute UL and DL beamforming solutions and thus, is able to send and receive unicast messaging with beamforming gain.

The AAS-RS receives a unicast ranging response message through a private DL-MAP allocation in the AAS access zone with the broadcast CID. In addition, it receives a periodic ranging codeword. Subsequent ranging uses the periodic ranging codeword. The ranging protocol proceeds normally as described in Section 6.3.10.3 OFDMA-Based Ranging.

Subsequent allocations can be managed with private DL-MAP and UL-MAP allocations sent to the RS nodes using multi-user beamforming.

Definition of Uplink Preambles

The uplink training preambles are based upon 64 QPSK subcarriers constructed from Hadamard sequences. The properties of these preambles are as follows:

Provides a spatial training sequence for up to 16 antennas with the adequate time bandwidth product

Provides unique RS identification at the base station. The preambles are detected with beamforming gain and interference cancellation

Provides an initial and periodic ranging capability

Provides multi-user bandwidth request capability with appropriate messaging.

8064 codes are available based on 64 codewords

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.

The base station can separate multiple RS in the access zone using different codes

Code construction

Each RS registered to a base is assigned a basic CID and a unique Hadamard access codeword (ACW) for bandwidth requests and for training. The base station binds the access code with the basic CID. Thus, within a given sub-band or sector, each RS has its own unique access and traffic code. There are a maximum of 8064 access codes. The access codes, $a = 2016t + c$, are divided into four equal sets; $0 \leq t \leq 3$, where t is the base reuse "color". Each set of 2016 codes are divided into two types with each type allocated a certain number of access codes: up to 2000 are assigned to the RS nodes for bandwidth request, periodic ranging and traffic: $0 \leq c \leq 1999$, and there are 16 access codes, c, for RS initial ranging: $2000 \leq c \leq 2015$.

ACW codewords are based on Hadamard basis functions. ACW are described by an access code, a, $0 \quad a \quad 8064$. A ACW codeword, $\mathbf{p}_{i_1 i_0}$ modulating the 64 QPSK subcarriers has in-phase and quadrature components taken from the columns of a 64 by 64 Hadamard matrix,

$$\mathbf{p}_{i_1 i_0} \quad A\mathbf{F}_1\mathbf{h}_{i_1} \quad jA\mathbf{F}_1\mathbf{h}_{i_0}, \quad i_1 \quad i_0 ... if\, 0 \quad a \quad 4031$$

$$\mathbf{p}_{i_3 i_2} \quad A\mathbf{F}_2\mathbf{h}_{i_1} \quad jA\mathbf{F}_2\mathbf{h}_{i_0}, \quad i_3 \quad i_2 .... if\, 4032 \quad a \quad 8063$$

F1 is a 64 x 64 toggle matrix derived from the identity matrix with the following diagonal values toggled to -1: 4, 8, 9, 14, 15, 20, 24, 30, 35, 41, 46, 47, 50, 52, 56, 62.

F2 is a 64 x 64 toggle matrix derived from the identity matrix with the following diagonal values toggled to -1: 1, 2, 5, 6, 18, 21, 23, 26, 28, 32, 34, 38, 43, 48, 49, 54, 60.

The first 2-bit symbol of the Hadamard sequence modulates the first subcarrier in the first bin of the subchannel definition. Mapping proceeds in ascending order with all pilot subcarriers in the AMC subchannel skipped.

AAS Access Zone Downlink Preamble

The AAS Access Zone downlink preamble marks the being of the DL access zone. It length is specified in the OFDMA_AAS _Downlink_IE. Construction of the preamble follows 8.4.4.6.4.1

AAS Informational Element Modifications

Add Table xxx in section 8.4.5.4.6 with the following:

Table xxx—AAS_ Relay_Uplink IE

Syntax	Size	Notes
AAS_UL_IE() {		
Extended UIUC	4 bits	AAS = 0x02
Length	4 bits	Length = 0x034
Permutation	2 bits	0b00 = PUSC permutation 0b01 = Optional PUSC permutation 0b10 = adjacent-subcarrier permutation 0b11 =*Reserved*
UL_PermBase	7 bits	
OFDMA symbol offset	8 bits	
AAS zone length	8 bits	Number of OFDMA symbols in AAS zone
Uplink_preamble_config	2 bits	0b00 - 0 symbols 0b01 - 1 symbols 0b10 - 2 symbols, 4 symbols if AAS-Access Zone=1 0b11 - 3 symbols, 8 symbols if AAS-Access Zone=1
Preamble type	1 bit	0 – Frequency shifted preamble is used in this UL AAS zone 1 – Time shifted preamble is used in this UL AAS zone 0 = Hadamard preamble, if AAS_Access Zone=1) 1 = Reserved
Number of AAS access zone subchannels	1 bit	0 = 1 subchannel pair 1 = 2 subchannel pairs
AAS-Access Zone	1 bit	0 = Diversity Map Zone 1 = AAS Access Zone
Reserved	~~4~~ 2 bits	Shall be set to zero
}		

References

[1] V. Erceg, K.V.S. Hari, M.S. Smith, D.S. Baum et al, ”Channel Models for Fixed Wireless Applications,” IEEE 802.16.3 Task Group Contributions, Feb. 2001, Document IEEE 802.16.3.c-01/53.

[2] ”Channel Models for Fixed Wireless Applications”, IEEE 802.16.3 Task Group Contributions, 2001, July 2001, Document IEEE 802.16.3.c-01/29r4.

[3] *Microwave Mobile Communications*, Edited by William C. Jakes, Jr., John Wiley & Sons, 1974.

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[5] D. Baum and J. Hansen, G. Del Galdo, M. Milojevic, J. Salo, P. Kyösti ,”An Interim Channel Model for Beyond-3G Systems”, Vehicular Technology Conference, 2005. VTC 2005-Spring. 2005