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Abstract	
Purpose	Adoption of proposed changes into P802.16e ~~Crossed-out indicates deleted text,~~ <u>underlined blue indicates new text change to the Standard</u>
Notice	
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Patent Policy and Procedures	

Adaptive Bit Loading for Vertically Encoded MIMO

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Abstract

In the usage scenario of closed-loop MIMO defined in D6 standard, there exists imbalance over the signal qualities of the beamformed spatial channels. The performance of uniform bit loading scheme is limited by the weakest beamformed channel even though there are excessive signal quality in the strong channels. Adaptive bit loading (ABL) can mitigate this problem by loading bits on each spatial channel according to its channel quality. A 4-bit index is proposed to be added in MIMO compact DL-MAP IE to enable ABL for closed-loop MIMO.

1 Usage Scenario

In the closed-loop MIMO of D6 standard, base station (BS) requires feedback from mobile station. The feedback can be obtained by three means: a) feedback from mobile station (MS) using a defined beamforming codebook, b) direct channel feedback, and c) uplink channel sounding. For b) and c), channel matrix is obtained at the BS and beamforming matrix is obtained by singular value decomposition (SVD) of the channel matrix. For a), the MS estimates the channel matrix from midamble or pilots, and searches a designated codebook for a codeword matrix that delivers the best beamforming performance. After the matrix is found, an index is fed back to the BS, which allows the BS recovers the matrix.

The column vector of the beamforming matrix is referred to as beamforming vector. Each beamforming vector is for the beamforming of one data stream. The order of beamforming vectors is implicitly determined by the feedback index. The index indicates a beamforming matrix in a matrix codebook. The order of the columns in the indicated matrix is the final order of the beamforming vectors. This order information is important for adaptive bit loading because it determines the mapping between a beamforming vector and an eigenvalue of the channel matrix. Therefore, the feedback index in codebook approach specifies not only the beamforming vectors for data streams but also the mapping between beamforming vectors and channel eigenvalues. For b) and c), the beamforming vectors can be from singular value decomposition (SVD) of the channel matrix.

After the beamforming vectors and their order are obtained, the BS weights transmit antennas using the beamforming vectors for data streams, where one vector is for one stream. The beamforming not only increases the received signal power but also removes the inference between data streams. For slow fading channels, significant gain is observed compared to diversity schemes such as open loop STC codes.

For adaptive bit loading, the BS selects one modulation level for each data stream according to the CINR fed back by the MS for that stream. The BS load bits to each stream according to a selected modulation level. Each loaded data stream is then weighted by a corresponding beamforming vector and sent out by antennas. The modulation levels can be specified by an index in STC-ZONE-IE so that the receiver can demodulate the streams. The usage scenario is illustrated in Figure 1.

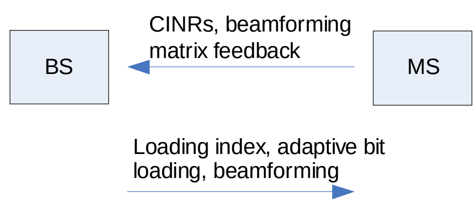

Figure 1 Illustration of usage scenario of closed-loop MIMO with ABL in the downlink.

2 Introduction of Adaptive Bit Loading

The performance of closed-loop MIMO can be improved further by adaptive bit loading for the reasons as follows. The signal qualities of the beamformed channels are typically significantly different due to the nature of wireless channel. Thus, the performance of closed-loop MIMO is dominated by the weakest channel even though there is excessive signal energy in the strong channels. Adaptive bit loading (ABL) can mitigate this problem by transmitting different number of bits on each spatial channel according to its received quality. For example, the transmitter may employ 64 QAM for the strong channel and QPSK for the weak channel respectively.

To demonstrate the advantage of adaptive bit loading (ABL), simulation results are shown in Figure 2 and Figure 3 for vertically and horizontally encoded MIMO respectively. Two data streams are sent using 2 transmit antennas with Matrix B and band AMC permutation over ITU, Pedestrian B, 2x2 channels, where transmit antenna correlations are 0.7 and 0.2 for vertically and horizontally encoded MIMO respectively. Packet error rates for packet size 64 bytes are plotted. The ABL scheme loads 6 and 2 bits on strong and weak spatial channels respectively while the uniform bit loading (UBL) scheme loads 4 bits on both spatial channels. The maximum throughputs of both cases are the same. Although the total number of bits per subcarrier is the same for both UBL and ABL, ABL outperforms UBL by more than 2 dB. Because the diversity order in the weakest eigenmode is less than 4, the performance of closed-loop horizontal MIMO is even poorer than that of open-loop horizontal MIMO as shown in Figure 3. More results for UBL and ABL comparison are documented in [2]. The comparison between vertically encoded MIMO (VE-MIMO) and horizontally encoded MIMO (HE-MIMO) are shown in Figure 4. Vertical MIMO outperforms horizontal MIMO in terms of diversity order (i.e. PER curve slope) and required SNR for given PERs. An ABL scheme is proposed for vertical MIMO next.

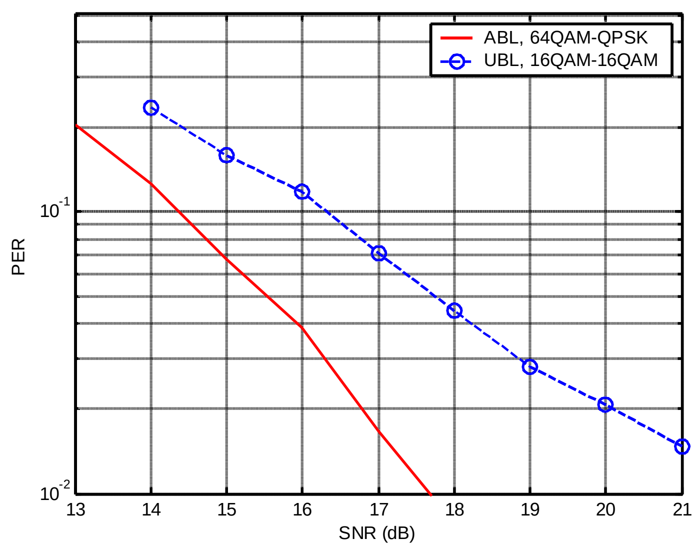

Figure 2 Comparison between ABL and UBL for 2x2 vertically encoded MIMO, where channel model is ITU, Pedestrian B with 0.7 Tx antenna correlation.

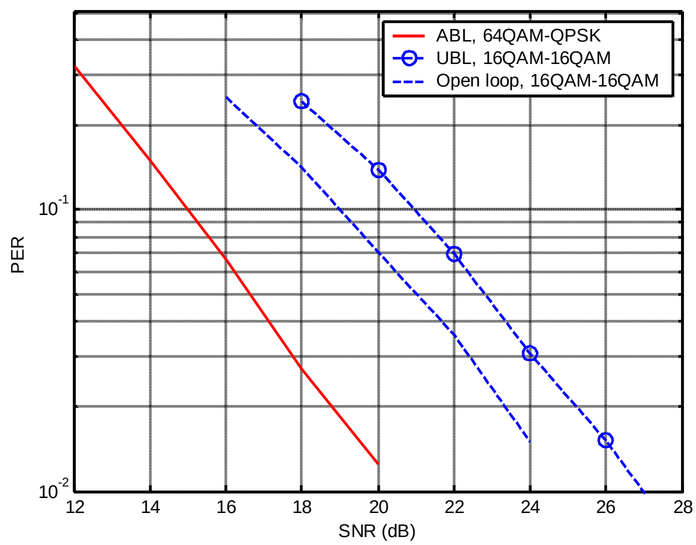

Figure 3 Comparison between ABL and UBL for 2x2 horizontally encoded MIMO, where channel model is ITU, Pedestrian B with 0.2 Tx antenna correlation.

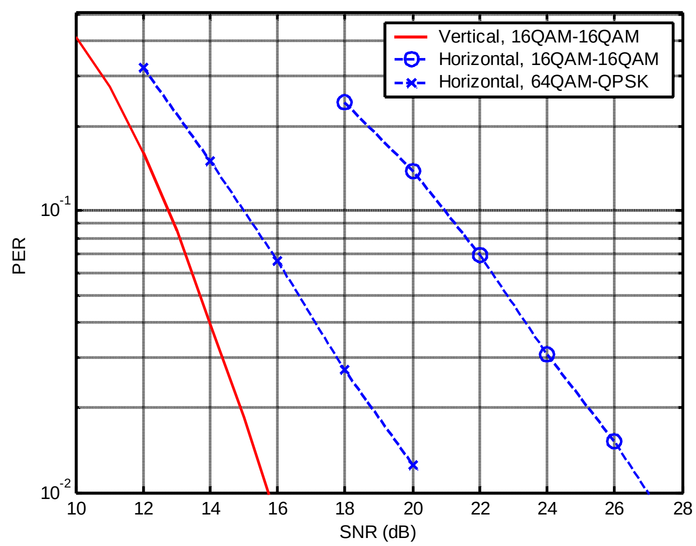

Figure 4 Comparison between horizontal and vertical MIMO for 2x2, where channel model is ITU, Pedestrian B with .2 Tx antenna correlation.

To simplify MAC signaling, we only propose per-stream ABL, where for a given spatial channel the modulation level is the same for each subcarrier assigned to the MS. Furthermore, the data streams in the transmitter are sorted so that the highest modulation level is employed for the first data stream and the lowest level is employed for the last stream. This is to match the order of the beamforming vectors in the feedback codeword matrix.

Vertically encoded MIMO (VE-MIMO) transmitters that support closed loop and ABL are shown in Figure 6 and Figure 6 for Turbo codes (CTC) and convolutional codes (CC) respectively. In Figure 5, the transmitter requires no interleavers for interleaving in frequency and space domains because CTC encoder has a built-in interleaver. In Figure 6, the transmitter employs legacy interleavers in order to interleave the codebits that are sequential encoded, where the interleaver are for existing single-input single-output systems. The demux supports ABL by distributing consecutive codebits to multiple streams according to specified modulation levels.

The transmitter works as follows. A block of data bits is first encoded by FEC encoder. The codebits are distributed to multiple streams according the modulation level selected for each spatial channel according to the CINR feedbacks. It should be noticed that the same modulation level is employed for all subcarrier for a given spatial channel. For CC, the distributed bits are interleaved by a legacy interleaver on each stream. The interleaved bits are then mapped to QAM symbols. The QAM symbols are weighted by beamforming vectors. After other baseband and RF processing, the beamformed streams are sent by antennas. The sizes of FEC blocks are determined by the subchannel concatenation on each spatial channel. The FEC encoder sequentially encodes the blocks channel by channel. Namely, the encoder finishes the encoding of all FEC blocks for the p-th spatial channel before those for the (p+1)-th channel. Detailed operations of the demux are depicted next.

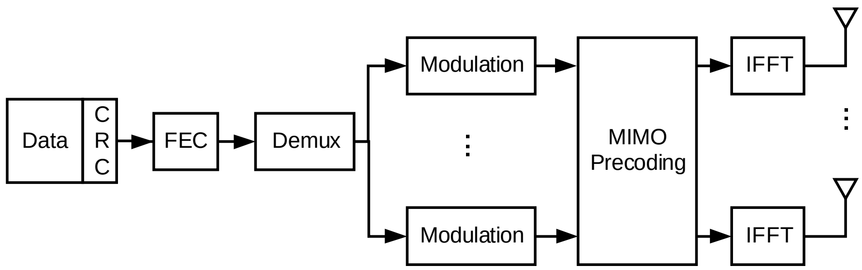

Figure 5 Vertically encoded MIMO with adaptive bit loading for CTC.

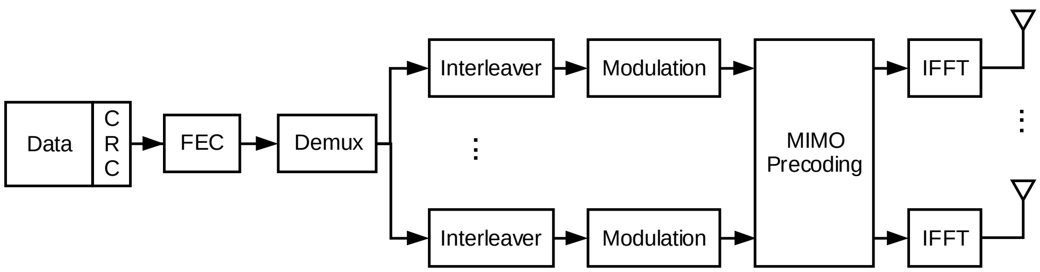

Figure 6 Vertically encoded MIMO with adaptive bit loading for CC.

The demux extracts bits for L layers one by one. In order to match to the order of feedback beamforming vectors, the modulation levels for layers are in descending order. The demux first evenly extracts the bits for the first layer, which employs the highest modulation level. Namely, the i-th bit in the first layer is the k-th bit in the original input bit sequence, where $k = \text{round}(i\, d_1)$ and $d_1 = \frac{1}{Q_1}\sum_{j=1}^{L} Q_j$; L is the number of spatial channels; and Q_j is the number of bits per subcarrier for the j-th data stream. For example, if the first and second layers employ 64QAM and QPSK, $Q_1 = 6$ and $Q_2 = 2$. The term d_1 is the nominal spacing between two extracted bits in the original bit sequence. Seen from the computation of index k, the extracted bits are evenly located in the original sequence. After extracting bits for the first stream from the input sequence, the demux extracts bits for the second stream from the remaining bits. Similarly, the i-th extracted bit is the k-th bit in the remaining bits, where $k = \text{round}(i\, d_2)$ and $d_2 = \frac{1}{Q_2}\sum_{j=2}^{L} Q_j$. For the extraction for the l-th data stream, the i-th extracted bit is the k-th bit in the remaining bits, where $k = \text{round}(i\, d_l)$ and $d_l = \frac{1}{Q_l}\sum_{j=l}^{L} Q_j$. This process repeats until there is only one data stream left and all the remaining bits are assigned to the stream. For UBL, the demux operation above naturally degenerates to a simple serial-to-parallel conversion.

Since the BS selects the modulation coding schemes according to CINR feedbacks form the MS, the MS doesn't need to feed back modulation coding schemes. Since the MS already can demodulate all UBL transmissions, the BS needs to signal the MS only for ABL with unequal modulation levels. This can be done by adding a 4-bit index in MIMO compact DL_MAP-IE. The index specifies one of the loading options that are listed in Table 1. The table specifies the modulation level employed by each active stream. If the index is 0b000, the modulation level is the same for all active streams (i.e. UBL) and the demodulation process is the same as the one in D6.

Table 1 Bit loading options

ID#	Stream Count	Stream ID vs. Modulation			
		stream 1	stream 2	Stream 3	stream 4
0	1—4	UBL	UBL	UBL	UBL
1	2	16 QAM	QPSK		
2	2	64 QAM	QPSK		
3	2	64 QAM	16 QAM		
4	3	16 QAM	QPSK	QPSK	
5	3	16 QAM	16 QAM	QPSK	
6	3	64 QAM	16 QAM	16 QAM	
7	3	64 QAM	64 QAM	QPSK	
8	3	64 QAM	64 QAM	16 QAM	
9	4	16 QAM	16 QAM	QPSK	QPSK
10	4	16 QAM	16 QAM	16 QAM	QPSK
11	4	64 QAM	16 QAM	16 QAM	QPSK
12	4	64 QAM	64 QAM	16QAM	QPSK
13	4	64 QAM	64 QAM	16 QAM	16 QAM
14	4	64 QAM	64 QAM	64 QAM	QPSK
15	4	64 QAM	64 QAM	64 QAM	16 QAM

3 Specific Text Changes

[Modify the following table in Section 6.3.2.3.43.6.7 as follows]

6.3.2.3.43.6.7 MIMO Compact_DL_MAP IE format

Table 101b—MIMO Compact_DL-MAP IE

Syntax	Size (bits)	Notes
MIMO_Compact_DL-MAP_IE() {		
Compact DL-MAP Type	3	Type = 7
DL-MAP Sub-type	5	MIMO = 0x01
Length	4	Length of the IE in Bytes
Mode Change	1 bit	Indicates change of MIMO mode 0 = No change from previous allocation 1 = Change of MIMO mode
Antenna Grouping/Selection	1 bit	Application of antenna grouping/selection to the burst 0 = Not applied 1 = AG/AS applied
Codebook based Precoding	1 bit	Application of codebook based precoding to the burst 0 = Not applied 1 = Codebook based precoding applied
Adaptive Bit Loading	1 bit	Application of adaptive bit loading to the burst 0 = Not applied 1 = ABL applied
N_layer	2	Number of multiple coding/modulation layers 00 – 1 layer 01 – 2 layers 10 – 3 layers 11 – 4 layers
if(Mode Change == 1){		
Matrix	2 bits	Indicates transmission matrix (See 8.4.8) 00 = Matrix A (Transmit Diversity) 01 = Matrix B (Hybrid Scheme) 10 = Matrix C (Spatial Multiplexing) 11 = Reserved
Mt	2 bits	Indicates number of STC output streams 00 = 1 stream 01 = 2 streams 10 = 3 streams 11 = 4 streams
if (Antenna Grouping/Selection == 1) {		
Antenna Grouping/Selection Index }	4 bits	Indicates the index of antenna grouping/selection See 8.4.8.3.4 and 8.4.8.3.5
if (Codebook based precoding == 1) {		
Codebook based precoding Index }	6 bits	Indicates the index of precoding matrix W in the codebook See 8.4.8.3.6
if (Adaptive Bit Loading == 1) {		
Bit Loading Index }	4 bits	Indicates the index of the modulation level for each layer

		See 8.4.8.10
}		
for (j=1;j<N_layer+1; j++) {		This loop specifies the Nep/DIUC for layers 2 and above when required for STC. The same Nsch and RCID applied for each layer

if (H-ARQ Mode =CTC Incremental Redundancy) {
Nep }
elseif (H-ARQ Mode = Generic Chase) {
DIUC
}
	4 bits	H-ARQ Mode is specified in the H-ARQ Compact_DL-MAP IE format for Switch H-ARQ Mode.

if (CQICH indicator == 1) {		CQICH indicator comes from the preceding Compact DL-MAP IE
Allocation Index[1]}	6	Index to CQICH assigned to this layer.
}		
if (CQICH indicator == 1) {	2	The number of additional CQICHs allocated to this SS. (0 – 3)
CQICH_Num	2	The number of additional CQICHs allocated to this SS. (0 – 3)
for (i=0; i<CQICH_Num; i++) {		
Feedback_type	3	Type of contents on the additional CQICH 000 = Fast DL measurement/Default Feedback with antenna grouping 001 = Fast DL measurement/Default Feedback with antenna selection 010 = Fast DL measurement/Default Feedback with reduced code book 011 = Quantized precoding weight feedback 100 = Index to precoding matrix in code book 101 = Channel Matrix Information 101 = Per stream power control 110 = Adaptive bit loading 111 = Reserved
Allocation index	6	
CQICH Usage	2	Indicates the usage of this CQICH 00 = 6 bit CQI (default) 01 = DIUC-CQI 10 = 3 bit CQI (even) 11 = 3 bit CQI(odd)
}		
}		
Padding	variable	Padding to byte; shall be set to 0
}		

Added section 8.4.8.10 at line 27 on page 442 of [1] as follows

8.4.8.10 Adaptive Bit Loading for MIMO

Figure 254a and 254b illustrate transmitters of vertically encoded MIMO with adaptive bit loading for CTC and CC respectively, where there are L layers in each transmitter. The FEC encoder generates coded blocks for the layers sequentially. The code bits of each block are distributed into L layers by the demultiplexer. The demultiplexer extracts bits for the layer with a higher modulation level before those with lower modulation levels. Denote the number of bits per subcarrier on the j-th stream as Q_j. For the extraction for the l-th layer, the i-th extracted bit is the k-th bit in the remaining bits, where $k = \text{round}(i\, d_l)$ and $d_l = \frac{1}{Q_l}\sum_{j=l}^{L} Q_j$.

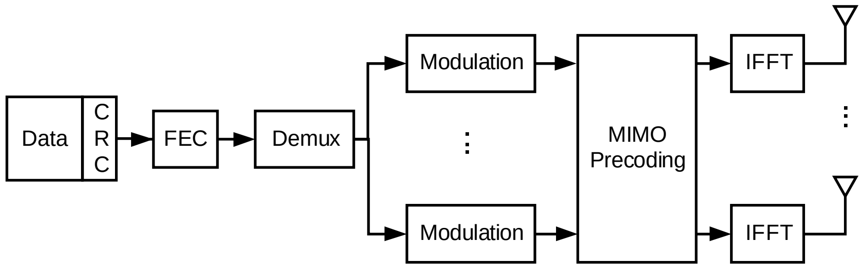

Figure 254a Adaptive bit loading for vertically encoded MIMO with CTC in optional zones.

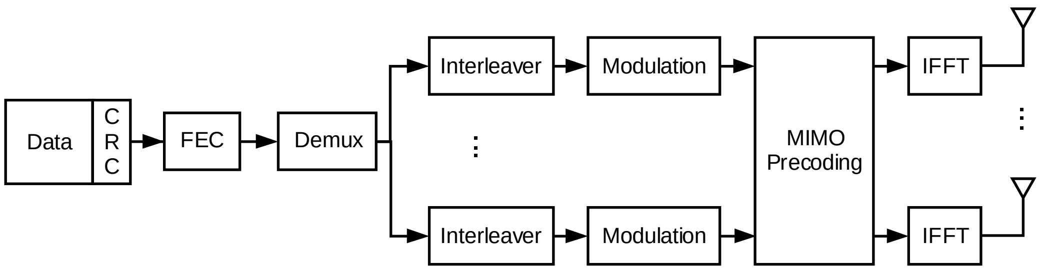

Figure 254b Adaptive bit loading for vertically encoded MIMO with CC in optional zones.

The options of modulation levels for the layers are listed in Table 319.

Table 319 Bit loading options

ID#	Layer Count	Layer ID vs. Modulation Level			
		Layer 1	Layer 2	Layer 3	Layer 4
0	1-4	UBL	UBL	UBL	UBL
1	2	16 QAM	QPSK		
2	2	64 QAM	QPSK		
3	2	64 QAM	16 QAM		
4	3	16 QAM	QPSK	QPSK	
5	3	16 QAM	16 QAM	QPSK	
6	3	64 QAM	16 QAM	16 QAM	
7	3	64 QAM	64 QAM	QPSK	
8	3	64 QAM	64 QAM	16 QAM	
9	4	16 QAM	16 QAM	QPSK	QPSK
10	4	16 QAM	16 QAM	16 QAM	QPSK
11	4	64 QAM	16 QAM	16 QAM	QPSK
12	4	64 QAM	64 QAM	16QAM	QPSK
13	4	64 QAM	64 QAM	16 QAM	16 QAM
14	4	64 QAM	64 QAM	64 QAM	QPSK
15	4	64 QAM	64 QAM	64 QAM	16 QAM

References:

[1] IEEE P802.16e/D6 Air Interface for Fixed and Mobile Broadband Wireless Access Systems – Amendment for Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands, 2004.

[2] Q. Li, *et al*., "Per-Stream Bit Loading for MIMO Precoding," IEEE C80216-04_529r5, Nov. 2004.