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Source(s)	Xiangyang (Jeff) Zhuang Timothy A. Thomas Frederick W. Vook Kevin L. Baum Mark C. Cudak Motorola Labs 1301 E. Algonquin Road Schaumburg, IL 60196 Email: Jeff.Zhuang@motorola.com
Re:	IEEE P802.16-REVe/D7
Abstract	Defines the missing details on per stream power control feedback in CQICH enhanced allocation IE
Purpose	Adoption of proposed changes into P802.16e
Notice	
Release	
Patent Policy and Procedures	

	will disclose this notification via the IEEE 802.16 web site <http://ieee802.org/16/ipr/patents/notices>.

Per Stream Power Control in CQICH Enhanced Allocation IE

Xiangyang (Jeff) Zhuang, Timothy A. Thomas, Frederick W. Vook, Kevin L. Baum, Mark C. Cudak
Motorola Labs, Schaumburg, IL, USA

1 Introduction

In section 8.4.5.4.15 of IEEE 80216e/D7, several types of feedback information are specified in the CQICH_Enhanced_Alloc_IE() so that the SS can transmit feedback information of a specified type on the assigned CQICH. However, when per-stream power control feedback is required by the base (feedback type "101"), there is no specification in IEEE 80216e/D7 for how the payload bits are to be interpreted.

This contribution provides the missing specification for how the feedback payload bits for per-stream power weighting feedback are to be interpreted by the BS. More specifically, this contribution provides an efficient method for specifying the range and quantization levels for the power weighting values of the different MIMO streams.

This contribution does **not** specify a method for determining the per-stream power weights for MIMO. A per-stream power control strategy is a vendor-specific implementation and does not need to be specified in the standard. This contribution simply specifies an efficient strategy for encoding the power levels that have been determined by a vendor-specific per-stream power control strategy. The payload bits of the CQICH simply convey the encoded bits that indicate the per-stream power levels.

Power weighting on different streams can be very effective in dealing with the different spatial channel quality in both closed- and open-loop MIMO communications. When the power weighting of streams are ordered and summed up to one, the quantization of the power weightings can be done with very fine granularity and also very efficiently (for example, as proposed in this contribution, three bits of feedback is used for up to two streams, six bits for up to three streams, and nine bits for up to four streams).

2 Feedback Types and Per Stream Power Control Feedback

2.1 Problem Statement

In table 302a of section 8.4.5.4.15 of IEEE 80216e/D7, a three bit feedback type field is defined for each CQICH. For example, "000" indicates that the CQICH should carry the information about Fast DL measurement/Default Feedback with antenna grouping, i.e., both the DL SNR measurement and MIMO mode can be fed back where some codewords for MIMO mode feedback are interpreted differently in case of antenna grouping (“000”), antenna selection (“001”), or reduced precoding matrix code book (“010”), as detailed in section 8.4.5.4.10.7. Feedback type “011” indicates that the MSS shall report the quantized MIMO precoding coefficient according to the mapping defined in section 8.4.5.4.10.6. Feedback type “100” indicates that the MSS shall report the index to the precoding matrix defined in 8.4.5.4.11. However, **bits “101” is defined twice**: once for “channel matrix information” and once for “per stream power control”. The “channel matrix information” might mean the same as quantized MIMO coefficients by bits “011”. If so, it can be deleted. Otherwise, a new bit word out of the reserved ones must be used for “per stream power control”. **The encoding of the payload bits for “per stream power control” is not defined anywhere.** As a result, there is no specification for how to interpret the payload bits for “per-stream power control,” which may cause inter-operability problems

2.2 Benefits of Per-Stream Power Control

Although this contribution does not specify a power control strategy that may be dependent on the receiver processing, it is worth pointing out why per-stream power control is beneficial and how the method in this contribution for encoding the per-stream power control levels can be used in the standard. Per stream power weighting can be very effective in dealing with the different qualities of the spatial channels formed in closed-loop MIMO communications. In closed-loop MIMO transmission with horizontal encoding, MAP allocations can assign each beamformed stream a different modulation and coding selection (MCS) level, and the per-stream power control feedback in Section 8.4.5.4.15 can be used to adjust the power levels of the different streams. The ability to adjust the MCS level (through the MAPs) and the power levels (through CQICH_Enhanced_Alloc_IE()) enables the MIMO transmission to better accommodate the different qualities of the spatial streams formed by the transmitter. Furthermore, when the same data rate is used on all the streams and successive cancellation receivers are used, per-stream power control can significantly increase performance, as is shown in the simulation results below. Similarly, per-stream power control in open-loop MIMO transmission with horizontal encoding has been shown [1] to significantly increase the performance of successive cancellation receivers.

2.3 Methodology for encoding per-stream power levels

For the quantization of power weightings for all streams, an efficient quantization method is described here after recognizing the fact that the range of each stream can be refined after the power weightings of previous streams are quantized. The method sequentially quantizes the power weightings of the data streams in a numerical range that depends on the power weighting of the previously quantized stream powers. Also noted here that the streams are indexed in the order of decreasing power weighting and all power weightings sum up to one. So the number of bits assigned to quantize each successive stream can be smaller due to the decreasing range of possible values. Due to the fact that only a minimum dynamic range is quantized, the quantization granularity is very fine. In most of the cases a granularity of less than 0.01 in power difference is achieved with extreme cases being about 0.08. Also, in open-loop transmission, the strongest stream (i.e., the stream that has the largest power weighting) is transmitted from the first antenna; the second stream is transmitted from the second antenna and so on. In the closed-loop case, the strongest stream corresponds to the first beamforming vector (i.e., first column of the beamforming matrix) and so on.

The quantization scheme is given as (note that the quantization step includes both the lower and upper range values and the remaining B-2 levels are uniformly positioned between the lower and upper limits):

1. Determine the maximum number of data streams that the BS and MSS support based on the number of antennas at MSS and BS (e.g., up to N_s data streams)
2. Determine the power weighting P_1 of the strongest data stream between $1/N_s$ and 1. Quantize the squared root of P_1 (i.e., α_1=sqrt(P_1)) with B_1 bits (B_1=3 if N_s=2, B_1=4 if N_s=3 or 4).
3. For the m-th stream where m=2 to N_s-1, determine the power weighting of the m-th data stream that should be in the range of $\frac{1}{N_s+1-m}(1-\sum_{n=1}^{m-1}\alpha_n^2) \le \alpha_m^2 \le \min(\alpha_{m-1}^2, 1-\sum_{n=1}^{m-1}\alpha_n^2)$. Quantize α_m with B_m bits (B_2=2 if N_s=3, B_2=3 and B_3=2 if N_s=4).
4. The power weighting of the last stream is $1-\sum_{n=1}^{N_s-1}\alpha_n^2$, which does not need to be fed back.

Thus the total amount of feedback (in number of bits) needed for the power weight is $\sum_{m=1}^{N_s-1} B_m$. A three-bit CQICH is allocated if the feedback for up to N_s=2 streams is requested by the BS. A six-bit CQICH is allocated (or two three-bit CQICH) if the feedback for up to N_s=3 streams is requested by the BS. A six-bit and a three-bit CQICH (or 3 three-bit CQICH) are allocated if the feedback for up to N_s=4 streams is requested by the BS. Note that if the MSS preferred a stream number smaller than N_s, the remaining streams will be allocated with zero power.

2.4 Simulation Results

Although this contribution does not specify a per-stream power control strategy, simulation results are now presented to show the benefits of using the per-stream power weighting feedback option that is currently in the standard and also the benefits of successive interference cancellation at the receiver. The channel was simulated using a COST-259 channel model with 2.0 μsec RMS delay spread with a 15 degree angular spread at the BS and a 360 degree angular spread at the MSS. The BS has four transmit antennas (one lambda spacing) and the MSS has four receive antennas (half lambda spacing). The BS sends four data streams to the MSS and horizontal encoding of the data is used. Each stream is a rate ½ convolutionally encoded QPSK data stream. For the closed-loop results, a matrix codebook of 64 vectors was used and the codebook was designed using the criteria discussed in [2]. The codebook selection criterion at the MSS is to choose the codebook matrix that maximizes the capacity. For the closed-loop results, equal-stream power using the codebook matrix to transmit the data streams is compared to per-stream power weights which are designed to equalize the MSE on each data stream after successive cancellation reception. Figure 1 shows the closed-loop FER results comparing the different methods (the MSS is moving at 2 MPH and has a feedback delay of 10 msec). Note that linear MMSE combining is significantly worse than successive cancellation (SC) reception for equal power weightings. Also note that there is a significant improvement for using per-stream power weightings along with the matrix codebook selection. Figure 2 and Figure 3 show the benefit of power weighting feedback for open loop MIMO with the same parameters as the closed-loop results except there is no feedback delay for the power weights. In both the narrowband (2×6 band AMC) and broadband (PUSC with 2048 size FFT) cases, there is over a 4.0 dB gain for power weightings calculated based on the measured downlink channel.

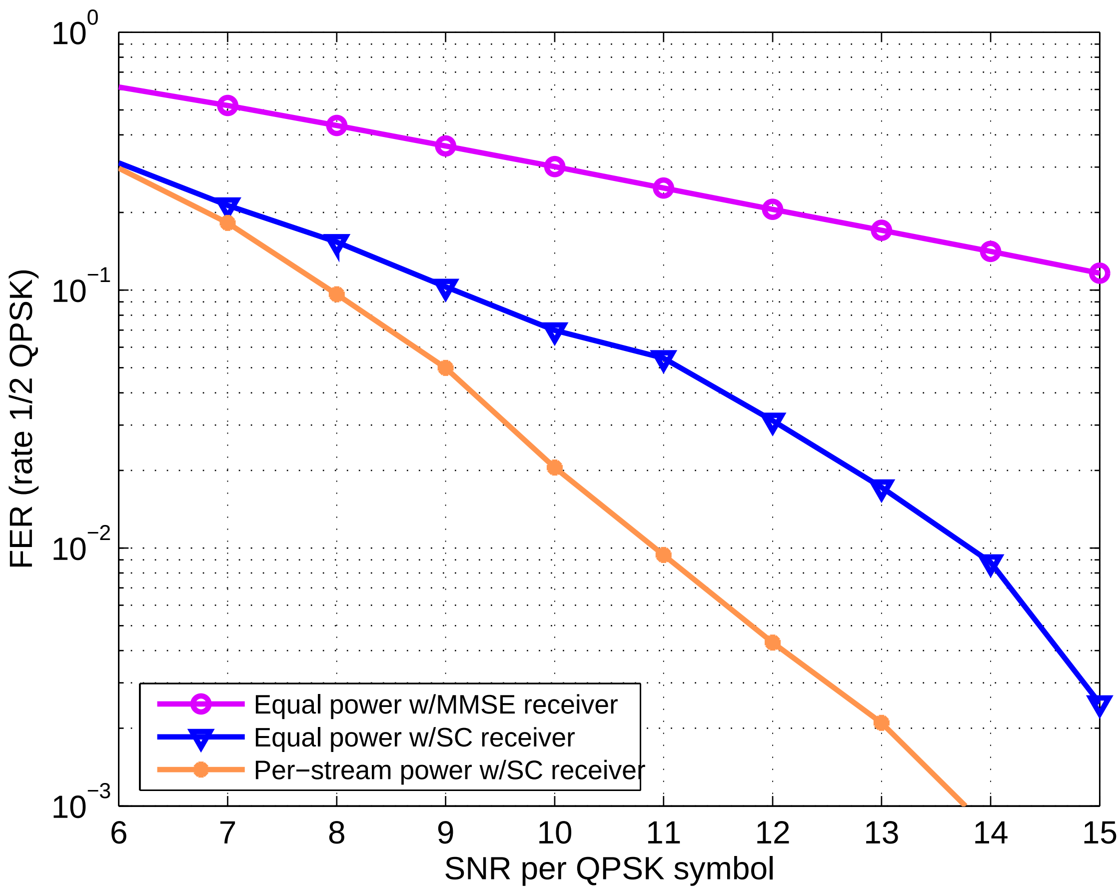

Figure 1. Simulation results showing the benefits of per-stream power weighting for four data stream closed-loop MIMO for four antennas at the BS and four antennas at the MSS. The MSS is moving at 2.0 MPH and there is a 10 msec feedback delay.

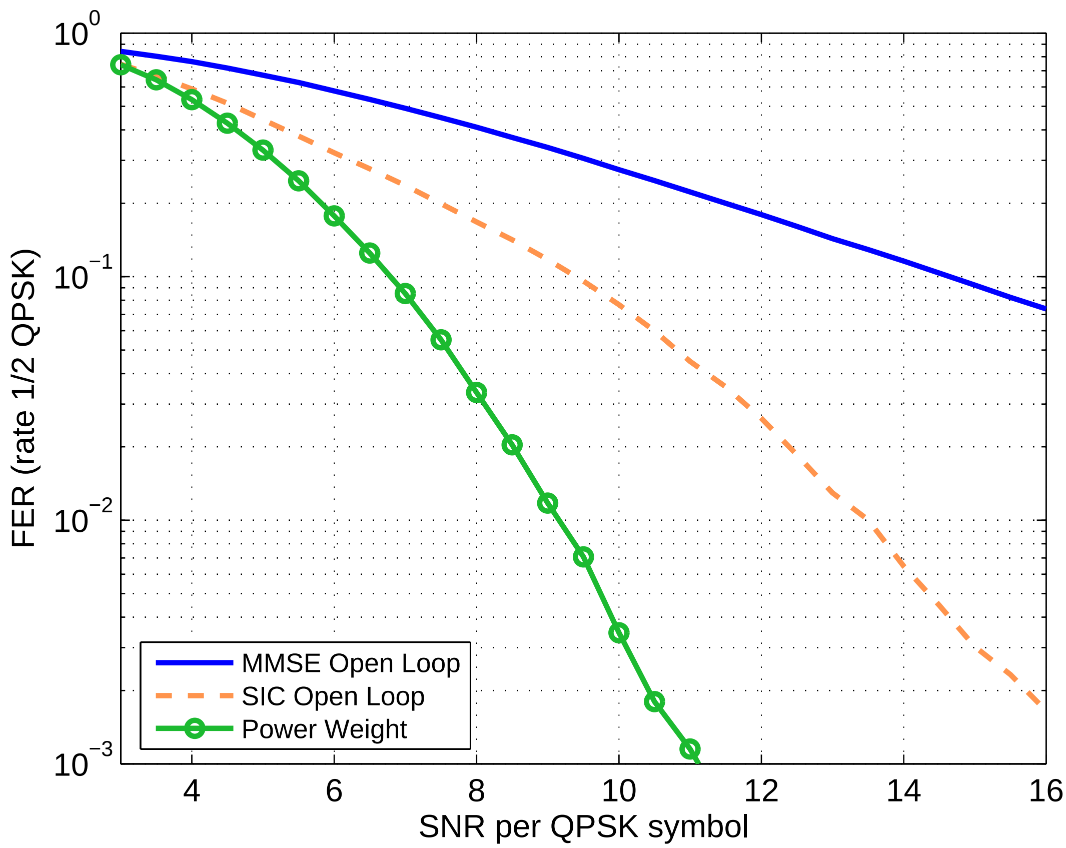

Figure 2. Narrowband (band AMC) simulation results showing the benefits of per-stream power weighting for four data stream open-loop MIMO for four antennas at the BS and four antennas at the MSS.

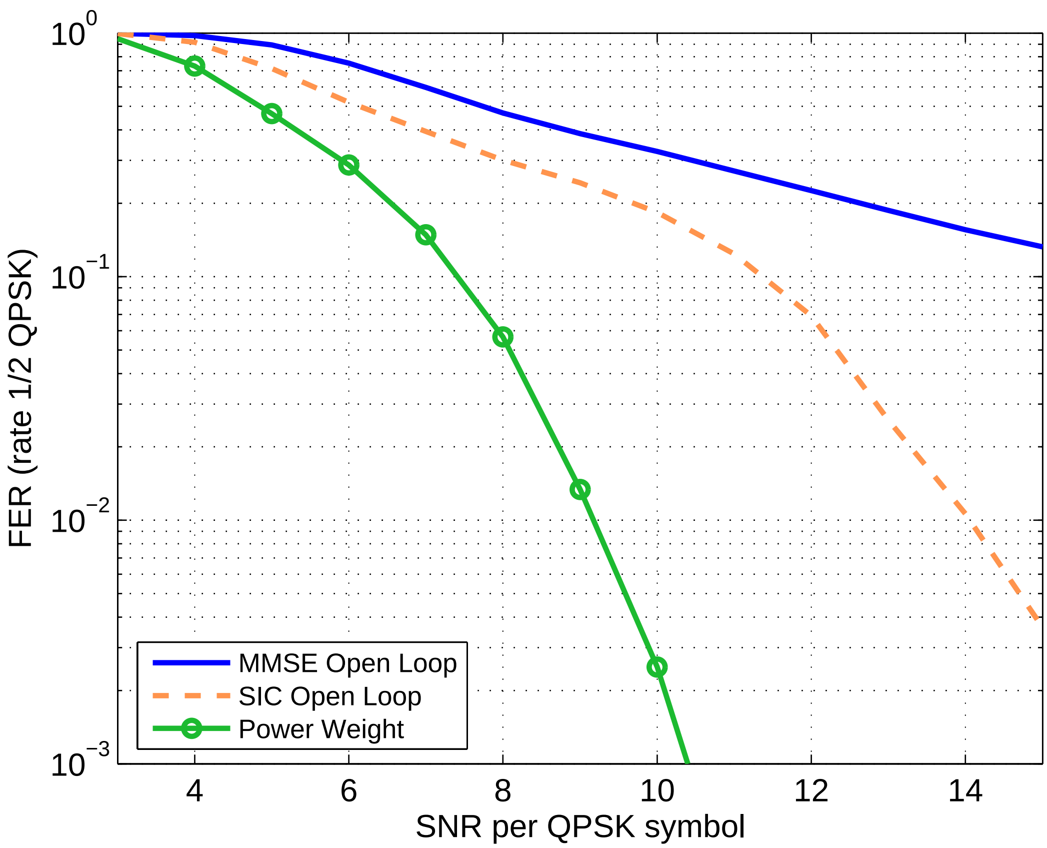

Figure 3. Broadband (PUSC) simulation results showing the benefits of per-stream power weighting for four data stream open-loop MIMO for four antennas at the BS and four antennas at the MSS.

3 Specific Text Changes

[Insert the following after Section 8.4.5.4.10.12:]

8.4.5.4.10.13 Per Stream Power Control

When the feedback type field in CQICH Enhanced Allocation IE is "101" = Per stream power control, the BS require the power weighting of each spatial streams that can be supported by the MSS if the BS considers sending more than one stream to this MSS. If required by the BS, the MSS shall report the square root of the power weighting factors of the spatial streams (i.e., to report α_i with $i=1..N_s$ (number of streams) where $\sum_i \alpha_i^2=1$). The first stream shall correspond to the largest weighting and the second stream to the second largest weighting, and so on. The power weighting of the last stream can be derived as the remaining power and thus needs not to be reported. When no codebook matrix is fed back and horizontal encoding is being used, the 4 lsb of the SS MAC address determine which antenna the first (highest) stream power is for (antenna_start = the decimal value modulo the number of BS antennas). The next stream power is for the antenna number (antenna_start +1) modulo the number of BS antennas, and so forth. When a beamforming codebook matrix is also fed back, the strongest stream corresponds to the first beamforming vector (i.e., first column of the beamforming matrix) and so on.

The feedback allocation and power weighting quantization procedure is as follows:

If the BS wants the MSS to feed back the power weightings for up to Ns=2 streams, one 3-bit CQI channel is allocated, or alternatively one 4-bit secondary fast feedback channel is allocated with its MSB always set to zero. A numerical range of [$\sqrt{1/2}$,1] is first uniformly divided into 2^3=8 levels (i.e., with the interval between levels being (1-$\sqrt{1/2}$)/7) and the MSS quantizes the squared root of the power weighting of the first stream to the nearest level. The value of "1" means the first stream uses all transmit power (i.e., a single stream is preferred by the MSS, rather than two streams).

If the BS wants the MSS to feed back power weighting for up to Ns=3 streams, one 6-bit CQI (or two 3-bit CQI channels) is allocated. The first power weighting is quantized using 4 bits and the second using 2 bits. A numerical range of [$\sqrt{1/3}$,1] is first uniformly divided into 2^4=16 levels (i.e., with the interval between levels being (1-$\sqrt{1/3}$)/15) and the MSS quantizes the squared root of the power weighting of the first stream to the nearest level (denoted as α_1). Then, 2 bits are used to quantize the range of [$\frac{1}{2}(1-\alpha_1^2)$, min($\alpha_1^2$, $1-\alpha_1^2$)].

If the BS wants the MSS to feed back power weighting for up to Ns=4 streams, one 6-bit CQI and one 3-bit CQI (or three 3-bit CQI channels or one 6-bit CQI and one 4-bit secondary fast feedback channel is with its MSB always set to zero) are allocated. The first power weighting is quantized using 4 bits, the second using 3 bits, and the third using 2 bits. A numerical range of [$\sqrt{1/4}$,1] is first uniformly divided into 2^4=16 levels (i.e., with the interval between levels being (1-$\sqrt{1/4}$)/15) and the MSS quantizes the squared root of the power weighting of the first stream to the nearest level (denoted as α_1). Then, 3 bits are used to quantize the range of [$\frac{1}{3}(1-\alpha_1^2)$, min($\alpha_1^2,1-\alpha_1^2$)] for the second stream squared-root power weighting (denotes as α_2). Finally, 2 bits are used to quantize the range of [$\frac{1}{2}(1-\alpha_1^2-\alpha_2^2)$, min($\alpha_2^2,1-\alpha_1^2-\alpha_2^2$)] for the third stream squared-root power weighting.

Instead of using the CQICH assigned by the BS, the MSS can also use the Feedback header defined in 6.3.2.1.6.1 to provide the per-stream power weighting to the BS. The feedback can be initiated by the MSS for recommending power weightings that do not change rapidly. The feedback type is "1101" and the content of the feedback consists of 3, 6, or 9 bits, corresponding to a maximum of two, three, or four streams sent to the MSS. Other bits in the feedback content field are unused since the allowed number of feedback content bits is 16 in the Feedback header when the CID field is present. The quantization of the per-stream power weighting in Feedback header is the same as in CQI fast feedback.

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[Add the following field to table 7i at the end of section 6.3.2.1.6.1]

Table 7i. Feedback Type and feedback content.

Feedback Type	Feedback contents	Description
0b1101	Per-stream power weighting in multi-stream transmission (3, 6, or 9 bits for a maximum of two, three, or four streams transmitted to the MSS	The recommended per-stream power weighting when multiple streams are transmitted to a multi-antenna MSS (quantization defined in 8.4.5.4.10.11)
0b11~~01~~10-0b1111	Reserved for future use	

[End of "Add the following fields to Table 7i at the end of section 6.3.2.1.6.1"]

3.1.1 Modification to HARQ MAP IE (Normal MAP Extension)

The following addition to the normal MAP IE for MIMO HARQ is, if necessary, to feed forward the actually applied per-stream power weightings that either confirm or override the MSS recommendation.

[Add the highlighted rows (blue text) to Table 101b in Section 8.4.5.3.22.1 as follows]

8.4.5.3.22.1 Dedicated MIMO DL Control IE Format

Table 285u -- Dedicated MIMO DL Control IE Format

Syntax	size	Note
Dedicated MIMO DL Control IE() {		
Length	5 bits	Length of following control information in Nibble.
Control Header	3 bits	Bit #0 : MIMO Control Info Bit #1 : CQI Control Info Bit #2 : Closed MIMO Control Info
N_layer	2 bits	Number of coding/modulation layers 00 = 1 layer 01 = 2 layers 10 = 3 layers 11 = 4 layers
if(MIMO Control Info == 1){		
Matrix	2 bits	Indicates transmission matrix (See 8.4.8)
Per-stream power weighting	1 bit	Indicates presence of power weighting information
if (Per-stream power weighting == 1) {		
Per-stream power weighting}	Variable	Indicates the actual per-stream power weighting defined in 8.4.5.4.10.11 (uses 3, 6, or 9 bits for 2, 3, or 4 transmitted streams as indicated by “Num_stream” above)
if (Dedicated Pilots == 1) {		Dedicated Pilots field in STC_Zone_IE()
Num_Beamformed_Streams	2 bits	Indicates the number of beamformed streams which is equal to the number of pilot patterns 00 = 1 stream 01 = 2 streams 10 = 3 streams 11 = 4 streams
}		
}		
If(CQICH Control Info == 1){		
Period	3 bits	Period (in frame) = 2^period
Frame offset	3 bits	

Duration	4 bits	A CQI feedback is transmitted on the CQI channels indexed by the CQICH_ID for 10 x 2^d frames.
For (j=0;N_layer+1;j++) {		
Allocation index[1]	6 bits	Index to CQICH assigned to this layer.
}		
CQICH_Num	2 bits	Number of additional CQICHs assigned to this SS (0-3)
for (i=0; i<CQICH_Num; i++) {		
Feedback type	3 bits	Type of feedback on this CQICH
Allocation index	6 bits	
}		
}		
if(Closed MIMO Control Info == 1){		

if(MIMO Control Info==1)
MIMO mode = Matrix
else
MIMO mode = Matrix in STC_Zone_IE()		

If (MIMO mode == 00 or 01) {		

Antenna Grouping Index }	3 bits	Indicates the index of antenna grouping
		See 8.4.8.3.4 and 8.4.8.3.5
		If((Matrix_indicator == 00)
		000~010 = 0b101110~0b110000 in Table 298c
		else
		000~101 = 0b110001~0b110110 in Table 298c

elseif (MIMO mode == 10) {		
Num_stream	2 bits	Indicates the number of streams in Table 316f for 3 Tx and Table 316g for 4 Tx.
Antenna Selection Index	3 bits	Indicates the index of antenna selection See 8.4.8.3.4 and 8.4.8.3.5 000~110 = 0b110000~0b110101 in Table 298d
elseif (MIMO mode == 11) {		
Num_stream	2 bits	Indicates number of streams
Codebook Precoding Index	6 bits	Indicates the index of precoding matrix W in the codebook See 8.4.8.3.6
Per-stream power weighting	1 bit	Indicates presence of power weighting information

if (Per-stream power weighting == 1) {		
Per-stream power weighting}	Variable	Indicates the actual per-stream power weighting defined in 8.4.5.4.10.11 (uses 3, 6, or 9 bits for 2, 3, or 4 transmitted streams as indicated by "Num_stream" above)
}		
Padding	Variable	Padding to Nibble; shall be set to 0
}		

[End of "Add the highlighted rows to Table 285u in Section 8.4.5.3.22.1 "]

3.1.2 Adding receiver capability to do successive cancellation

[Add a new section 11.7.8.11]

11.7.8.11 Advanced Receiver Capability

This field indicates whether the MSS is advanced receiver capable

Type	Length	Value	Scope
21	1	Bit 0: Successive Interference Receiver Capability Bit 1-7: Reserved	REG-REQ REG-RSP

[End of "Adding receiver capability to do successive cancellation"]

References

[1] T. A. Thomas and F. W. Vook, "A Method for Improving the Performance of Successive Cancellation in Mobile Spread MIMO OFDM," *Proc. IEEE VTC-2002/Fall*, Vancouver, Canada, September 2002.

[2] D. J. Love, and R. W. Heath Jr., "Limited Feedback Unitary Precoding for Spatial Multiplexing Systems," *to appear in IEEE Transactions on Information Theory*.