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Title	**Modifications to the Feedback Methodologies in UL Sounding**
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Re:	LB26b – IEEE802.16 REV2/D3.
Abstract	This contribution proposes modifications to the feedback mechanism contained in the UL sounding signaling.
Purpose	Review and adopt.
Notice	
Release	
Patent Policy	

Modifications to the Feedback Methodologies in UL Sounding

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Introduction

Direct feedback techniques such as direct or analog feedback of channel coefficients are generally effective techniques for enabling closed loop transmission techniques such as beamforming and closed-loop MIMO. However, the direct coefficient feedback methodology ("include additional feedback"==0b01) in the UL sounding signaling has modes that are either very inefficient or not well specified. An alternative direct feedback method is required.

This contribution proposes a simple modification to the UL Sounding Command IE that enables the direct feedback of the transmit covariance matrix from the MS to the BS. This functionality provides a better alternative to the direct coefficient feedback methodology currently included in the sounding signaling. Note that in the UL Sounding Command IE (Table 463), the "Include Additional Feedback" has a setting of 0b11 to mean "include feedback message"; however no corresponding feedback message or method is defined in the spec. This contribution can be viewed as filling in the missing functionality for when the “Include Additional Feedback” is set to 0b11.

Overview of proposed modifications

The proposed modifications are straightforward and do not break backward compatibility with any mobile stations that are constructed to support UL Sounding as specified in [1] and profiled in [2]. These modifications enable the MS to transmit to the BS an analog copy of the downlink transmit covariance matrix as estimated by the MS. The BS then can use the transmit covariance matrix to perform closed-loop transmission on the downlink (e.g., beamforming and MIMO+Beamforming).

- Within each sounding band allocated to an MS, the MS constructs a modified UL sounding waveform that consists of the usual UL sounding waveform in which the usual sounding waveform values have been punctured by the unique analog values of the covariance matrix entries. Covariance matrix feedback is defined for cyclic shift separability.

- When this covariance matrix feedback methodology is used, the multi-antenna flag is not needed since only one MS transmit antenna is used to send back the modified sounding waveform. Hence, when covariance matrix feedback is used, the multi-antenna flag is used as a “band relevance flag” to indicate whether the covariance matrix being sent back on a sounding band is a “narrowband” or “wideband” covariance matarix. For the case of a “wideband” covariance matrix, the MS must compute the covariance matrix over all subcarriers of the downlink OFDMA signal bandwidth. For the case of a “narrowband” covariance matrix, the covariance matrix must be computed over the subcarriers corresponding to the sounding band (when the sounding allocation mode is normal) or over the subcarriers corresponding to the logical AMC band containing the sounding band (when the sounding allocation mode is band AMC).

- Finally, when the band AMC bit-map allocation mode is used (rather than the normal allocation mode) to indicate which AMC logical bands the MS must sound on, only one of the sounding bands contained within a logical AMC band are used by the MS to transmit the modified sounding waveform, and that particular sounding band is indicated with a “sounding band index” that replaces two previously unused reserve bits. Note that if a narrowband covariance matrix is being requested in the band AMC sounding allocation mode, the MS is to compute covariance matrix over all subcarriers belonging to the logical AMC band rather than just the subcarriers belonging to the sounding band within the logical band.

Proposed Text Changes

[Table 463 – UL Sounding Command IE Format]

[Additions in underlined blue. Deletions in ~~strikethrough red~~.]

Syntax	Size (Bit)	Notes
UL_Sounding_Command_IE(){	--	--
Extended-2 UIUC	4	UL_Sounding_Command_IE() = 0x04
Length	8	*variable*
Sounding_Type	1	0 = Type A 1 = Type B
Send Sounding Report Flag	1	-
Sounding_Relevance_Flag	1	0 = Sounding relevance is the same for all CIDs 1 = Sounding relevance is specified for each CID
if(Sounding_Relevance_Flag == 0) {	-	-
Sounding_Relevance	1	0 = All CIDs respond in the frame carrying the instruction 1 = All CIDs respond in next frame
Reserved	2	Shall be set to zero.
} else {	-	-
Reserved	3	Shall be set to zero.
}	-	-
Include additional feedback	2	0b00 = No additional feedback 0b01 = Include channel coefficients (see 8.4.6.2.7.3) 0b10 = Include received pilot coefficients ~~0b11 = Include feedback message~~ 0b11 = Include covariance matrix feedback (See 8.4.6.2.7.5)
if (Sounding_Type == 0) {	-	-

Num_Sounding_symbols	3	Total number of sounding symbols being allocated, from 1 (0b000) to 2^3 = 8 (0b111)
reserved	1	Shall be set to zero
for(i=0; i<Num_Sounding_symbols;i++){	-	-
Separability Type	1	0: occupy all subcarriers in the assigned bands 1: occupy decimated subcarriers
if (Separability type == 0) {	-	(using cyclic shift separability)
Max Cyclic Shift Index P	3	0b000: P = 4 0b001: P = 8 0b010: P = 16 0b011: P = 32 0b100: P = 9 0b101: P = 18 0b110–0b111: *Reserved*
Reserved	1	Shall be set to zero.
} else {	-	(using decimation separability)
Decimation Value *D*	3	Sound every Dth subcarrier within the sounding allocation. Decimation value *D* is 2 to the power of (1 plus this value), hence 2,4,8,… up to maximum of 128, and 0b111 means decimation of 5.
Decimation offset randomization	1	0 = no randomization of decimation offset 1 = decimation offset pseudo-randomly determined
}		
Sounding symbol index	3	Symbol index within the Sounding Zone, from 1 (value 0b000) to 2^3 = 8 (value 0b111)
Number of CIDs	7	Number of CIDs sharing this sounding allocation
Reserved	1	Shall be set to zero.
for (j = 0; j < Num. of CIDs; j++) {	-	-
Shorted basic CID	12	12 LSBs of the MS basic CID value
Power Assignment Method	2	0b00 = Equal power 0b01 = *Reserved* 0b10 = Interference dependent; per subcarrier power limit 0b11 = Interference dependent; total power limit.
Power boost	1	0 = No power boost 1 = Power boost

If (Include additional feedback == 0b11){		Covariance matrix feedback (Section 8.4.6.2.7.5)
Band Relevance Flag	1	0 = "Wideband" covariance matrix: Covariance matrix being fed back on a sounding band corresponds to the entire DL signal bandwidth 1 = "Narrowband" covariance matrix: Covariance matrix being fed back on a sounding band corresponds to the subcarriers of the sounding band (when Allocation mode==0) or all subcarriers of the logical AMC band (when Allocation mode==1) .
} else {		
Multi-Antenna Flag	1	0 = MS sounds first antenna only 1 = MS sounds all antennas
}		
Allocation Mode	1	0: Normal 1: Band AMC
If (Allocation Mode == 1) {	-	-
Band bit Map	12	See logical band defined in 8.4.6.3.2.
If (Include additional feedback == 0b11){		Covariance matrix feedback (Section 8.4.6.2.7.5)
Sounding band index within "AMC logical band"	2	Note that a "sounding band" has 18 subcarriers. When "AMC logical band" has 72 subcarriers: This field further instructs the MS to sound on one of the four sounding bands within the AMC logical band in case of "1" in the corresponding AMC band bitmap. When "AMC logical band" has 36 subcarriers, the first bit further instructs the MS to sound on one of the two sounding bands within AMC logical band in case of "1" in the corresponding AMC band bitmap. The second bit is reserved.
} else {		
Reserved	2	Shall be set to zero.
}		
} Else {	-	-
Starting Frequency Band	7	Out of 96 bands at most (FFT size dependent)
Number of frequency bands	7	Contiguous bands used for sounding
}	-	-

If (Sounding Relevance Flag == 1) {	-	-
Sounding_Relevance	1	-
} else {	-	-
Reserved	1	Shall be set to zero
}		
if (Separability Type == 0) {		
Cyclic time shift index *n*	5	Specifies a frequency-domain phase ramp to be multiplied to the Golay Sequence as shown in Equation 83. The value of n ranges from 0 to P-1.
} else {	-	-
Decimation Offset d	6	Relative starting offset position for the first sounding occupied subcarrier in the sounding allocation
If (Include additional feedback == 0b01) {	-	
Use same symbol for additional feedback	1	0 = The additional feedback is sent in the symbol(s) following the allocated sounding symbol. 1 = The additional feedback is sent in the same symbol as the allocated sounding symbol.
Reserved	2	Shall be set to zero
} else {		
Reserved	3	Shall be set to zero.
}		
}		
Periodicity	3	0b000 = Single command, not periodic, or ter-minate periodicity. Otherwise, repeat sounding once per *r* frames, where $r = 2^{(n-1)}$, where n is the decimal equivalent of the periodicity field.
}	-	-
}	-	-
} else {	-	-

Permutation	3	0b000 = PUSC perm 0b001 = FUSC perm 0b010 = Optional FUSC perm 0b011 = PUSC-ASCA 0b100 = TUSC1 0b101 = TUSC2 0b110 = AMC (2x3) 0b111 = *Reserved*
DL_PermBase	6	-
Num_Sounding_symbols	3	-
for (i = 0; i < Num_Sounding_symbols; i++){	-	-
Number of CIDs	7	-
Reserved	1	Shall be set to zero.
for (j = 0; j < Number of CIDs; j++) {		
Shortened basic CID	12	12 LSBs of the MS basic CID value
If(Sounding_Relevance_Flag == 1){	-	-
Sounding_Relevance	1	0 = Respond in the frame carrying the instruction 1 = Respond in next frame
Reserved	3	Shall be set to zero
}	-	-
Subchannel offset	7	The lowest index subchannel used for carrying the burst, starting from subchannel 0
Power boost	1	0 = No power boost 1 = Power boost
Number of subchannels	3	The number subchannels with subsequent indexes, used to carry the burst.
Periodicity	3	0b000 = Single command, not periodic, or terminate periodicity. Otherwise, repeat sounding once per r frames, where $r = 2^{(n-1)}$, where n is the decimal equivalent of the periodicity field.
Power Assignment Method	2	0b00 = Equal power 0b01 = *Reserved* 0b10 = Interference dependent; per subcarrier power limit 0b11 = Interference dependent; total power limit
}	-	-
}	-	-

Padding	*Variable*	Pad IE to octet boundary. Bits shall be set to 0
}	-	-

[Insert new Section 8.4.6.2.7.5]

8.4.6.2.7.5 Direct Feedback of Transmit Covariance Matrix

If the Include Additional Feedback field is set to 0b11, then the UL Sounding Command IE() enables the MS to perform direct transmission of the DL transmit covariance matrix to the BS along with the UL sounding waveform. This functionality provides the BS with the transmit covariance matrix of the DL channel, which the BS can use to perform closed loop transmission on the DL (e.g., beamforming or MIMO+Beamforming in an STC zone with "dedicated pilots"==1).

When direct feedback of the transmit covariance matrix is requested, the sounding command IE will indicate which sounding bands will be occupied by the MS in the relevant sounding symbol of the sounding zone. When the allocation mode is zero (normal allocation), then the "Start frequency band" and "number of frequency bands" indicates a range of contiguous sounding bands that the MS occupies as is done when no additional feedback is requested. However, when the allocation mode is one (sounding bands allocated according to the Band AMC bitmap), then for each AMC logical band for which the bitmap value is set to one, the MS will occupy only the sounding band indicated by the field "Sounding band index within AMC logical band" rather than all sounding bands that belong to that AMC logical band. The ordering of the sounding bands within the AMC logical band is in the same direction of increase as the ordering used to number the AMC bands across the OFDMA bandwidth.

When using direct feedback of the transmit covariance matrix, the sounding separability type must be set to cyclic shift separability. Furthermore, since only one MS transmit antenna is used for feedback of the covariance matrix, the multi-antenna flag is not used and is replaced with the band-relevance flag as described in more detail below.

The frequency domain signal to be transmitted on an occupied sounding bands is constructed as follows: The MS is first expected to measure the DL transmit covariance matrix by first estimating the multi-antenna downlink channel response across the signal bandwidth by using for example the MIMO midamble (Section 8.4.8.5) or by using the broadcast pilots transmitted by the BS in an STC zone with broadcast pilots or by using any other means of estimating the DL multi-transmit antenna channel. Because the MIMO midamble and STC zones support only up to four transmit antennas, the direct feedback of the transmit covariance matrix is supported only for two and four BS transmit antennas. Let the matrix $\mathbf{H}(k)$ be the Mr×Mt estimate of the downlink channel matrix at subcarrier k, where Mt is the number of downlink transmit antennas used by the BS (either physical or otherwise), and Mr is the number of receive antennas used by the MS. The Mt×Mt DL transmit covariance matrix $\mathbf{R}$ for a given set of subcarriers $S(k)$ is defined to be:

$$\mathbf{R} = \sum_{k \in S(k)} \mathbf{H}^H(k)\mathbf{H}(k)$$

During each sounding band assigned to the MS, the MS is expected to transmit an encoded form of the transmit covariance matrix, where there are two possible types of transmit covariance matrix to be transmitted depending on the setting of the Band Relevance Flag. If the Band Relevance Flag is set to 0 (wideband covariance matrix), then the set of subcarriers $S(k)$ over which **R** is computed using the previous equation is equal to all usable subcarriers of the DL signal bandwidth. If the Band Relevance Flag is set to 1 (narrowband covariance matrix), then the set of subcarriers over which the MS must compute the **R** is equal to the subcarriers contained in that sounding band (for the case of normal allocation mode) or all subcarriers belonging to the logical AMC band that contains that sounding band (for the case of band AMC allocation mode). The methodology for encoding the transmit covariance matrix onto a sounding band is as follows.

For two transmit antennas at the BS, the covariance matrix **R** has the following structure:

$$\mathbf{R} = \begin{bmatrix} r_{11} & r_{12} \\ r_{12}^* & r_{22} \end{bmatrix}$$

For four transmit antennas at the BS, the covariance matrix **R** has the following structure:

$$\mathbf{R} = \begin{bmatrix} r_{11} & r_{12} & r_{13} & r_{14} \\ r_{12}^* & r_{22} & r_{23} & r_{24} \\ r_{13}^* & r_{23}^* & r_{33} & r_{34} \\ r_{14}^* & r_{24}^* & r_{34}^* & r_{44} \end{bmatrix}$$

Once the covariance matrix R to be conveyed on that sounding band is calculated, a scaling factor must be computed. For four BS transmit antennas, the scale factor is

$$\beta = \frac{1}{10}\sum_{i=1}^{4}\sum_{j=i}^{4}\left|r_{ij}\right|^2$$

For two BS transmit antennas, the scale factor is

$$\beta = \frac{1}{3}\sum_{i=1}^{2}\sum_{j=i}^{2}\left|r_{ij}\right|^2$$

Figure NNN shows a sounding band format for use when the BS has two and four transmit antennas. The sounding band format with direct covariance matrix feedback contains two types of frequency domain symbols: P_n and R_{ij}. The symbol P_n is equal to the value of the sounding waveform value for the nth carrier within the sounding band. The symbol R_{ij} is the (i,j)th entry of the **R** matrix scaled by one over the square root of the scale factor β:

$$R_{ij} = \frac{1}{\sqrt{\beta}} r_{ij}$$

As shown in Figure NNN, certain sounding values that would have ordinarily been transmitted according to the settings within the UL Sounding Command IE are replaced with scaled analog values of the DL transmit covariance matrix.

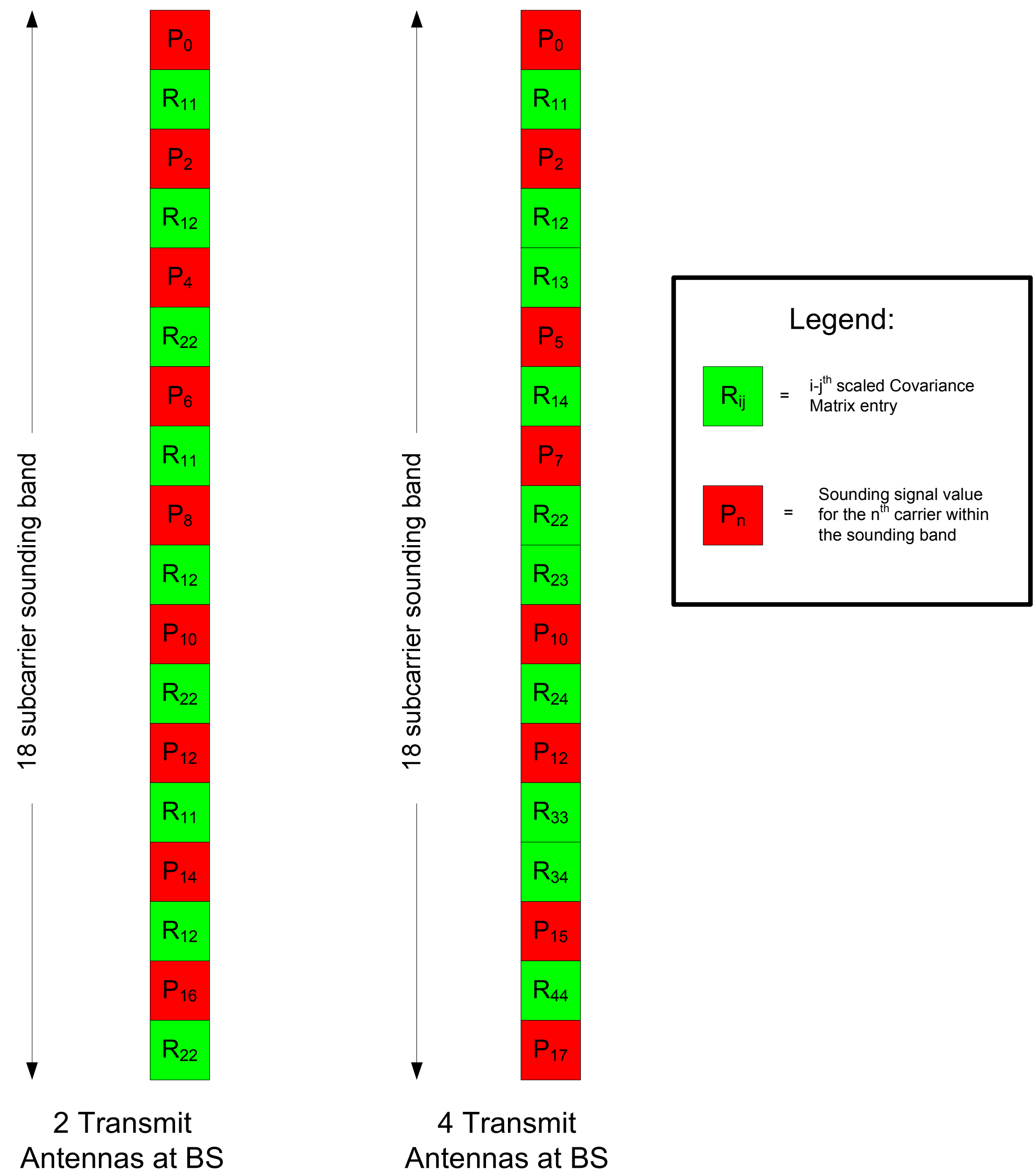

Figure NNN – 18 subcarrier sounding band layout for transmitting direct covariance matrix feedback.

References

[1] IEEE P802.16-2004/Cor2/D4 – Draft Corrigendum to IEEE Std 802.16-2004, May 22, 2007

[2] WiMAX Forum™ Mobile System Profile – Release 1.0 Approved Specification (Revision 1.4.0: 2007-05-02).