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Title	**Improvements to the Uplink Channel Sounding Signaling for OFDMA**
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Re:	IEEE P802.16-REVe/D5a-2004
Abstract	Modifications to Uplink Channel Sounding methodology to optionally include DL channel coefficients.
Purpose	Adoption of proposed changes into P802.16e
Notice	
Release	
Patent Policy and Procedures	

Improvements to the Uplink Channel Sounding Signaling for OFDMA

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1 Introduction

This contribution provides a modification to the Uplink channel sounding methodology in Section 8.4.6.2.7 of IEEE 802.16e to include the optional direct transmission of DL channel coefficients [1][2] in addition to the sounding waveform. The modification extends the UL channel sounding signaling to enable closed-loop transmission in FDD systems and TDD systems in which BS array transceiver calibration is not implemented. The modification consists of an additional bit in the UL_Sounding_Command_IE() for the purpose of indicating whether or not channel coefficients are to be transmitted along with the sounding waveform in the sounding zone. When this functionality for the direct transmission of channel coefficients is used, the sounding waveform specified by the Sounding Command enables the BS to estimate the UL channel, which the BS then uses to estimate the DL channel coefficients being sent by the MSS in the subsequent symbol interval(s). These estimated DL channel coefficients can then be used by the BS to perform closed-loop transmit precoding.

2 Specific Text Changes

---------------------- Beginning of Text Changes -------------------------------------

[In Section 8.4.6.2.7, modify Table 311 as follows: (deletions in ~~red~~, additions in blue)]

Table 311: UL_Sounding_Command_IE()

Syntax	Size	Notes
UL_Sounding_Command_IE(){		
Extended UIUC	4 bits	0x09
Length	4 bits	Variable
Sounding_Type	1 bit	0 = Type A 1 = Type B
Send Sounding Report Flag	1 bit	
Include additional feedback	2 bits	00 = No additional feedback 01 = include channel coefficients (See Section 8.4.6.2.7.3) 10 = include received pilot coefficients 11 = include feedback message
If (Sounding_Type == 0) {		
Num_Sounding_symbols	3 bits	Total number of sounding symbols being

		allocated, from 1 (“000”) to 2^3=8 (“111”)
Separability Type	1 bit	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	2 bits	00: P=4; 01: P=8; 10: P=16, 11: P=32
} Else {		(using decimation separability)
Decimation Value D	3 bits	Sound every D^{th} subcarrier within the sounding allocation. Decimation value D is 2 to the power of (2 plus this value), hence 4,8,… up to maximum of 64.
Decimation offset randomization	1 bit	0= no randomization of decimation offset 1= decimation offset pseudo-randomly determined
}		
For (i=0;i<Num_Sounding_symbols;i++){		
Sounding symbol index	3 bits	Symbol index within the Sounding Zone, from 1 (bits “000”) to 2^3=8 (bits “111”)
Number of CIDs	4 bits	Number of CIDs sharing this sounding allocation
For (j = 0; j<Num. of CIDs; j++) {		
Shorted basic CID	12 bits	12 LS bits of the MSS basic CID value
Starting Frequency Band	7 bits	Out of 96 bands at most (FFT size dependent)
Number of frequency bands	7 bits	Contiguous bands used for sounding
Power Assignment Method	2 bits	0b00 = equal power; 0b01 = reserved; 0b10 = Interference dependent. Per subcarrier power limit; 0b11 = Interference dependent. Total power limit
Power boost	1 bit	0 = no power boost 1= power boost
Multi-Antenna Flag	1 bit	0=MSS sounds first antenna only 1=MSS sounds all antennas
if (Separability type==0) {		
Cyclic time shift index m	5 bits	Cyclically shifts the time domain symbol by multiples (from 0 to P –1) of N/P where N=FFT size, and P=Max Cyclic Shift Index.
} Else {		
Decimation Offset d	6 bits	Relative starting offset position for the first sounding occupied subcarrier in the sounding allocation
}		
Periodicity	~~2~~ 3 bits	~~00=single command, not periodic, or~~

		~~terminate periodicity~~ ~~01=repeat sounding once per frame until terminated~~ ~~10= repeat instructions once per 2 frames~~ ~~11= repeat instructions once per 4 frames~~ 000 = 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
}		
}		
} else {		
Permutation	2 bits	0b00 = PUSC perm. 0b01 = FUSC perm. 0b10 = Optional FUSC perm. 0b11 = Adjacent subcarrier perm.
IDcell	6 bits	
Num_Sounding_symbols	3 bits	
for (i=0;i<Num_Sounding_symbols;i++){		
Number of CIDs	7 bits	
For (j=0; j<Number of CIDs; j++) {		
Shortend basic CID	12 bits	12 LS bits of the MSS basic CID value
Subchannel offset	7 bits	The lowest index subchannel used for carrying the burst, starting from subchannel 0
Number of subchannels	3 bits	The number subchannels with subsequent indexes, used to carry the burst.
Periodicity	~~2~~ 3 bits	~~00=single command, not periodic, or terminate periodicity~~ ~~01=repeat sounding once per frame until terminated~~ ~~10= repeat instructions once per 2 frames~~ ~~11= repeat instructions once per 4 frames~~ 000 = 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 bits	0b00 = equal power; 0b01 = reserved;

		0b10 = Interference dependent. Per subcarrier power limit; 0b11 = Interference dependent. Total power limit
Power boost	1 bit	0 = no power boost 1= power boost
}		
}		
}		
Padding	Variable	Pad IE to octet boundary. Bits shall be set to 0
}		

[Add a new section 8.4.6.2.7.3 "Direct transmission of channel coefficients". Add the following text.]

Section 8.4.6.2.7.3 Direct transmission of DL channel coefficients

If the "Include additional feedback" field is set to 01, then the UL Sounding Command IE() enables the MSS to perform the direct transmission of DL channel coefficients to the BS along with the UL sounding waveform. This functionality provides downlink channel state information to the BS in both FDD systems and TDD systems in which BS array transceiver calibration is not implemented. With this functionality enabled, DL channel coefficients are encoded as described below and are transmitted in one or more sounding zone symbols that immediately following each symbol being used to transmit UL sounding waveforms. In this case, the UL sounding waveform is used by the BS to estimate the UL channel so that the DL channel coefficients transmitted by the MSSs can be estimated by the BS. The channel coefficients can then be used to enable closed-loop transmission on the downlink.

There are two cases depending on the value of the separability type field. First, if separability type is 0 (cyclic shift separability in the sounding waveform), then a single additional symbol follows each sounding symbol being allocated with the UL_Sounding_command_IE(). In that additional symbol, an MSS antenna that transmits sounding in the sounding symbol will transmit an encoded channel coefficient waveform that occupies the same sounding bands allocated for the sounding waveform. The encoded waveform for the u^{th} MSS (where u is the cyclic shift index in the UL Sounding Command) is defined for two cases: The first case is for where the MSS has a single transmit antenna, but multiple receive antennas, and is told with the sounding command IE to sound all antennas (multi-antenna flag set to 1). In this case, the single transmit antenna transmits the sounding waveform appropriate for the single transmit antenna on the sounding symbol and transmits the following encoded waveform in the next symbol interval:

$$Z_u(k) = \beta_u \sum_{\ell=1}^{M_b} \sum_{m=1}^{M_{m,u}} \hat{H}_{u,m,\ell}(k) s_u(k) \exp\{-j2\pi k(m-1+(\ell-1)M_{m,u})/\alpha_u\}$$

where $\hat{H}_{u,m,\ell}(k)$ is the estimated DL channel coefficient between the ℓ^{th} BS transmit antenna and the m^{th} receive antenna of the u^{th} MSS for subcarrier k; β_u is a scaling to make the average transmit power of the feedback waveform (averaged across all frequency) of $Z_u(k)$ be one; $s_u(k)$ is the sounding sequence of Section 8.4.6.2.7.1; $M_{m,u}$ is the number of receive antennas on the u^{th} MSS, α_u is $M_{m,u}M_b$; and M_b is the number of BS transmit antennas.

The second case for a separability type of 0 is for when the MSS has a number of transmit antennas equal to the number of receive antennas. In this case, the encoded waveform to be transmitted by the MSS antenna assigned to cyclic shift index of *u* in the UL Sounding Command is

$$Z_u(k) = \beta_u \sum_{\ell=1}^{M_b} \hat{H}_{u,\ell}(k) s_u(k) \exp\{-j2\pi k(\ell-1)/\alpha_u\}$$

where $\hat{H}_{u,\ell}(k)$ is the estimated DL channel coefficient between the ℓ^{th} BS transmit antenna and the MSS antenna assigned to the cyclic shift index of *u* in the UL Sounding Command for subcarrier *k*; β_u is a scaling to make the average transmit power of the feedback waveform (averaged across all frequency) of $Z_u(k)$ be one; $s_u(k)$ is the sounding sequence of Section 8.4.6.2.7.1; α_u is $M_{m,u}M_b$; and M_b is the number of BS transmit antennas.

When separability type is 1 in the UL Sounding Command (decimation separability in the sounding waveform), then every allocated sounding symbol is followed by a number of additional symbols equal to the number of BS antennas. In this case, an MSS antenna that transmits on subcarrier *k* of the sounding symbol shall transmit the DL channel coefficient for the i^{th} base antenna to that MSS antenna for the k^{th} subcarrier on subcarrier *k* of the i^{th} additional symbol following the allocated sounding symbol. In equation form, the MSS that transmits a sounding signal on subcarrier *k* of the sounding symbol shall transmit $\hat{H}_\ell(k)$ on the ℓ^{th} symbol following the sounding symbol, where $\hat{H}_\ell(k)$ is the DL channel coefficient from the ℓ^{th} BS antenna to that MSS antenna.

If the "Include additional feedback" field is set to 10, the above equations are modified by sending the measured pilot signal values instead of the measured channel.

-------------------------- End of Text Changes ---

3 Appendix: Simulation Results

Example simulations results are presented for the following closed loop techniques, for the case of broadband transmission.

- CQI channel based techniques: Antenna grouping, antenna selection, and codebook techniques. Both antenna grouping and antenna selection are assumed to need only 2 bits to select the antenna combination (although in the actual system the number of required bits may be 3 since there is no 2 bit CQI definition – rather, a 3 bit CQI is being proposed by others). The codebook-based approach is assumed to use a 6 bit codebook.

- Sounding-based techniques: uplink sounding (as in 802.16e), direct channel feedback (proposed enhancement for FDD systems, this contribution)
- Speeds: Results are shown for both quasi-static channels (no velocity, but independent fading draws for different simulation trials) to identify the gains for slowly fading channels, and for high velocity. The high velocity case is for 50 kph at 2.6 GHz, and we assume a 10 ms delay between the time where the downlink channel is measured and when the CL-MIMO transmission is made based on that DL measurement (e.g., a 10 ms feedback delay).
- System: 2048 FFT in 20 MHz, turbo coding over all subcarriers. This represents a broadband scenario when an SS is allocated most or all of the channel bandwidth in order to get the maximum data rate.
- Channel Model: Cost 259-based spatial channel model, 2 us delay spread, 15 degree angular spread. Transmit antenna spacing at the BS is 1 wavelength or 5 wavelengths. For all cases, the uplink SNR is fixed at 0 dB.
- Channel Frequency Tracking Strategy: Track the frequency selective channel as much as possible with each technique, for the same total feedback overhead. Techniques with compact feedback get better frequency tracking than others (e.g., antenna selection with 2 bits gets 3x better frequency tracking than the 6-bit codebook). The normalized uplink feedback overhead set to be equivalent to a single OFDM symbol per broadband SS. For antenna selection and grouping, that means a new grouping (2 bits) is selected every 24 subcarriers. For direct channel coefficient feedback, a decimation of 2 is used, and for the 6 bit codebook-based technique a new selection is made from the codebook every 72 subcarriers.
- Results are shown in the next figures. For each case, different modulation and coding rates are simulated (from R=1/4 QPSK up to R= ¾ 64-QAM), and a hull curve is created by selecting the best modulation/coding scheme for each SNR. The vertical axis represents the bits/subcarrier obtained after taking the frame error rate into account (e.g., R=1/2 QPSK with no errors would provide 1 bit/subcarrier).

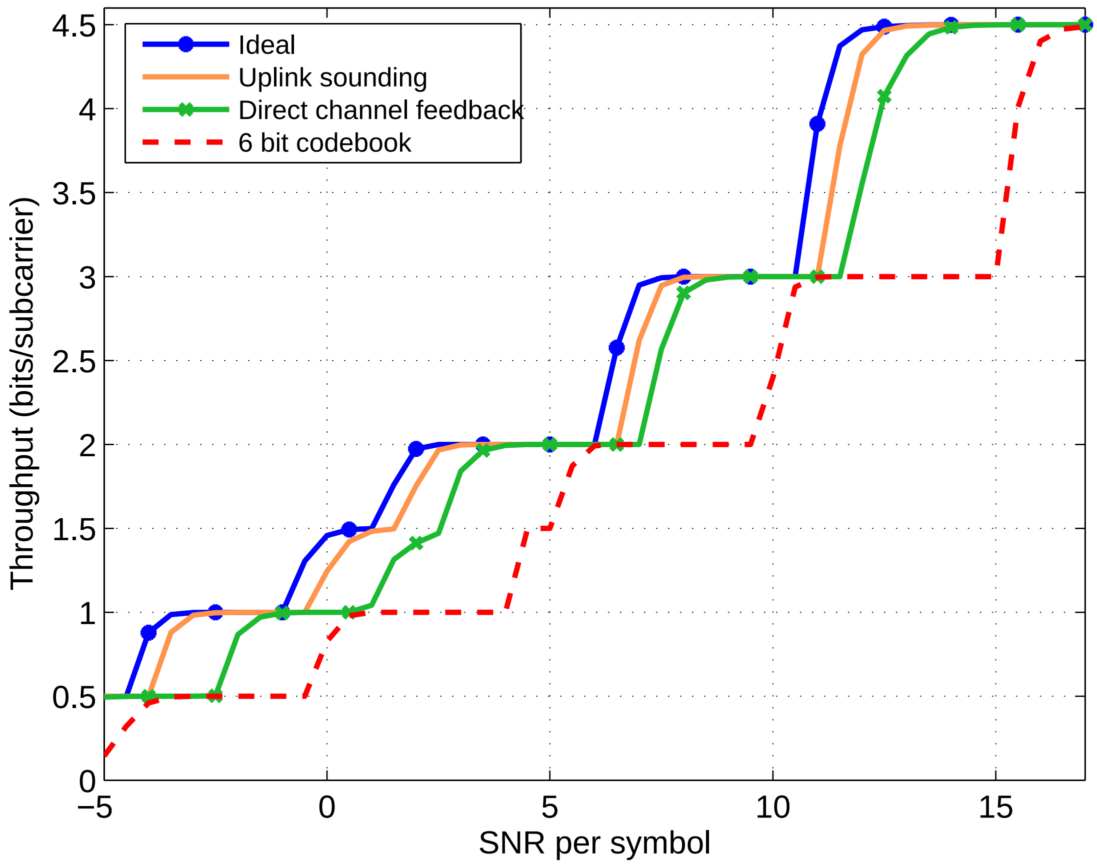

Figure 1. Simulation results for 4 Tx antennas at the BS (5 λ spacing) and one receive antenna at the SS. Faded quasi-static (near-zero velocity) case. Results are shown for ideal instantaneous per-subcarrier channel knowledge, uplink sounding, direct channel feedback (this contribution), and the 6 bit codebook.

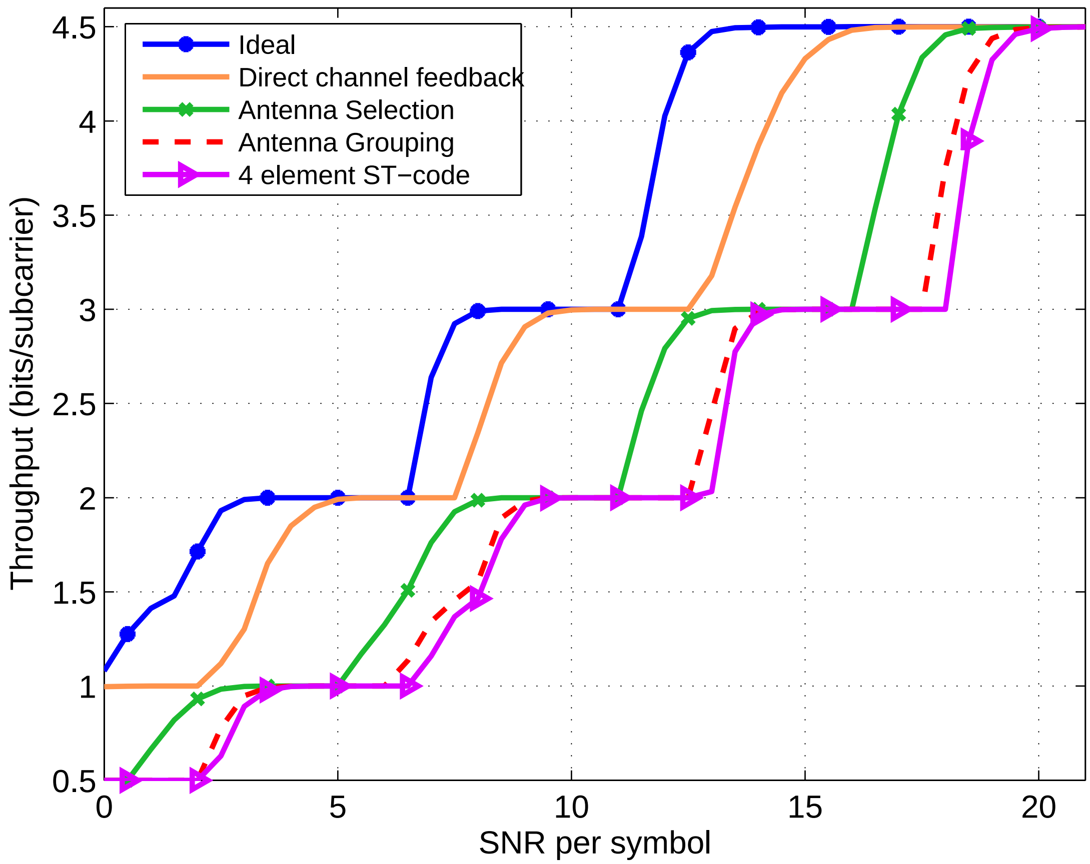

Figure 2. Simulation results for 4 Tx antennas at the BS (1 λ spacing) and one receive antenna at the SS. Faded quasi-static (near-zero velocity) case. Results are shown for ideal instantaneous per-subcarrier channel knowledge, direct channel feedback (this contribution), antenna selection, antenna grouping, and open-loop space-time coding.

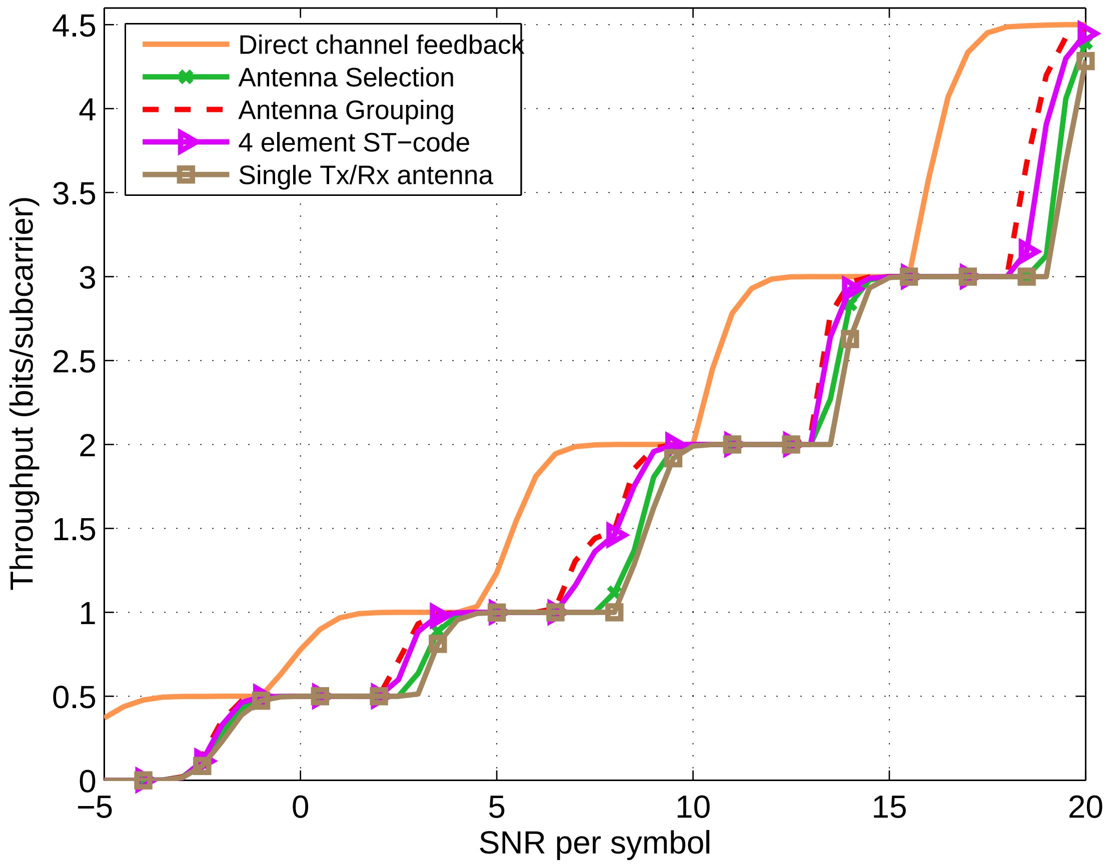

Figure 3. High velocity case: 50 kph at 2.6 GHz with a 10 ms of feedback delay. 4 Tx antennas at the BS (1 λ spacing) and one receive antenna at the SS. Results are shown for antenna selection, antenna grouping, open-loop space-time coding, and direct channel feedback (this contribution). In this example, the direct channel feedback is averaged and the averaged information is used to set the transmit weights, thus providing a performance gain even in the high velocity case due to the finite angular spread of the channel.

References

[1] T. L. Marzetta and B. M. Hochwald, "Fast Transfer of Channel State Information in Wireless Systems," submitted to IEEE Transactions on Communications, June 2004, available at http://mars.bell-labs.com.

[2] T. L. Marzetta and B. M. Hochwald, "Learning the Channel at the Transmitter," *Forty-Second Annual Allerton Conference on Communication, Control, and Computing*, Monticello, IL, September 29-October 1, 2004.