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Title	**Closed-Loop Cluster-Based Transmit Power Control**
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Re:	IEEE P802.16e/D5-2004
Abstract	The proposed power redistribution scheme has the advantages of low feedback BW requirement and low computational complexity. In addition, this scheme can also be applied to the non-STC/MIMO Zones.
Purpose	To enhance STC/MIMO performance
Notice	
Release	
Patent Policy and Procedures	

Closed-Loop Cluster-Based Transmit Power Control

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1. Introduction

STC has shown significant performance improvement in wireless channel environment. To further improve the performance, transmit antenna power can be redistributed across subcarriers such that power of low SNR subcarriers can be boosted and consequently more BER performance gain can be achieved. While boosting the power of low SNR subcarriers, the power of high SNR subcarriers is reduced accordingly so that the total power remains the same.

The proposed power redistribution scheme has the advantages of low feedback BW requirement and low computational complexity. In addition, this scheme can also be applied to the non-STC/MIMO Zones.

2. Background

Due to multiple scattering, channel experiences frequency selective fading. Figure 1 shows a typical snapshot of the channel SNR distribution across a section of subcarriers, containing several clusters. As seen from the figure, the received SNR for cluster k+1 from Tx antenna 1 is much weaker than the others due to multipath fading. If in a similar snapshot taken from other Tx antenna shows a similar deep fade, then STC/MIMO performance will be reduced. Although statistically this is a small probability event (assuming independent Rayleigh fading among multiple transmit antennas), the performance loss cannot be ignored, especially when the number of antennas in a MIMO system is not large.

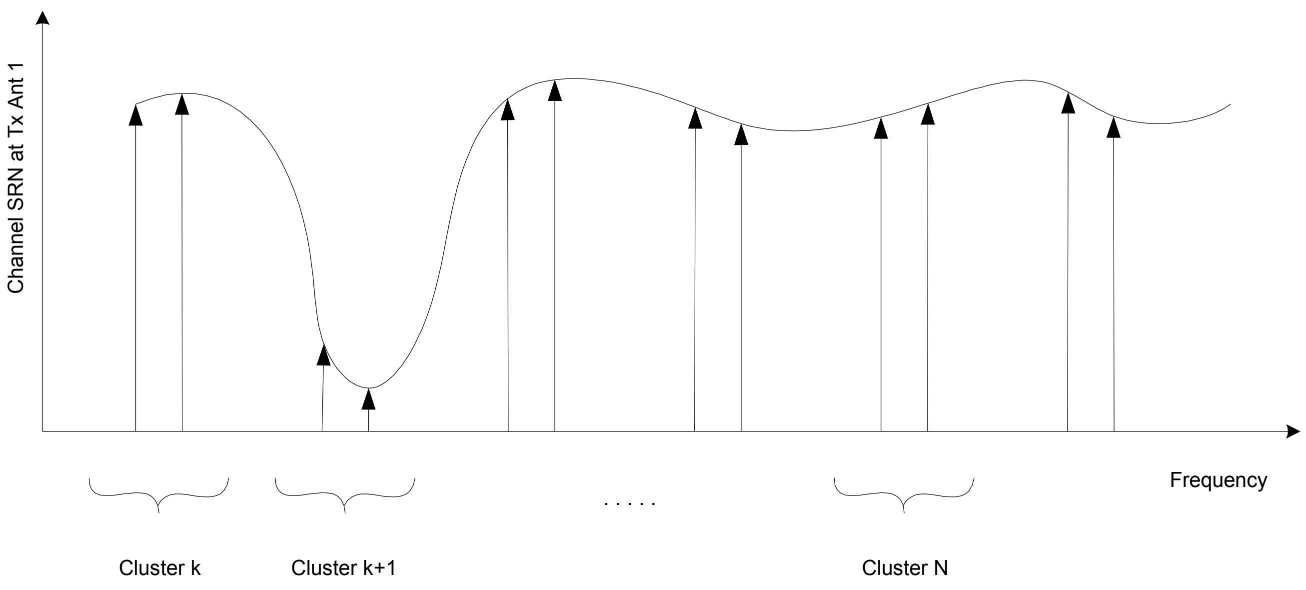

Fig. 1 Channel SNR distribution for Tx Ant 1

We propose to increase the transmit power for those clusters with deep fades while reduce others (slightly), resulting a better (more uniformly) power distribution over the subcarriers. One can show the probability of same level of deep fading is reduced and therefore, a better performance is achieved. The power adjusted subcarrier SNR distribution is shown in Fig. 2.

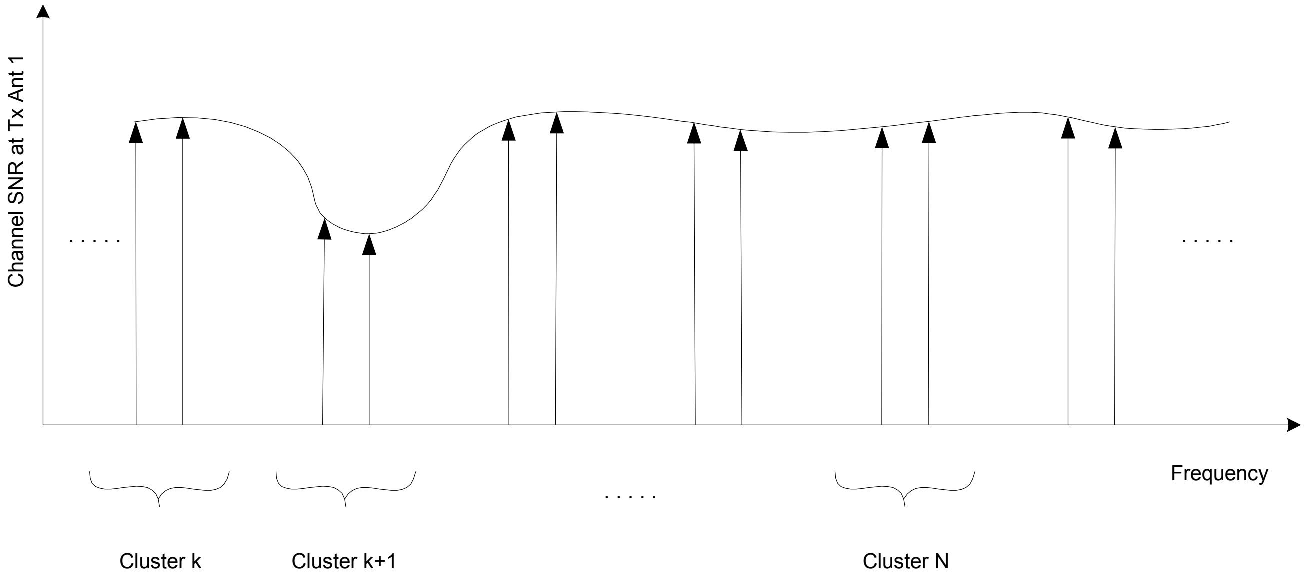

Fig. 2 Power adjusted channel SNR distribution for Tx Ant 1

The information that cluster k+1 is in deep fade could be obtained from CQI measurement. For example, it can be determined by comparing the measured average SNR over a cluster to a predetermined threshold. To reduce the overhead of such channel reporting, only the clusters with averaged SNR below or above the thresholds are notified to BS for power boosting.

Similarly, for multiple antennas, the composite averaged SNR (over multiple antennas) is measured, and one CQI channel is required for each transmit antenna. Fig. 3 shows the case for two transmit antennas.

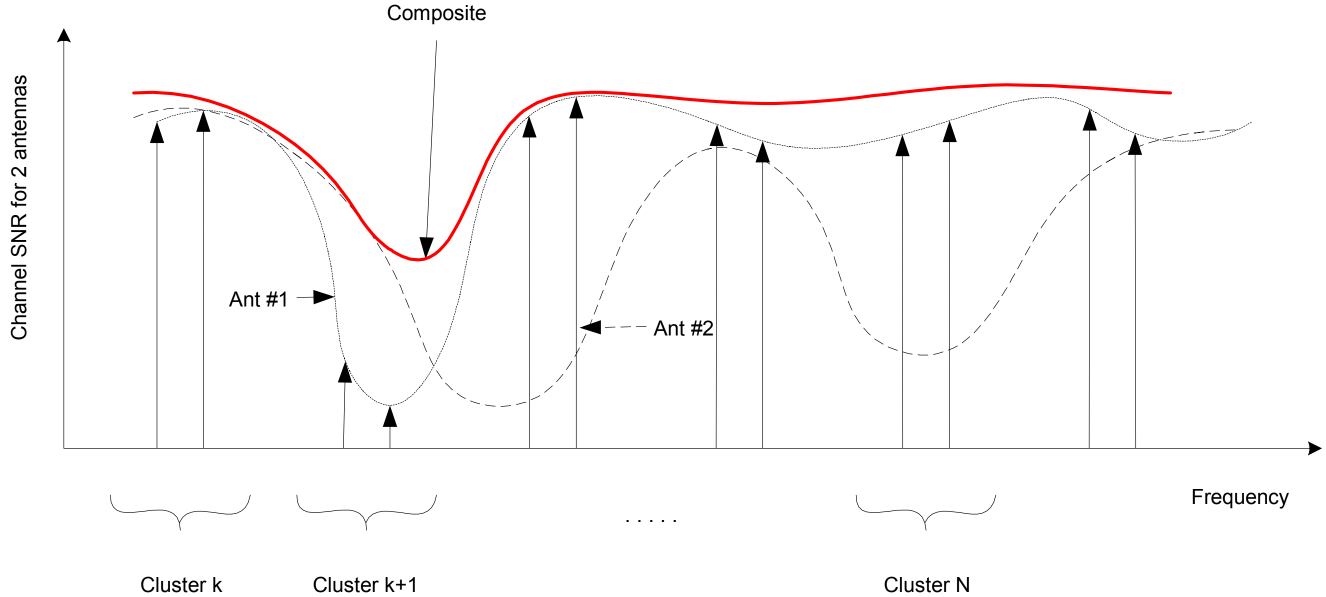

Fig. 3 Channel SNR distribution for Tx Ant 1, 2

Once the CQI measurement is performed, the result is fed back to BS via a CQI channel, encompassing two parameters, (the physical cluster number with inadequate or excess SNR, relative nominal SNR level (measured in dB)). Each CQI measurement requires 7 bits (2^7=128) to address the 120 physical clusters and 3 bits to describe the power level difference as showed in Table 298b.

3. Simulation Results

Simulation results are presented in the following figures

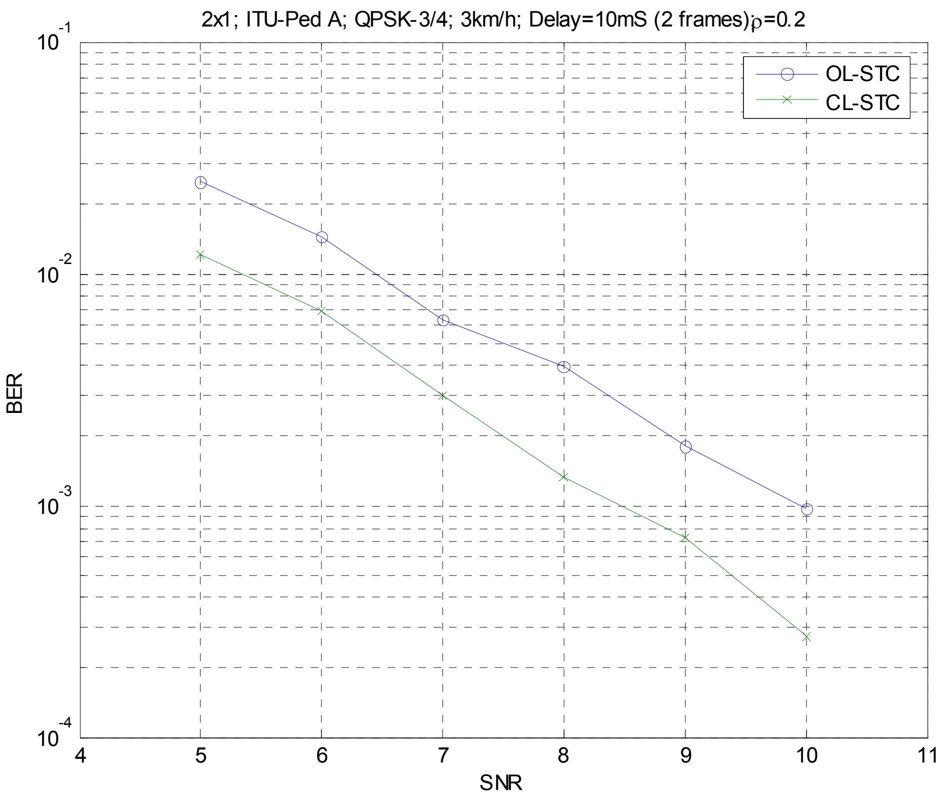

Fig.4 Performance comparison of 2×1 open-loop STC against closed-loop STC; Channel fading model using ITU pedestrian model A at 3km/h; QPSK at Rate 3/4; Feedback delay at 10 ms (2 frame); ρ= 0.2

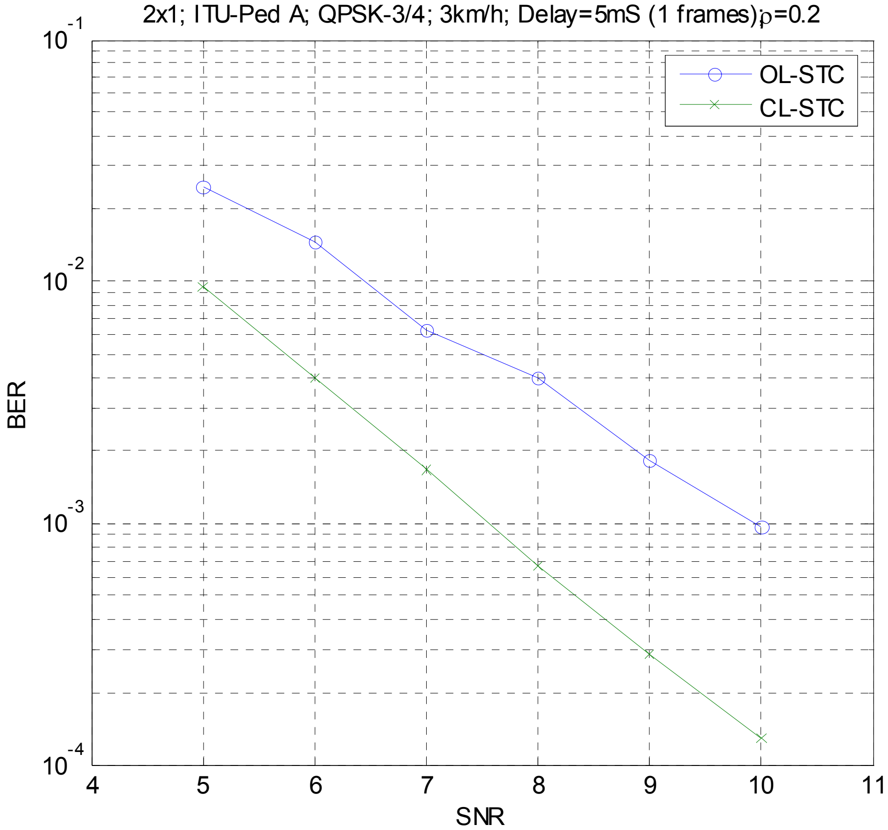

Fig. 5 Performance comparison of 2×1 open-loop STC against closed-loop STC; Channel fading model using ITU pedestrian model A at 3km/h; QPSK at Rate 3/4; Feedback delay at 5 ms (1 frame); ρ= 0.2

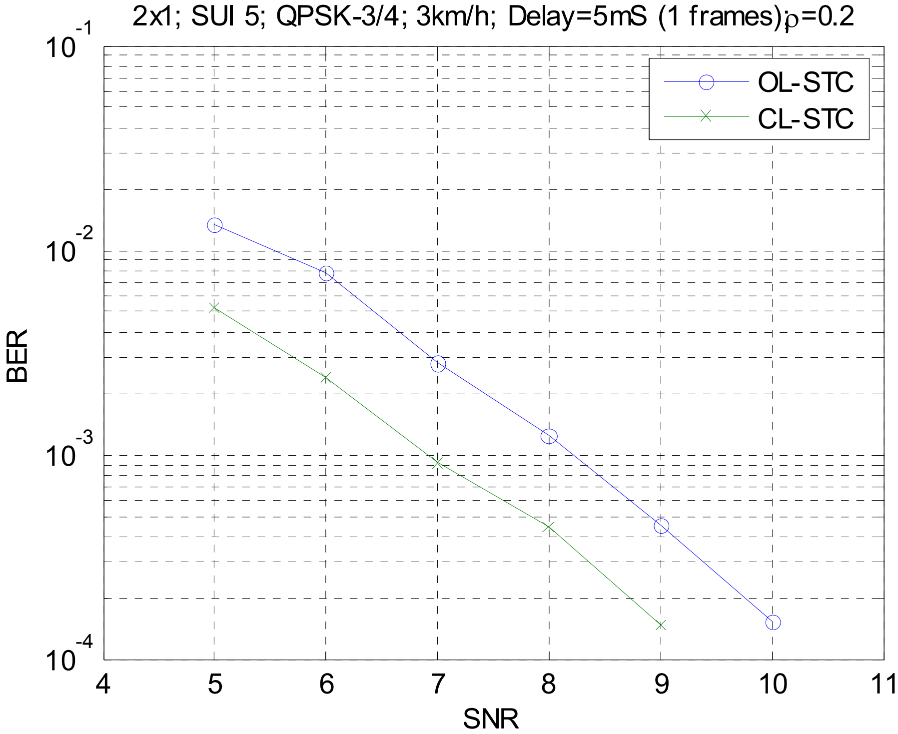

Fig. 6 Performance comparison of 2×1 open-loop STC against closed-loop STC; Channel fading model using SUI 5 model at 3km/h; QPSK at Rate 3/4; Feedback delay at 5 ms (1 frame); ρ= 0.2

The simulation results show that the proposed scheme

1) Suitable for, but not limited to, cluster based PUSC application, with a gain of 1.5 to 2 dB on top of STC gain;
2) Performs well in highly frequency selected fading channels, e.g. SUI 5;
3) Low feedback bandwidth requirement.
4) Works well with small number of transmit antennas and also applicable to single transmit antenna system.

4. Specific Text Changes

[Add section 8.4.8.3.6.1 as follows]

8.4.8.3.6.1 Closed-loop cluster based transmit power control

Based on the information provided by feedback method described in *8.4.5.4.10.10*, transmit antenna power shall be redistributed across subcarriers in different clusters. Power of low SNR subcarriers shall be boosted and consequently more BER performance gain will be achieved. While boosting the power of low SNR subcarriers, the power of high SNR subcarriers shall be reduced accordingly so that the total power remains the same.

[Add section 8.4.5.4.10.10 as follows]

8.4.5.4.10.10 MIMO channel condition feedback

One CQICH channel containing two slots is used to feedback single cluster channel condition or channel pre-equalization parameters. A cluster is defined in section 8.4.6.1.2.1 for PUSC mode. There are total 12 bits included in two slots of the cluster based MIMO pre-equalization feedback CQICH channel, which are split into several segments as showed in Figure 232.

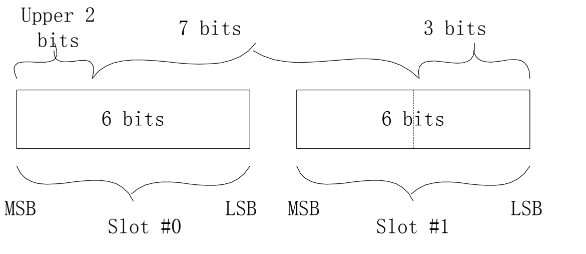

Figure 232—Structure of two slots of the cluster based MIMO pre-equalization feedback CQICH channel

8.4.5.4.10.10.1 Case 1: Channel fading information feedback

The Upper 2 bits defined in Table 298a are used to identify the antenna whose power needs to be changed.

Table 298a—antenna index

Value	Corresponding Antenna
00	Antenna 1
01	Antenna 2
10	Antenna 3
11	Antenna 4

Following 7 bits defined in Table 298b are used to identify the clusters as specified in table 298b. Cluster index is the cluster number defined in section 8.4.6.1.2.1. before renumbering.

Table 298b—Cluster index

Value	Corresponding Cluster
0000000	Cluster 0
0000001	Cluster 1
0000010	Cluster 2
. . .	. . .
1110110	Cluster 118
1110111	Cluster 119
1111000	Reserved for Channel pre-equalization parameters feedback
1111001	
1111010	
1111011	
1111100	
1111101	
1111110	
1111111	

The following 2 bits defined in Table 298c are used to describe the relative power level, which indicate the power fading condition of the feedback cluster.

Table 298c—Encoding of relative power level

Value	Description
00	-9 dB <= Channel Power Fading level < -6 dB
01	-6 dB <= Channel Power Fading level < -3 dB
11	-3 dB =< Channel Power Fading level < 0 dB
11	3 dB =< Channel Power Fading level < 6 dB

The last 1 bit defined in Table 298d are used to specify if a higher rate burst profile is needed to adopt the better SNR after the power boost.

Table 298d—burst profile change

Value	Corresponding Antenna
0	Burst Profile keep unchanged
1	Burst Profile increase 1 level

8.4.5.4.10.10.2 Case 2: Channel pre-equalization parameters feedback

The Upper 2 bits defined in Table 299a are used to identify the antenna whose pre-equalization parameters need to be changed.

Table 299a—antenna index

Value	Corresponding Antenna
00	Antenna 1
01	Antenna 2
10	Antenna 3
11	Antenna 4

Following 7 bits defined in Table 299b are reserved from Cluster index to describe Precoding Decay Timer value, which the time duration of a boost shall exist.

Table 299b—Pre-equalization Decay Frame Timer

Value	Channel precoding parameter
1111000	Time Constant of 2 frames
1111001	Time Constant of 4 frames
1111010	Time Constant of 6 frames
1111011	Time Constant of 8 frames
1111100	Time Constant of 10 frames
1111101	Infinity
1111110	Power Fading Level=0
1111111	Burst Profile Decrease 1

The following 3 bits defined in Table 299c are used to specify the Fading Bandwidth Information.

Table 299c—Fading Bandwidth Information

Value	**Description**
000	Fade Coherence Bandwidth is 1 cluster
001	Fade Coherence Bandwidth is 3 cluster
010	Fade Coherence Bandwidth is 5 cluster
011	Fade Coherence Bandwidth is 7 cluster
100	Fade Coherence Bandwidth is 9 cluster
101	Fade Coherence Bandwidth is 11 cluster
110	Fade Coherence Bandwidth is 13 cluster
111	Fade Coherence Bandwidth is 15 cluster

[Modify Table 298a as follows]

Table 298a—CQICH Enhanced allocation IE format

Syntax	**Size (bits)**	**Notes**
CQICH_Enhanced_Alloc_IE() {		
Extended DIUC	4	0x09
Length	4	Length in bytes of following fields
CQICH_ID	variable	Index to uniquely identify the CQICH resource assigned to the MSS
Period (=p)	2	A CQI feedback is transmitted on the CQICH every 2^p frames
Frame offset	3	The MSS starts reporting at the frame of which the number has the same 3 LSB as the specified frame offset. If the current frame is specified, the MSS should start reporting in 8 frames
Duration (=d)	3	A CQI feedback is transmitted on the CQI channels indexed by the CQICH_ID for 10 x 2^d frames. If d== 0, the CQICH is deallocated. If d == 111, the MSS should report until the BS command for the MSS to stop.
NT actual BS antennas	3	001 = Reserved 010 = 2 actual antennas 011 = 3 actual antennas 100 = 4 actual antennas 101 = 5 actual antennas 110 = 6 actual antennas 111 = 7 actual antennas 000 = 8 actual antennas
Feedback_type	4	0000 = Open loop precoding. Pilots in burst to be precoded with *W*. SS to rely only on pilots in burst for channel estimation. 0001 = Complex weight of specific element of W 0010 = Fast DL measurement 0011 = Layer specific channel strengths 0100 = MIMO mode and permutation zone feedback 0101 = Feedback of subset of antennas to use 0110 = Cluster based MIMO precoding feedback 011~~0~~1 ~ 1111 reserved
CQICH_Num	4	Number of CQICHs assigned to this CQICH_ID is (CQICH_Num +1) When Feedback_type =0110, CQICH_Num =1. (First and second CQICH refer to slot 0 and 1, respectively)
for (i=0;i<=CQICH_Num;i++) {		
Allocation index	6	Index to the fast feedback channel region marked by UIUC=0
}		
if (Feedback_type != 10) {		

MIMO_permutation_feedback cycle	2	00 = No MIMO and permutation mode feedback 01 = the MIMO and permutation mode indication shall be transmitted on the CQICH indexed by the CQICH_ID every 4 frames. The first indication is sent on the 8th CQICH frame. 10 = the MIMO mode and permutation mode indication shall be transmitted on the CQICH indexed by the CQICH_ID every 8 frames. The first indication is sent on the 8th CQICH frame. 11 = the MIMO mode and permutation mode indication shall be transmitted on the CQICH indexed by the CQICH_ID every 16 frames. The first indication is sent on the 16th CQICH frame.
}		
Padding	*variable*	The padding bits are used to ensure the IE size is integer number of bytes.
}		

5. Appendix

5.1 Waterfilling (Optimal precoding allowing bit-loading)

In order to maximize

$$C = \sum_i C_i \propto \sum_i \log_2\left(1 + \frac{P_i\,|H_i|^2}{\sigma^2}\right) \qquad (1)$$

under the constraint of

$$\sum_i P_i = P_0\ . \qquad (2)$$

By using Lagrange's method, we found the well known results:

$$P_i = \frac{P_0}{N} + \frac{1}{N}\sum_j \frac{\sigma^2}{|H_j|^2} - \frac{\sigma^2}{|H_i|^2} \qquad (3)$$

and

$$C_{\max} \propto \sum_i \log_2\left(\frac{|H_i|^2}{\sigma^2}\right) + N\log_2\left(\frac{P_0}{N} + \frac{1}{N}\sum_j \frac{\sigma^2}{|H_i|^2}\right) \qquad (4)$$

To see this is a maximum, let assume there is another

5.2 Channel Inversion (Optimal precoding disallowing bit-loading)

In order to max (1) under the constraints (2) and

$$C_i = const\text{, or } P_i\,|H_i|^2 = const \qquad (5)$$

By using Lagrange's method, we found

$$P_i = \frac{P_0}{\sum_j \frac{1}{|H_j|^2}} \bullet \frac{1}{|H_i|^2} \qquad (6)$$

and

$$C_i \propto \log_2\left(1 + \frac{P_0}{\sum_j \frac{\sigma^2}{|H_i|^2}}\right) \qquad (7)$$

or

$$C_{\max} \propto N \log_2\left(1 + \frac{P_0}{\sum_j \frac{\sigma^2}{|H_i|^2}}\right) \qquad (8)$$

So far we have shown that P_i found this way achieves an *extreme* channel capacity. Now we show this extreme channel capacity is also a maximum channel capacity. We show this by contradiction.

Let's assume that we have found another set P_i (rather than (6)), called Q_i, that achieves a better C_i than (7), called D_i ($D_i > C_i$). Note Q_i has to satisfy the same normalization constraint $\sum_i Q_i = \sum_i P_i = P_0$. Since $Q_i \, |H_i|^2 = const$, condition $D_i > C_i$ is equivalent to $Q_i \, |H_i|^2 > P_i \, |H_i|^2$ for $|H_i|^2 > 0$, since log is a monotonic increasing function. Thus we have $Q_i > P_i$. But this is impossible since it would imply $\sum_i Q_i > \sum_i P_i$, which violates the power normalization condition. Therefore, P_i in (6) is not only an extreme, but also a maximum under (2) and (5). Q.E.D.

5.3 Comparison of the two

Define $\gamma_i = \frac{|H_i|^2}{\sigma^2}$, we can rewrite (4) and (8) as

$$C_1 = \sum_i \log_2\left(\gamma_i \frac{P_0}{N} + \frac{\gamma_i}{N}\sum_j \frac{1}{\gamma_j}\right)$$

and

$$C_2 = \sum_i \log_2\left(\frac{\frac{P_0}{N}}{\frac{1}{N}\sum_j \frac{1}{\gamma_j}} + 1\right).$$

After some derivation and by using of the inequality $\frac{1}{N}\sum_i\left(\frac{1}{\gamma_i}\right) \geq \sqrt[N]{\frac{1}{\gamma_1}\cdots\frac{1}{\gamma_N}}$, one can show $C_1 \geq C_2$, with equality if and only if $\gamma_i = \frac{|H_i|^2}{\sigma^2}$ = const, namely, flat fading.

6. References

[1] IEEE P802.16-REVd/D5-2004 Draft IEEE Standards for local and metropolitan area networks part 16: Air interface for fixed broadband wireless access systems