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Re:	IEEE P802.16-REVe/D3-2004
Abstract	This document contains suggestions for the performance improvement of the CQI signaling in the uplink of OFDMA mode.
Purpose	The document is submitted for discussion by 802.16e Working Group
Notice	
Release	
Patent Policy and Procedures	

CQI Signaling with Unequal Error Protection for OFDMA

1. Introduction

This document describes a method of CQI feedback enhancement for the IEEE 802.16e OFDMA specifications, and proposes a text for IEEE P802.16e/D4 as an optional fast DL measurement feedback.

In the 16-REVd/D5 document, a 4-bit CQI payload is used for fast DL measurement feedback in order to inform a base station of the measured DL SNR. Since the CQI message does not include CRC for error checking, we need more accurate CQI transmission method to improve the system capability. Moreover, the decoding accuracy of MSBs in CQI payload is more important than that of LSBs, because the error induced in the MSBs causes a large difference between the measured SNR at the MSS and the decoded SNR at the base station. Therefore, it is necessary to introduce an unequal error protection (UEP) method to the CQI signaling. This document proposes a simple and efficient method for the UEP CQI signaling.

2. CQI Signaling with UEP

The characteristics of the proposed method can be summarized by:

- Bit repetition in order to realize the unequal bit energy allocation,
- Bit interleaving in order to obtain frequency diversity,
- Binary DPSK modulation for non-coherent detection.

Figure 1 illustrates the proposed CQI signaling method. IEEE802.16d document defines a FAST_FEEDBACK channel composed of N (=6) tiles and L (=4×3 or 3×3) subcarriers in each tile. In such a FAST_FEEDBACK channel, the SS transmits the CQI according to the following procedure.

1. Repeat each CQI payload bit according to a repetition ratio, $R_0{:}R_1{:}R_2{:}R_3$, where R_0, R_1, R_2, and R_3 represent the repetition number for the MSB, the second MSB, ..., and the LSB, respectively.

2. Interleave the repeated bit sequence by,

$$y=\left\{\left(x\times\frac{R}{N}\right)\operatorname{mod}R\right\}+\left\lfloor\frac{x}{N}\right\rfloor \qquad (1)$$

where y bit index in the interleaved bit sequence ($y=0,1,2,\ldots,R-1$)

x bit index in the repeated bit sequence ($x=0,1,2,\ldots,R-1$)

R length of the repeated (interleaved) bit sequence, $R=N(L-1)$

3. Divide the interleaved bit sequence into N groups, each of which has (L-1) bits.

4. Make L DPSK symbols from ($L-1$) bits for each group, and map them to each tile.

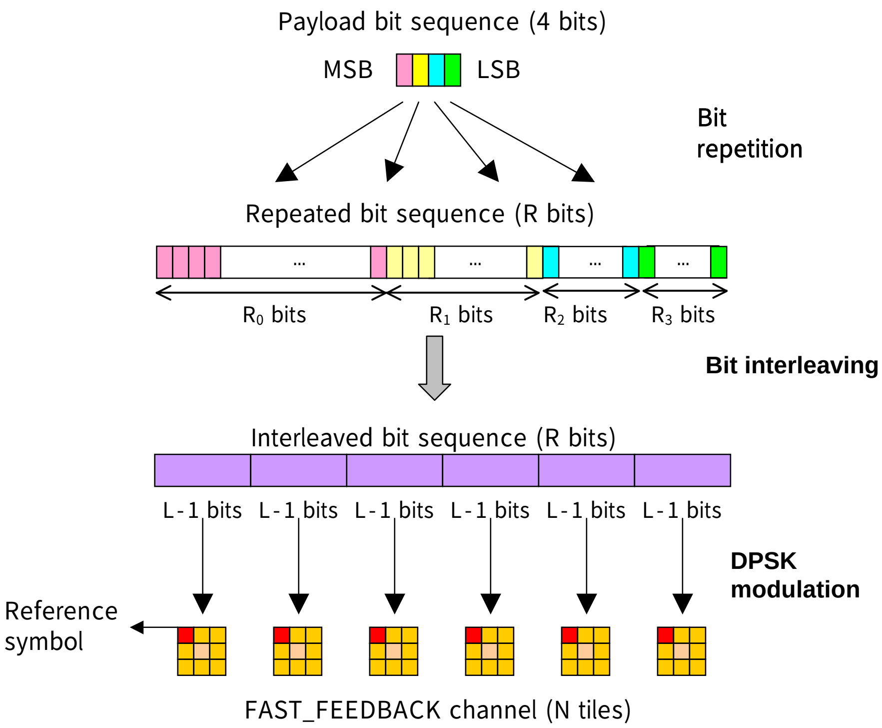


Figure 1: Proposed method for UEP CQI signaling.

In order to approximate a UEP ratio of 4:3:2:1, a repetition ratio of 19:14:10:5 is used for a FAST_FEEDBACK channel composed by six 3-by-3 tiles (i.e., N=6, L=9). For six 4-by-3 tiles (i.e., N=6, L=12), a repetition ratio of 26:19:14:7 is used.

3. Simulation Results

We compared the CQI signaling performance of the following two methods in the 3 by 3 uplink tile structure:

- Current method using non-binary block coding and 8-ary orthogonal QPSK modulation (in section 8.4.5.4.10 of P802.16-REVd/D5 document)
- Proposed UEP method using bit repetition and binary DPSK modulation

We considered two types of CQI payload; 4-bit CQI and 5-bit CQI.

For the 4-bit CQI,

- Payload bits defined by Equation 103 of P802.16-REVd/D5 document

$$\text{Payload bits nibble} = \begin{cases} 0 & S/N < -2\,\text{dB} \\ n & 2n-4 \le S/N < 2n-2\,\text{dB} \;\; ,0 < \text{n} < 15 \\ 15 & S/N \ge 26\,\text{dB} \end{cases} \tag{2}$$

(Ranges from –2 dB to 26 dB with a resolution of 2 dB)

- Block coding defined by Table 294 of P802.16-REVd/D5 document

For the 5-bit CQI,

- Payload bits defined by

$$\text{Payload bits nibble} = \begin{cases} 0 & S/N < -3\,\text{dB} \\ n & n-4 \le S/N < n-3\,\text{dB} \;\; ,0 < \text{n} < 31 \\ 31 & S/N \ge 27\,\text{dB} \end{cases} \tag{3}$$

(Ranges from –3 dB to 27 dB with a resolution of 1 dB)

- Block coding defined by the extended Table 294 in Appendix A

For the performance measure, we need another measure besides bit error rate (BER) and message error rate (MER) of the CQI payload, because we cannot know how much difference to be in the feedback SNR from the BER and MER. Therefore, we need to observe the SNR difference between the SNR actually transmitted from the MSS and the SNR decoded at the BS. For the performance measure, we defined the CQI error (dB) as the SNR difference, and we collected mean and standard deviation of CQI error (dB), as follows:

- CQI error (m) = SNR indicated by the m-th transmitted CQI at the MSS – SNR indicated by the m-th decoded CQI at the BS (dB) (4)

- Mean of CQI error = $\sum_{m=1}^{M} \text{CQI error}(m)/M$ (5)

- Standard deviation of CQI error = $\sum_{m=1}^{M} \text{CQI error}^2(m)/M - \sum_{m=1}^{M} \text{CQI error}(m)/M$ (6)

For the proposed method, the following UEP ratios are used:

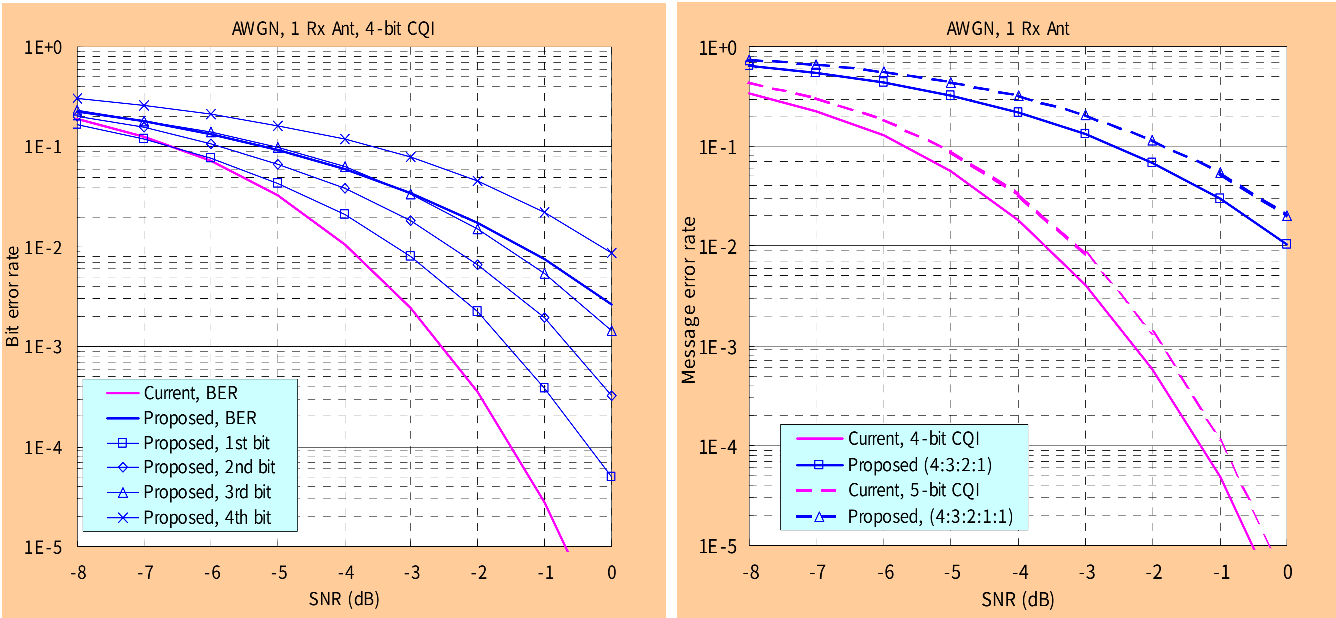
- $R_0{:}R_1{:}R_2{:}R_3$ =19:14:10:5 for the 4-bit CQI
- $R_0{:}R_1{:}R_2{:}R_3{:}R_4$ =17:13:8:5:5 for the 5-bit CQI

Figure 2 and Figure 3 shows BER and MER of the two methods on AWGN channel and ITU-R Pedestrian B channel, respectively. On AWGN channel, the proposed method shows degradation in the bit error rate and the message error rate performances. However, on PED-B channel, the proposed method improves the BER performance of the 1st and 2nd bits due to the UEP capability and frequency diversity, and thus, this leads to improve the CQI error performance as shown in Figure 5.

Figures 5 to 8 compare the CQI error performance for 4-bit CQI payload, and Figures 9 to 12 compare the performance for 5-bit CQI payload. From the simulation results, we can summarize the followings:

- In case of 1 RX antenna at the BS, the proposed method shows a SNR gain of 1 to 2 dB for a CQI error std. of 1 to 2 dB, depending on channel environments.
- In case of 2 RX antennas at the BS, the proposed method shows a SNR gain of –0.8 to 0.4 dB for a CQI error std. of 1 to 2 dB, depending on channel environments.
- For 5-bit CQI, the proposed method can obtain more SNR gain, even in case of 2 RX antennas.

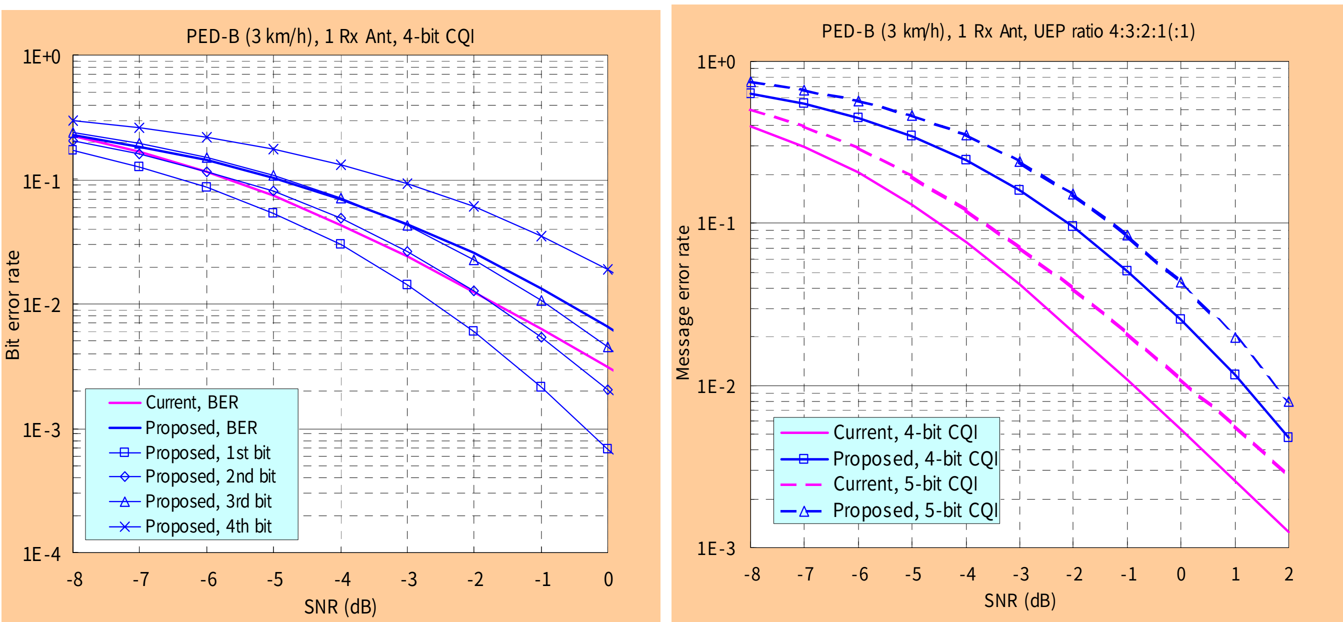
It should also be noted that the complexity of the proposed method is lower than that of the current method. The proposed method uses simple bit repetition instead of a nonbinary block coding and binary DPSK modulation instead of 8-ary orthogonal modulation.



(a) Bit error rate

(b) Message error rate

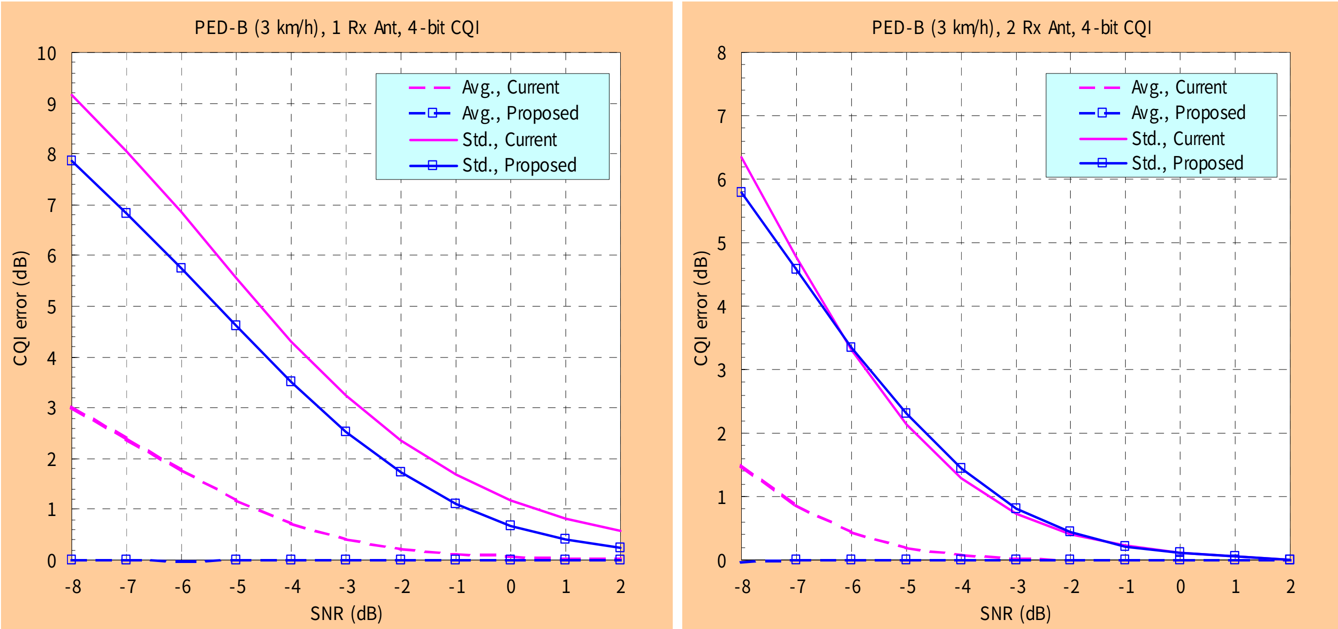
Figure 2: BER and MER on AWGN channel.



(a) Bit error rate

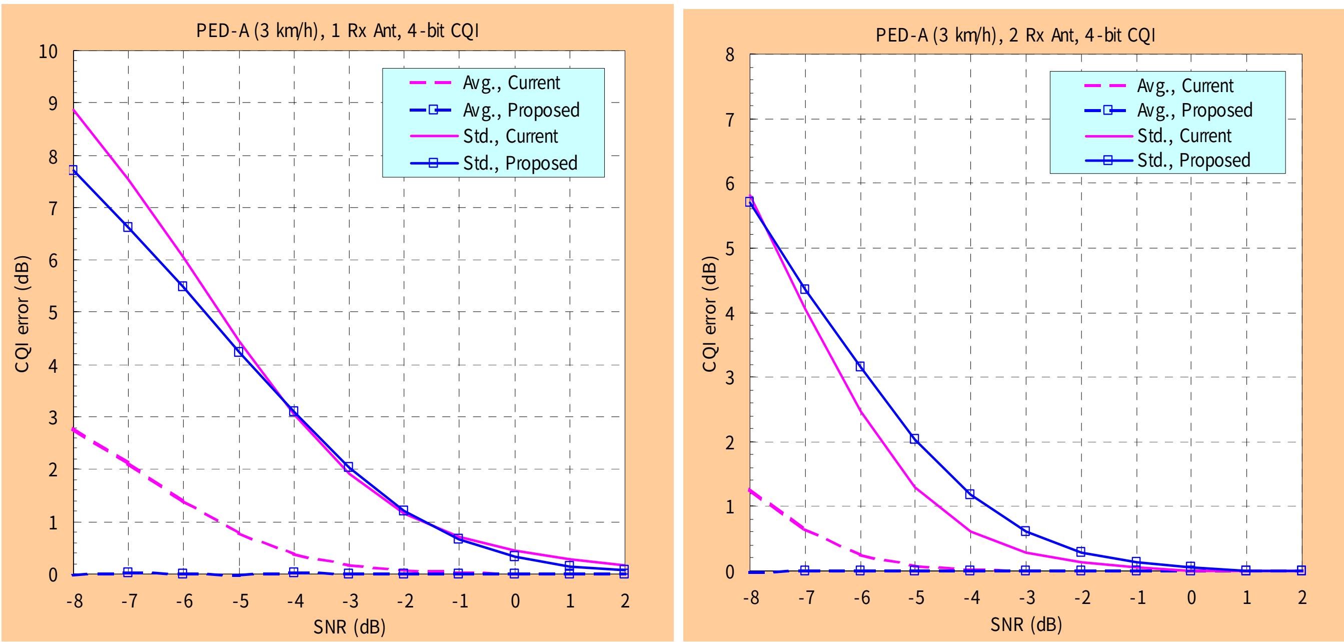
(b) Message error rate

Figure 3: BER and MER on PED-B channel.



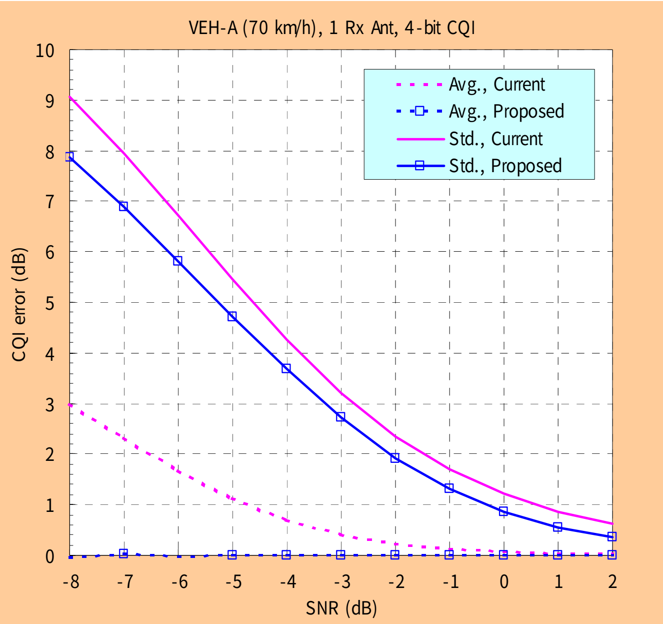
(a) 1 RX ant **(b) 2 RX ant**

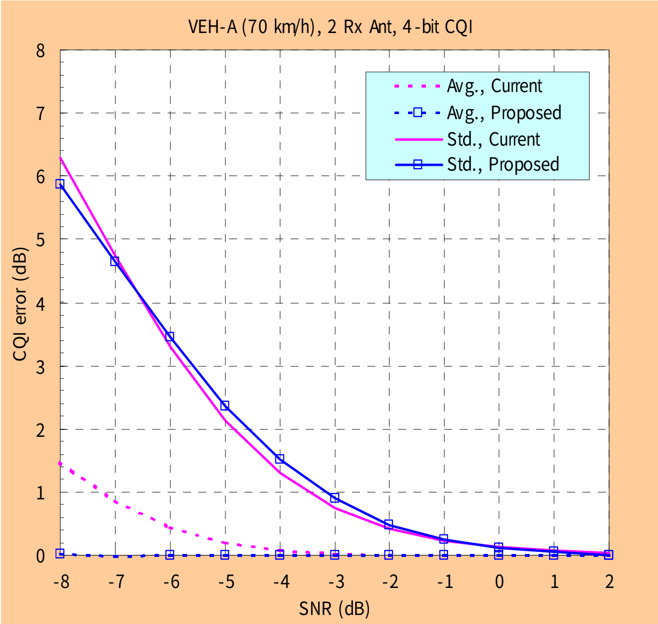
Figure 5: CQI error statistics on PED-B channel (4-bit CQI).



(a) 1 RX ant **(b) 2 RX ant**

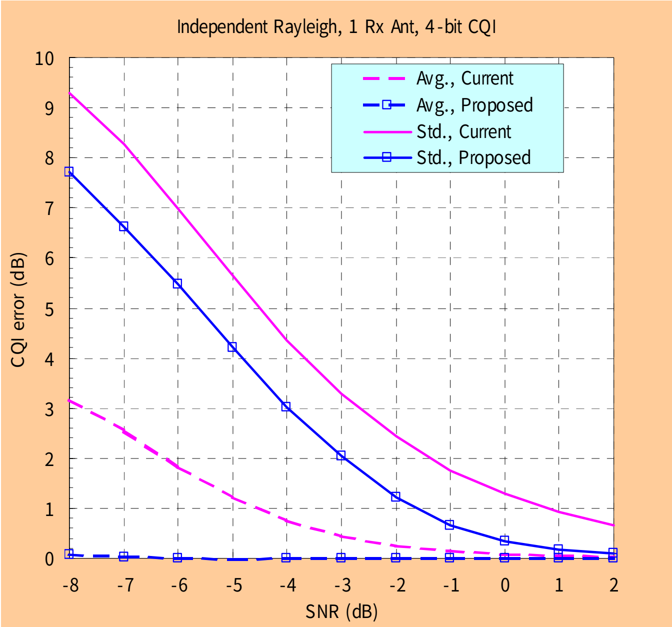
Figure 6: CQI error statistics on PED-A channel (4-bit CQI).

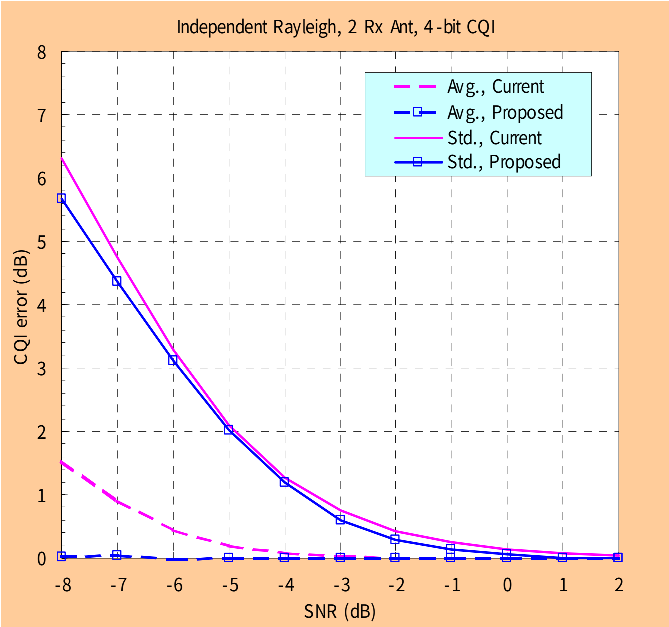




(a) 1 RX ant **(b) 2 RX ant**

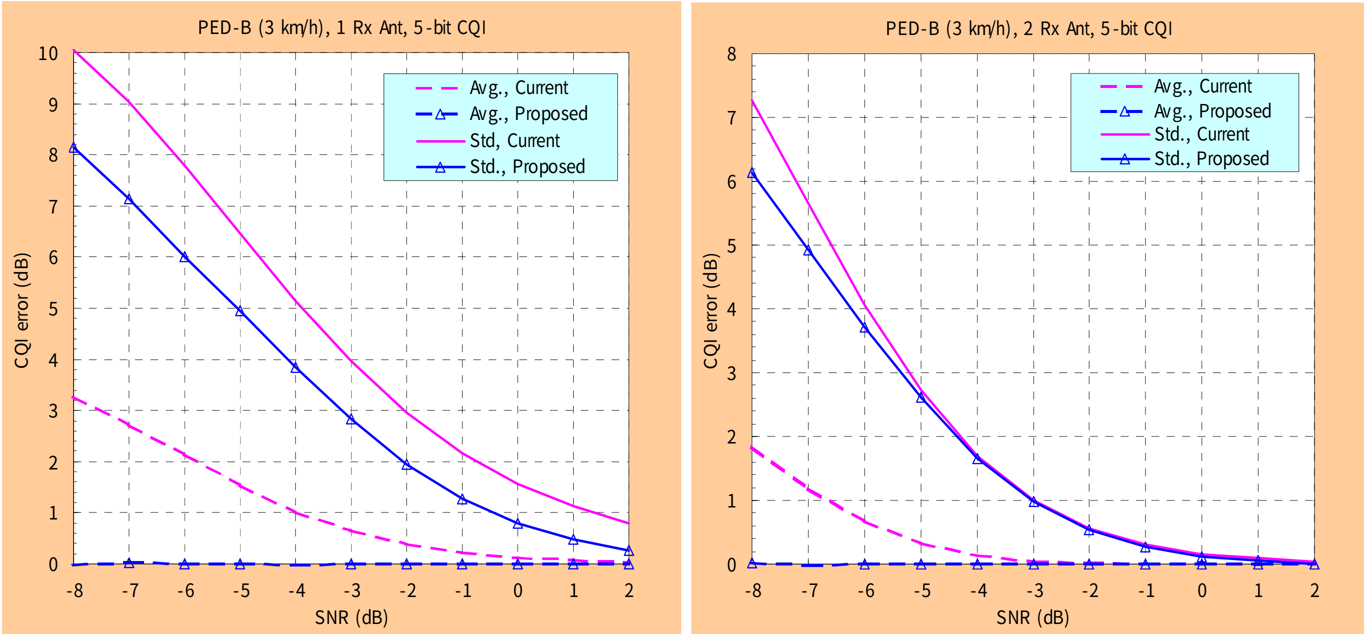
Figure 7: CQI error statistics on VEH-A channel (4-bit CQI).





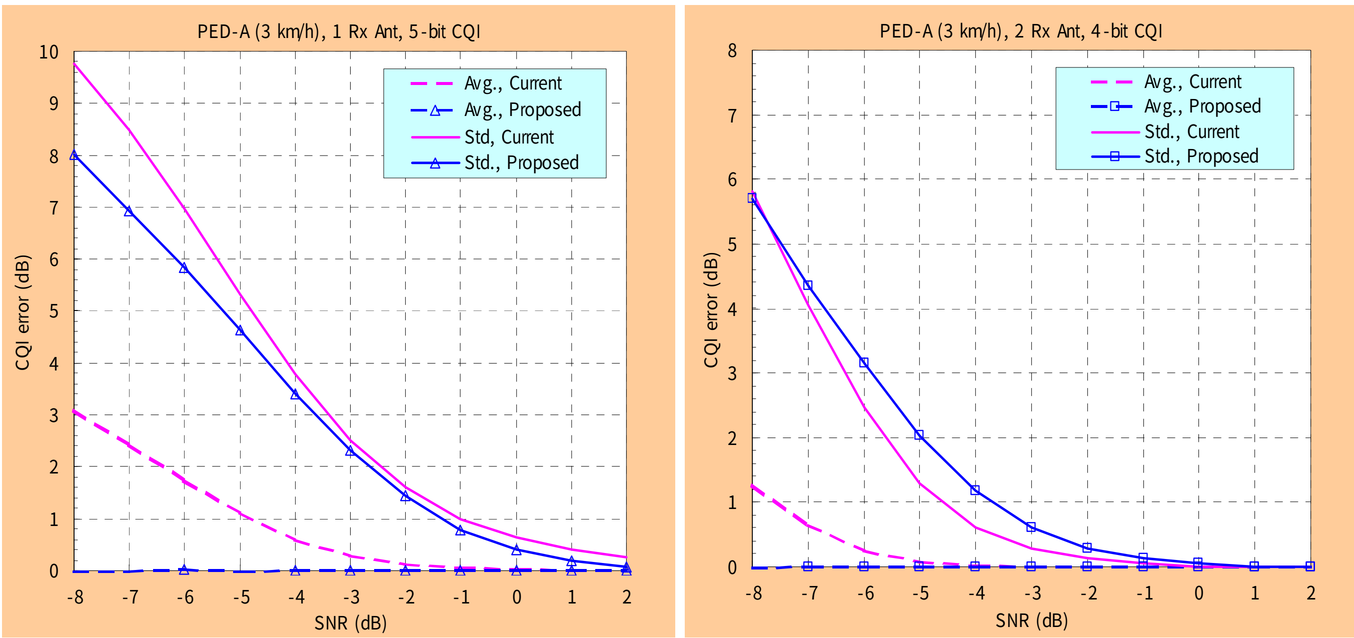
(a) 1 RX ant **(b) 2 RX ant**

Figure 8: CQI error statistics on i.i.d. Rayleigh fading channel (4-bit CQI).



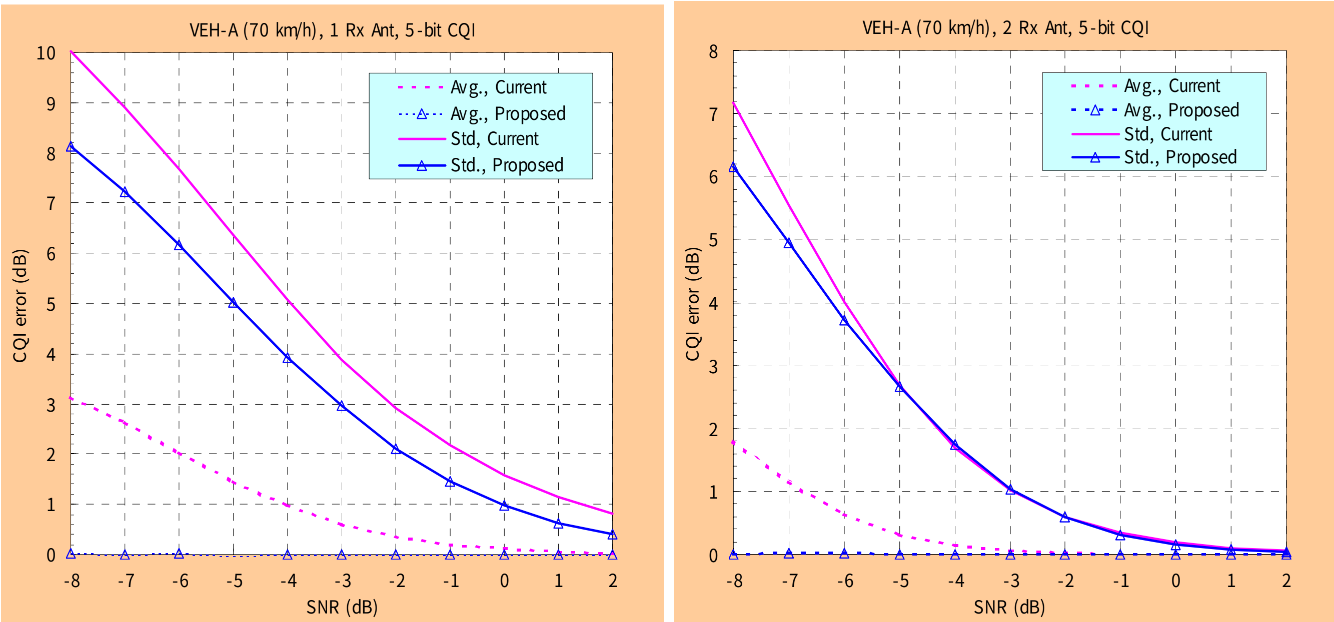
(a) 1 RX ant **(b) 2 RX ant**

Figure 9: CQI error statistics on PED-B channel (5-bit CQI).



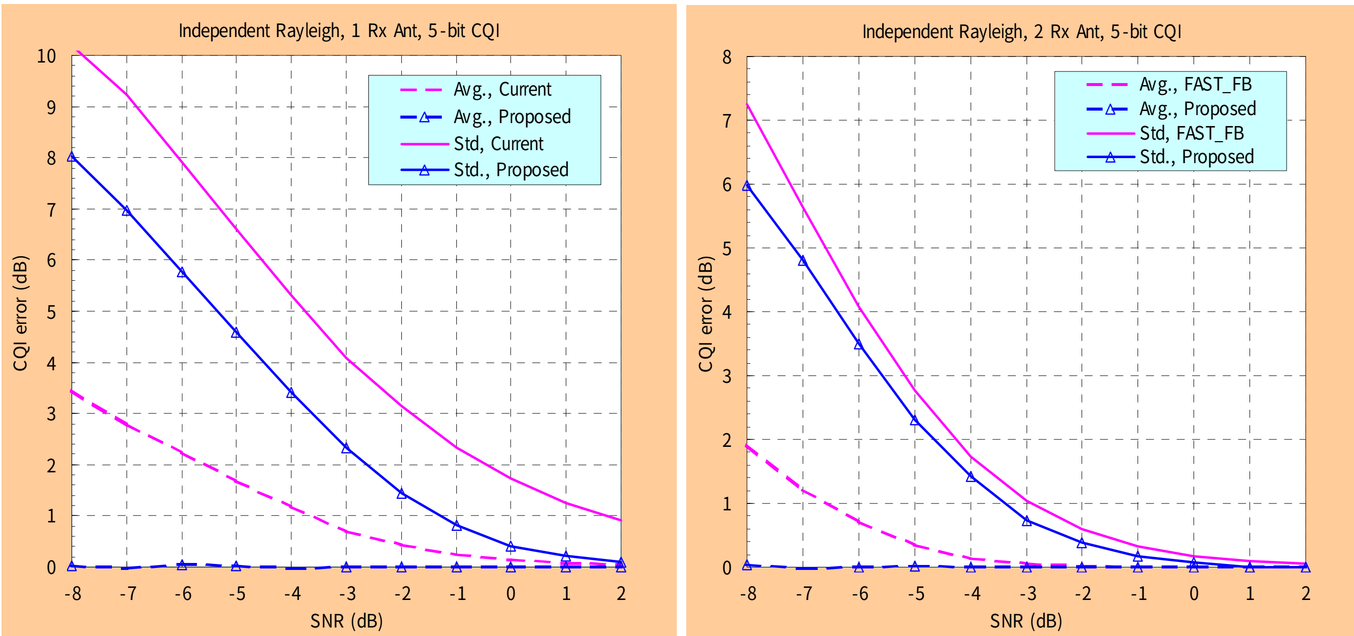
(a) 1 RX ant **(b) 2 RX ant**

Figure 10: CQI error statistics on PED-A channel (5-bit CQI).



(a) 1 RX ant **(b) 2 RX ant**

Figure 11: CQI error statistics on VEH-A channel (5-bit CQI).



(a) 1 RX ant **(b) 2 RX ant**

Figure 12: CQI error statistics on i.i.d. Rayleigh channel (5-bit CQI).

4. Proposed Text Changes

------------ *Start of Text Proposal* --------------

[Insert the following text after section 8.4.5.4.10.3]

8.4.5.4.10.4 Optional fast DL measurement feedback

The optional fast DL measurement feedback provides the payload bits carried by the FAST_FEEDBACK channel with the unequal error protection (UEP) capability. The optional fast DL measurement feedback repeats each payload bit according to a predefined repetition ratio, as illustrated in Figure xxx. The repeated bit sequence is interleaved and used for binary DPSK modulation on the sub-carriers for the FAST_FEEDBACK channel.

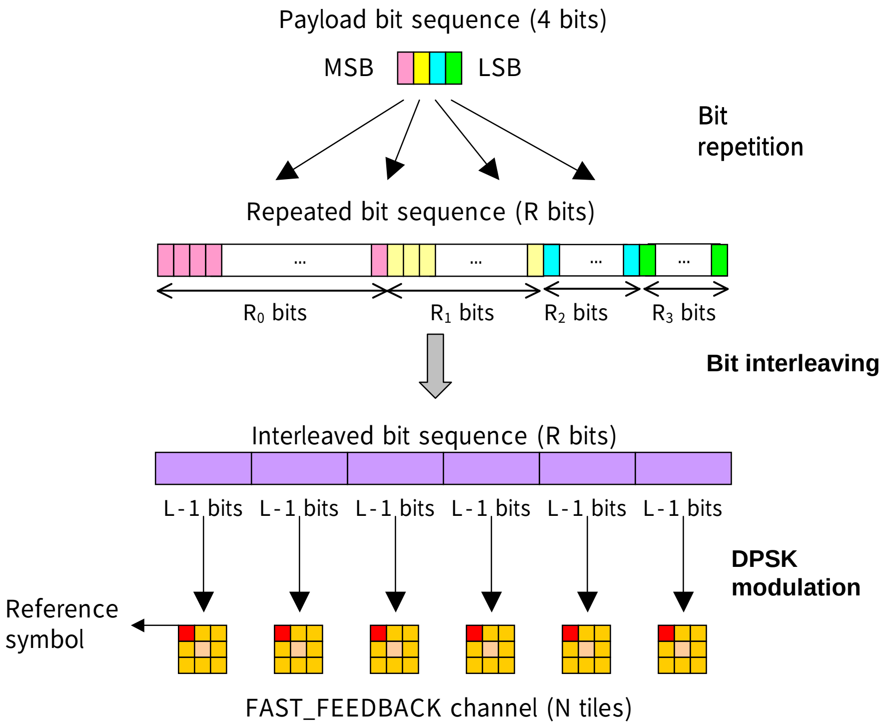


Figure xxx Mapping of the payload bit sequence to a FAST_FEEDBACK channel

When the 4 by 3 uplink tile structure is used (see section 8.4.6.2.1), the number of tiles in a channel, N, is 6 and the number of subcarriers in a tile, L, is 12. When the 3 by 3 uplink tile structure is used (see section 8.4.6.5.1), N is 6 and L is 9.

Each payload bit is repeated according to the predefined UEP ratio $R_0:R_1:R_2:R_3$, where R_0, R_1, R_2, and R_3 represent the repetition number for the 1st payload bit b_0 (MSB), the 2nd payload bit b_1, the 3rd payload bit b_2, and the 4th payload bit b_3 (LSB), respectively. A ratio of $R_0:R_1:R_2:R_3$ = 26:19:14:7 is used for the 4 by 3 uplink tile structure. For the 3 by 3 uplink tile structure, $R_0:R_1:R_2:R_3$ =

19:14:10:5 is used.

The repeated bit sequence is interleaved according to Equation (yyy) before binary DPSK modulation.

$$y = (xR/N) \bmod R + \lfloor x/N \rfloor, \qquad \text{(yyy)}$$

where y denotes the bit index in the interleaved bit sequence (y=0,1,2,...,R-1), x denotes bit index in the repeated bit sequence (x=0,1,2,...,R-1), and $R = R_0 + R_1 + R_2 + R_3 = N(L-1)$.

The interleaved bit sequence is divided into N groups and each group has L-1 bits. The n-th group (n=0, 1, ...N-1) is used for binary DPSK modulation on the subcarriers in the n-th uplink tile, as shown in Figure xxx. The first subcarrier in each tile is used as a phase reference. The L-1 bits in the n-th group are mapped to L DPSK symbols for the n-th tile as follows.

$$C_{n,k}^{\mathrm{CQI}} = \begin{cases} 1 & \text{if } k = 0 \\ C_{n,k-1}^{\mathrm{CQI}} & \text{if } k > 0 \text{ and } B_{n,k-1}^{\mathrm{CQI}} = 0 \\ -C_{n,k-1}^{\mathrm{CQI}} & \text{if } k > 0 \text{ and } B_{n,k-1}^{\mathrm{CQI}} = 1 \end{cases}, \qquad \text{(zzz)}$$

where

$C_{n,k}^{\mathrm{CQI}}$ mapping symbol of the k-th subcarrier in n-th tile (k=0, 1, ..., L-1),

$B_{n,k}^{\mathrm{CQI}}$ k-th bit of n-th group in the interleaved bit sequence (k=0, 1, ..., L-2).

------------ *End of Text Proposal* --------------

Appendix Extended Table 294 for 5-bit CQI

n	5-bit payload	Fast Feedback vector indices per Tile
0	0b00000	0 0 0 0 0 0
1	0b00001	1 1 1 1 1 1
2	0b00010	2 2 2 2 2 2
3	0b00011	3 3 3 3 3 3
4	0b00100	4 4 4 4 4 4
5	0b00101	5 5 5 5 5 5
6	0b00110	6 6 6 6 6 6
7	0b00111	7 7 7 7 7 7
8	0b01000	0 1 2 3 4 5
9	0b01001	1 2 3 4 5 6
10	0b01010	2 3 4 5 6 7
11	0b01011	3 4 5 6 7 0
12	0b01100	4 5 6 7 0 1
13	0b01101	5 6 7 0 1 2
14	0b01110	6 7 0 1 2 3
15	0b01111	7 0 1 2 3 4
16	*0b10000*	*4 7 2 5 1 6*
17	*0b10001*	*5 0 3 6 2 7*
18	*0b10010*	*6 1 4 7 3 0*
19	*0b10011*	*7 2 5 0 4 1*
20	*0b10100*	*0 3 6 1 5 2*
21	*0b10101*	*1 4 7 2 6 3*
22	*0b10110*	*2 5 0 3 7 4*
23	*0b10111*	*3 6 1 4 0 5*
24	*0b11000*	*4 6 0 2 5 7*
25	*0b11001*	*5 7 1 3 6 0*
26	*0b11010*	*6 0 2 4 7 1*
27	*0b11011*	*7 1 3 5 0 2*
28	*0b11100*	*0 2 4 6 1 3*
29	*0b11101*	*1 3 5 7 2 4*
30	*0b11110*	*2 4 6 0 3 5*
31	*0b11111*	*3 5 7 1 4 6*