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Re:	IEEE P802.16-REVe/D2-2004
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
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CQI Signaling with Unequal Error Protection for OFDMA

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1. Introduction

This document describes the CQI signaling enhancement to the OFDMA mode of IEEE802.16e. To support mobile applications, FAST_FEEDBACK channel is used to transmit CQI messages in the OFDMA mode. The CQI is periodically reported by a subscriber station (SS) in order to inform a base station of the SNR measurement. The measured SNR is represented by a 4-bit CQI message. Since the CQI messages on the FAST_FEEDBACK channel do not include CRC for error checking, we need more accurate CQI transmission method to improve the system capability. When transmitting the CQI messages, the transmission accuracy of MSBs is more important than that of LSBs, because the error induced in the MSBs causes a large difference between the measured SNR at the SS and the value reported to the base station. Therefore, it is necessary to introduce an unequal error protection (UEP) method to the CQI signaling. This contribution proposes a simple and efficient method of unequal error protection for CQI transmission.

2. CQI Signaling with UEP

In order to realize the UEP for CQI transmission in the uplink, we need to allocate more energy to MSBs and less energy to LSBs of CQI message. The proposed UEP DPSK modulation can be summarized as:

- The CQI is represented by 5 bits according to the channel SNR measured in the SS,
- To realize the unequal energy allocation, we introduced different bit repetition depending on the bit position of CQI message,
- To obtain frequency diversity, interleaving is introduced in the frequency domain,
- DPSK is used for non-coherent demodulation.

IEEE802.16d document defines the FAST_FEEDBACK channel composed of 6 3-by-3 tiles. In the proposed method, CQI message will be transmitted using the current FAST_FEEDBACK channel but use more efficient modulation to reduce CQI decoding error. Following is the procedural explanation of UEP DPSK modulation for the transmission of CQI.

1. The CQI is represented by 5-bits according to the measured SNR at the SS as shown in Table xxx.

   Table xxx- CQI representation according to the measured SNR

Measured SNR [dB]	5-bits CQI
-10.0~-9.0	00000
-9.0~-8.0	00001
-8.0~-7.0	00010
-7.0~-6.0	00011
-6.0~-5.0	00100
-5.0~-4.0	00101
-4.0~-3.0	00110
-3.0~-2.0	00111
-2.0~-1.0	01000
-1.0~-0.0	01001
0.0~1.0	01010
1.0~2.0	01011
2.0~3.0	01100
3.0~4.0	01101
4.0~5.0	01110
5.0~6.0	01111
6.0~7.0	10000
7.0~8.0	10001
8.0~9.0	10010
9.0~10.0	10011
10.0~11.0	10100
11.0~12.0	10101
12.0~13.0	10110
13.0~14.0	10111
14.0~15.0	11000
15.0~16.0	11001
16.0~17.0	11010
17.0~18.0	11011
18.0~19.0	11100
19.0~20.0	11101
20.0~21.0	11110
21.0~22.0	11111

2. Repeat each bit of 5-bit CQI message according to a repetition ratio (R_0:R_1:R_2:R_3:R_4), where R_0, $R1$, $R2$, $R3$ and R_4 represent the repetition number for the MSB, the second MSB, …, the LSB respectively:

CQI message (5 bits) $b_0 b_1 b_2 b_3 b_4$

Repeated sequence (48 bits) $b_0 \ldots b_0$ $b_1 \ldots b_1$ $b_2 .. b_2$ $b_3 .. b_3$ $b_4 .. b_4$

R_0 bits R_1 bits R_2 bits R_3 bits R_4 bits

$$R = R_0 + R_1 + R_2 + R_3 + R_4 = N \times (L-1), R_0 \ge R_1 \ge R_2 \ge R_3 \ge R_4$$

N=6, L=9 (6 3-by-3 tiles)

3. Interleave the repeated bit sequence:

$$y = \left\{ \left(x \times \frac{R}{N} \right) \bmod R \right\} + \left\lfloor \frac{x}{N} \right\rfloor$$

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

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

4. Map *k-th* (*L-1*) bits to *k-th* tile:

5. Make L DPSK symbols for (L-1) bits mapped to each tile, with the first symbol used as phase reference:

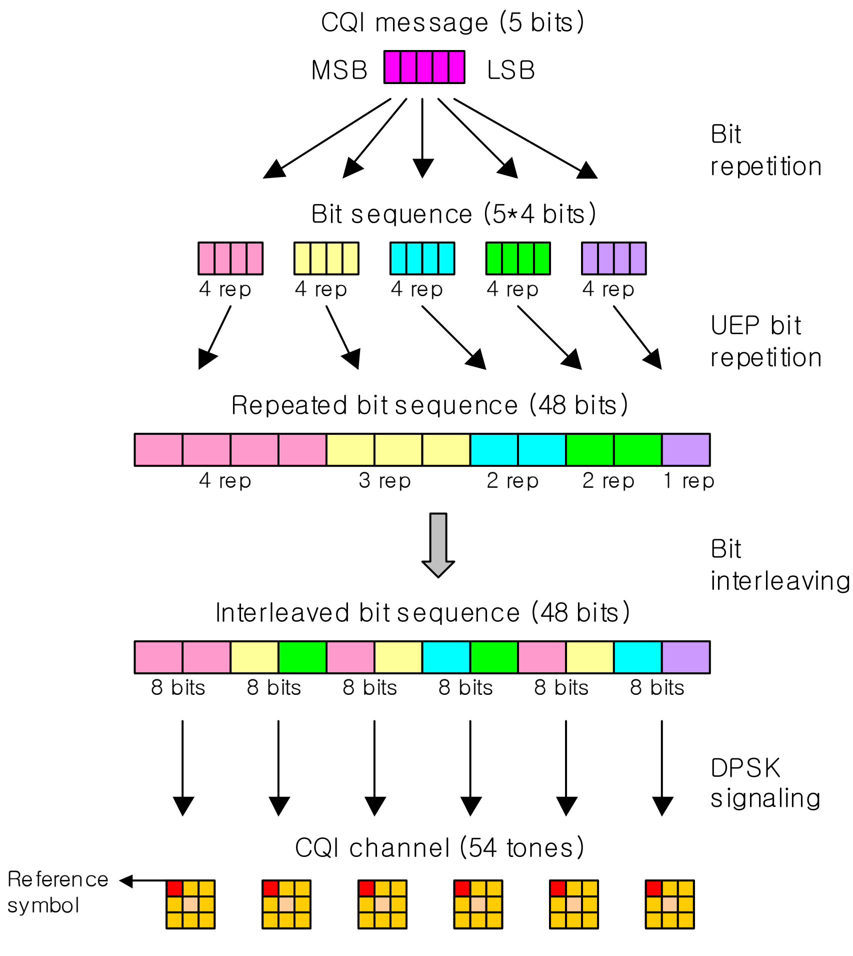


Fig. 1: DPSK with bit repetion

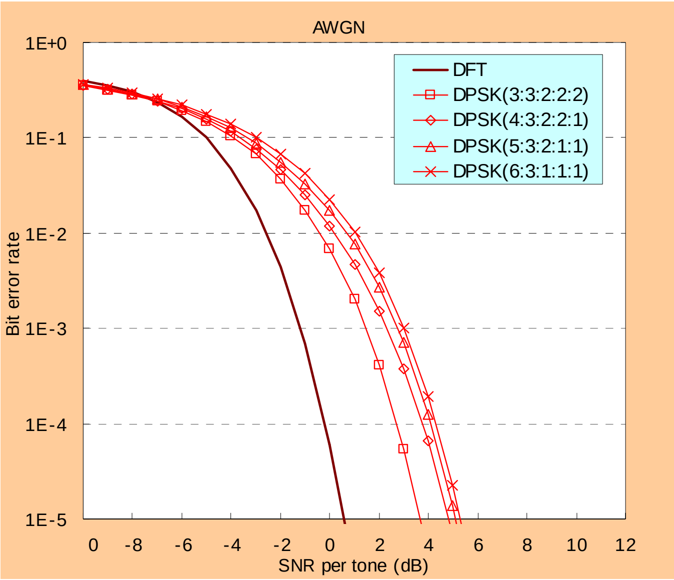
For the current FAST_FEEDBACK channel, six 3-by-3 tiles, the repetition ratio of 5×4:3×4:2×4:1×4:1×4 (=5:3:2:1:1) is recommended.

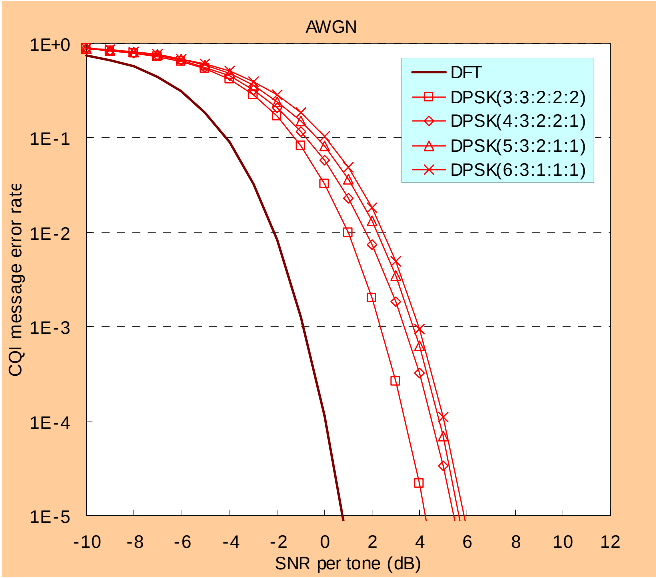
3. Simulation Results

Performances are compared for the current and proposed CQI transmission methods:

- FAST_FEEDBACK (or DFT orthogonal modulation with nonbinary block coding; See C80216d-04_85r1.pdf),
- Differential binary PSK with bit repetition (UEP).

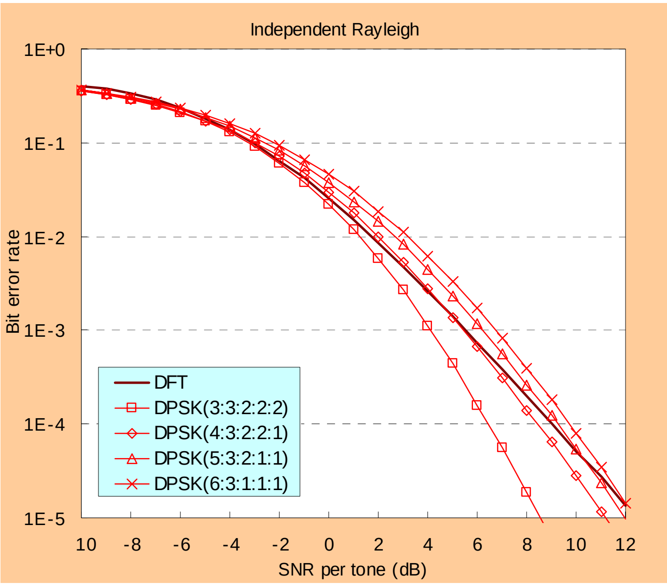
3.1 BER & MER comparison under AWGN

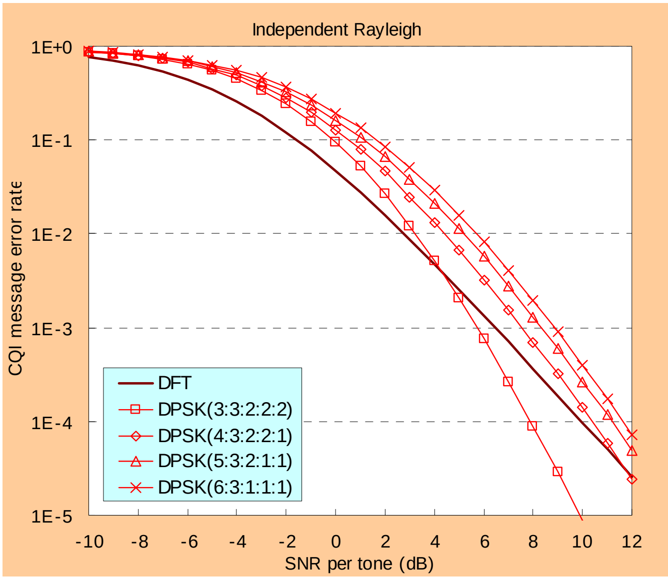




Simulation result summary: In the BER or MER point of view the performance of DFT is better than UEP DPSK over the entire SNR range.

3.2 BER & MER comparison under Rayleigh

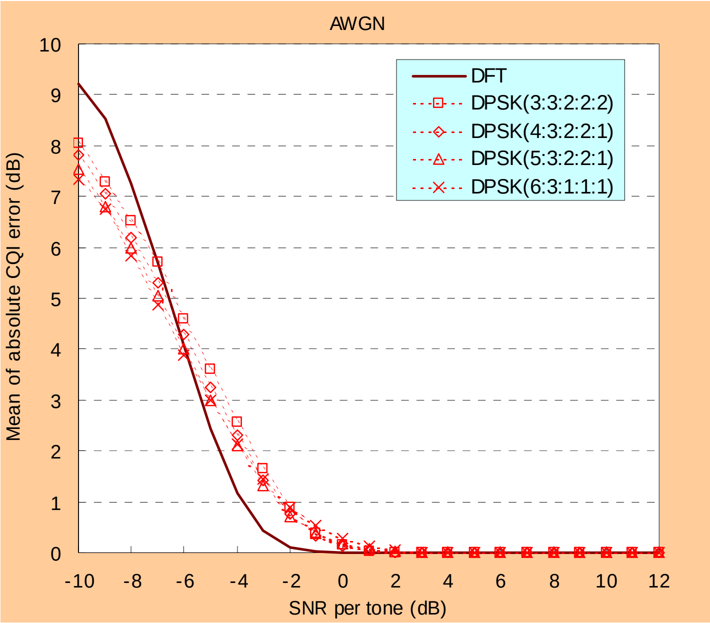


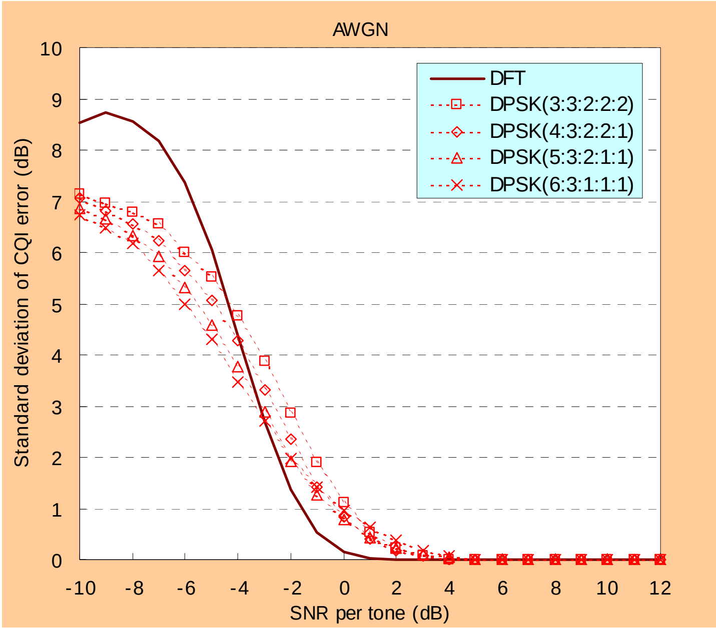


Simulation result summary: If the repetition rate is 3:3:2:2:2, then the BER performance of UEP DPSK is better than the that of DFT under Rayleigh channel conditions. Considering the MER point of view, DPSK is better than DFT when the SNR is higher than 4dB.

3.3 CQI Error comparison under AWGN

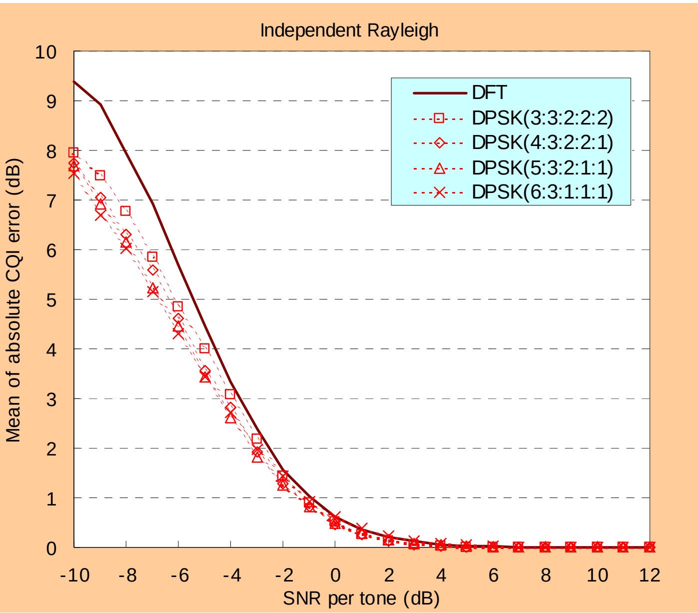
CQI error is defined by the difference between the actual SNR measured at the SS and the decoded SNR at the BS. The unit of CQI error is dB

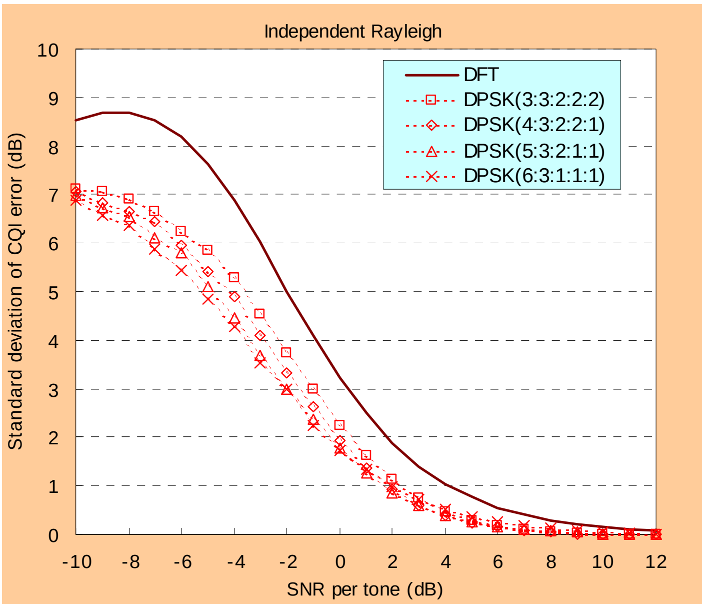




Under AWGN channel conditions, the performance of UEP DPSK is better than that of DFT except when the SNR is large.

3.4 CQI Error comparison under Rayleigh





The performance of UEP DPSK is better than that of DFT under Rayleigh channel condition over the entire SNR ranges. And the recommended repetition rate is 5:3:2:1:1.

Conclusions from Simulation Results are:

- We need more accurate CQI signaling method because the OFDMA mode does not use the CRC for error checking,
- The CQI error of the DPSK is smaller than that of FAST_FEEDBACK,
- The complexity of DPSK is simpler than that of FAST_FEEDBACK,
- The recommended repetition ratio for DPSK is 5:3:2:1:1.

4. Proposed Text Changes

4.1 PHY Changes

[Insert the text]

8.4.5.4.10.4 FAST_FEEDBACK (CQI) modulation using UEP DPSK (optional)

.By allocating different powers to the CQI bits and using DPSK, the CQI decoding error can be reduced. The CQI transmission using UEP DPSK is defined over the six 3-b-3 FAST_FEEDBACK channel. The procedure for this CQI modulation is as follows:

The CQI is represented by 5-bits according to a measured SNR at the SS as shown in Table xxx.

Table xxx- CQI representation according to a measured SNR

Measured SNR [dB]	5-bits CQI
-10.0~-9.0	00000
-9.0~-8.0	00001
-8.0~-7.0	00010
-7.0~-6.0	00011
-6.0~-5.0	00100
-5.0~-4.0	00101
-4.0~-3.0	00110
-3.0~-2.0	00111
-2.0~-1.0	01000
-1.0~-0.0	01001
0.0~1.0	01010
1.0~2.0	01011
2.0~3.0	01100
3.0~4.0	01101
4.0~5.0	01110
5.0~6.0	01111
6.0~7.0	10000
7.0~8.0	10001
8.0~9.0	10010
9.0~10.0	10011
10.0~11.0	10100
11.0~12.0	10101
12.0~13.0	10110
13.0~14.0	10111

14.0~15.0	11000
15.0~16.0	11001
16.0~17.0	11010
17.0~18.0	11011
18.0~19.0	11100
19.0~20.0	11101
20.0~21.0	11110
21.0~22.0	11111

Repeat each bit of 5-bit CQI message according to a repetition ratio (R_0:R_1:R_2:R_3:R_4=5:3:2:1:1), where R_0, R_1, R_2, R_3 and R_4 represent the repetition number for the b_0, b_1, b_2, b_3 and b_4, respectively.

CQI message (5 bits) $b_0b_1b_2b_3b_4$

Repeated sequence (48 bits) $\underbrace{b_0 \cdots b_0}_{R_0 \text{ bits}}\ \underbrace{b_1 \ldots b_1}_{R_1 \text{ bits}}\ \underbrace{b_2 \ldots b_2}_{R_2 \text{ bits}}\ \underbrace{b_3 \ldots b_3}_{R_3 \text{ bits}}\ \underbrace{b_4 \ldots b_4}_{R_4 \text{ bits}}$

$$R = R_0 + R_1 + R_2 + R_3 + R_4 = N \times (L-1),\ R_0 \geq R_1 \geq R_2 \geq R_3 \geq R_4$$

Interleave the repeated bit sequence to obtain frequency diversity.

$$y = \left\{ \left(x \times \frac{R}{N} \right) \mathrm{mod}\, R \right\} + \left\lfloor \frac{x}{N} \right\rfloor$$

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

Map *k-th* *(L-1)* bits to *k-th* tile.

Make L DPSK symbols for (L-1) bits mapped to each tile, with the first symbol used as phase reference.

4.2 MAC Changes

[Insert the text]

11.7.8.9 FAST_FEEDBACK(CQI) report control

CQI report method may be negotiated between MSS and BS during the registration procedure using the following TLV encoding.

Type	Length	Value	Scope
5.x	1	Bit#0: CQI report not supported Bit#1: FAST_FEEDBACK supported Bit#2: UEP DPSK-based CQI report supported Bit#3~7: Reserved	OFDMA REG-REQ REG-RSP