Project	**IEEE 802.16 Broadband Wireless Access Working Group** <http://ieee802.org/16>
Title	**Change Request of the 16m modulation for the IEEE 802.16m SDD**
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Re:	Change Request to 802.16m SDD (802.16m-08/003r7) - Target topic: “11.13.1.5 Modulation”.
Abstract	We propose that coding-rotated-modulation OFDM should be supported.
Purpose	For 802.16m discussion and adoption
Notice	
Release	
Patent Policy	

Change Request for the 16m modulation in 802.16m SDD

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1 Introduction

The conventional BICM-OFDM systems with low-code-rate FEC (forward error correction) codes can obtain the frequency diversity gain by utilizing the likelihood of information and parity bits from different sub-carriers. However, if the code rate increases, an OFDM system will show poor performance because high-code-rate FEC codes cannot obtain enough frequency diversity.

To overcome this disadvantage, an efficient coded-modulation scheme, called coding-rotated-modulation OFDM (CRM-OFDM), is proposed. It can improve the performance of OFDM systems by taking full advantage of the modulation diversity of rotated modulation (RM), the time and frequency diversity of OFDM system, and the coding-gain of LDPC (Turbo) codes all together.

2 Proposed coding-rotated-modulation OFDM scheme

The proposed CRM-OFDM scheme is shown in Fig.1. In the transmitter, information bits are firstly sent into a channel encoder, then the coded bits are rotated-modulated after a bit-interleaver. Turbo codes and LDPC codes are studied in this scheme. For the LDPC codes, the bit interleaver can be omitted due to the built-in interleaving effect of LDPC codes. The modulation constellations are decomposed to I (in-phase) component and Q (quadrature) component. For Q component, a time-frequency 2D (two-dimensional)-interleaver is used to compose new constellations with the original I component. Then, the new constellations are mapped into distributed sub-carriers, and OFDM modulation is performed, including adding CP (cyclic prefix) and IFFT (inverse fast Fourier transform) operations. A multi-path fading channel is assumed, which is the frequency-selective slow fading channel model defined in GSM standards. In the receiver, OFDM demodulation is carried out firstly, including deleting CP, FFT (fast Fourier transform) and phase-compensation operations. For the OFDM-demodulated signal, the Q component is de-interleaved to composed new constellations. Then, ML (Max-likelihood) demodulation is used to produce the LLRs (Log-likelihood-ratio) of encoded bits from the rotated constellations, so the channel deocoder can utilize the LLRs to decode the information bits. For the decoder, the Log-MAP and Log-BP decoding algorithm is used for the Turbo codes and LDPC codes, respectively. For the LDPC codes, the De-interleaving can be omitted.

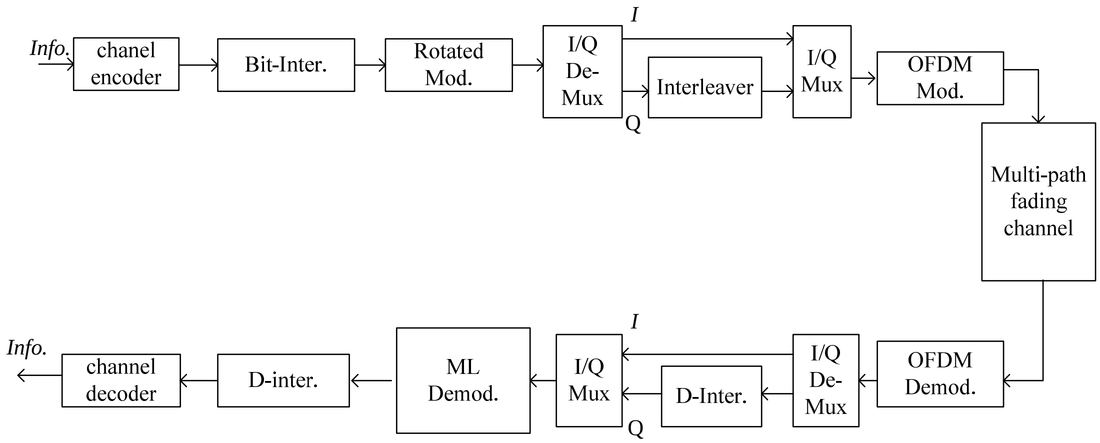

Fig.1 Coding-rotated-modulation OFDM scheme

2.1 Rotated Modulation (RM)

As compared with the conventional QAM/MPSK, rotated constellation can obtain the modulation diversity by rotating some angle [10] . For example, a usual QPSK constellation （A, B） becomes a new rotated constellation （X, Y）by rotating some angle θ_1 , as shown in Fig.2. The formula is given by the following:

$$\begin{pmatrix} X \\ Y \end{pmatrix} = \mathbf{R}_2 \begin{pmatrix} A \\ B \end{pmatrix} = \begin{pmatrix} \cos\theta_1 & \sin\theta_1 \\ -\sin\theta_1 & \cos\theta_1 \end{pmatrix} \begin{pmatrix} A \\ B \end{pmatrix}$$

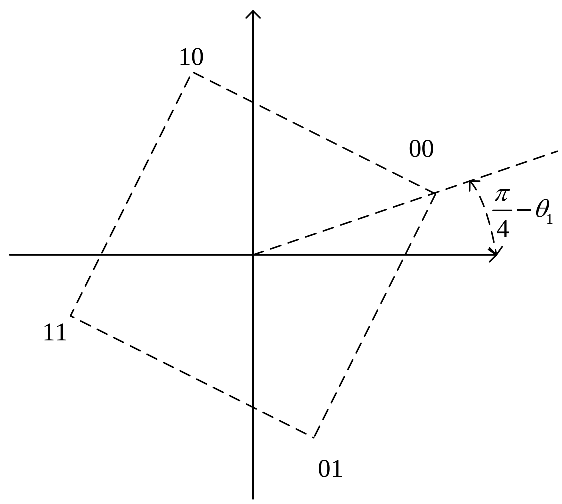

Fig.2 Rotated-QPSK constellation

By adjusting θ_1, the optimum modulation diversity can be obtained to minimize bit error rate. Different from the results of [10], we derive the optimum angle again, and come to the following conclusions:

For two-dimensional rotated QPSK, $\theta_1 = \arctan(\frac{1}{2}) = 0.463648$

For two-dimensional rotated 16QAM, $\theta_1 = \arctan(\frac{1}{4}) = 0.244979$

2.2 Rotated constellations mapping into OFDM and a time-frequency 2D-interleaver

A 1024-IFFT OFDM system is assumed, which consists of 1024 sub-carriers in frequency domain and 6 OFDM-symbols in time domain for five users. Each user occupies 6 OFDM-symbols and 200 sub-carriers, so each user takes up 1200 rotated-constellation symbols. We assume user i takes up some frequency-time resource block (f, t), where, f is the sub-carrier No., $f \in [0,1023]$, t is the OFDM-symbol No., $t \in [1,6]$. The user i occupies from No.i sub-carrier to No.(995+i) sub-carrier by 5 spacing sub-carriers, where, $i \in [0,4]$. [1000,1023] sub-carriers are reserved. So, it is the distributed－OFDM allocation to take advantage of the frequency diversity. For each user, QPSK/QAM modulation symbol is rotated, and then only the Q component of rotated constellations is interleaved to compose new constellations. The Q interleaver is based on time-frequency 2D interleaving, which is important to maximize the modulation diversity and the frequency diversity. We design a low-complexity and efficient time-frequency 2D Q-interleaver. Assuming six Q-component signals （$q_1q_2q_3q_4q_5q_6$） takes up the time-frequency resource block {（f1, 1），（f2, 4），（f1, 2），（f2, 5），（f1,3）,(f2,6)}, after interleaving, they occupy {f2, 4），（f1, 2），（f2, 5），（f1,3）,(f2,6), （f1, 1）}, as shown is Fig.3, where, f1=(f2+500) %1000. So, this interleave is the right-cyclic-shift result of the original resource block queue, which can maximize the modulation diversity, the frequency diversity and the time diversity of OFDM system.

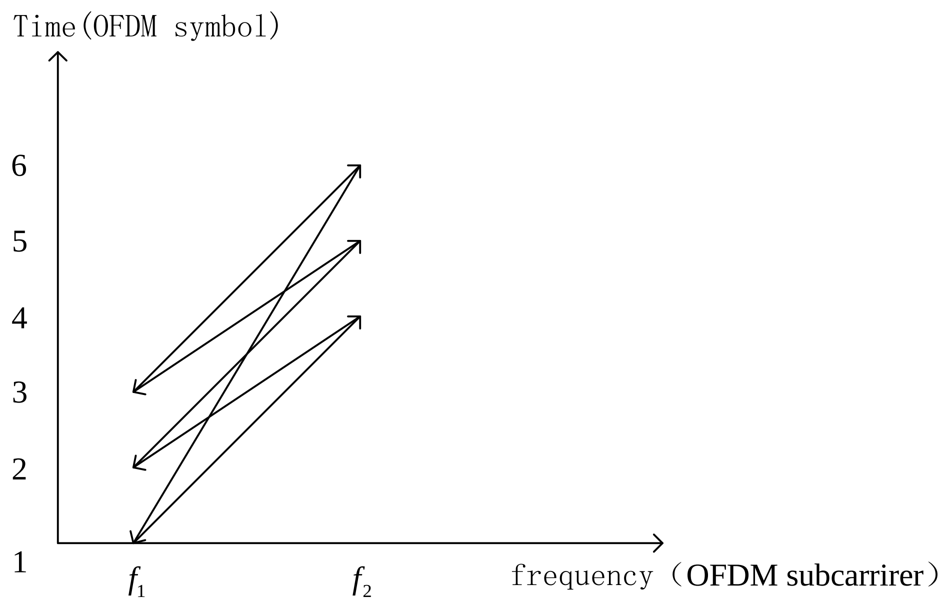

Fig.3 Time-frequency interleaver mapping

3 Performance evaluation

Simulations are carried out to compare our proposed CRM-OFDM with the conventional BICM-OFDM system. Our proposed rate-compatible QC-LDPC codes and 3GPP-LTE Turbo codes are studied in this scheme. The fading channel models are two kinds of six-delay-tap models which are defined in GSM standards with classical Doppler spectrum, TU, RA. The maximum Doppler frequency shift f_D=56 Hz. a 1024-subcarrier OFDM system is assumed, which consists of 6 OFDM-symbols in time domain for five users. The transmission bandwidth is 10M Hz, sampling rate is 0.0651μs, OFDM-symbol duration is 66.7μs, CP duration is 4.75μs. The code rate is 3/4, QPSK and 16QAM with Gray mapping are studied.

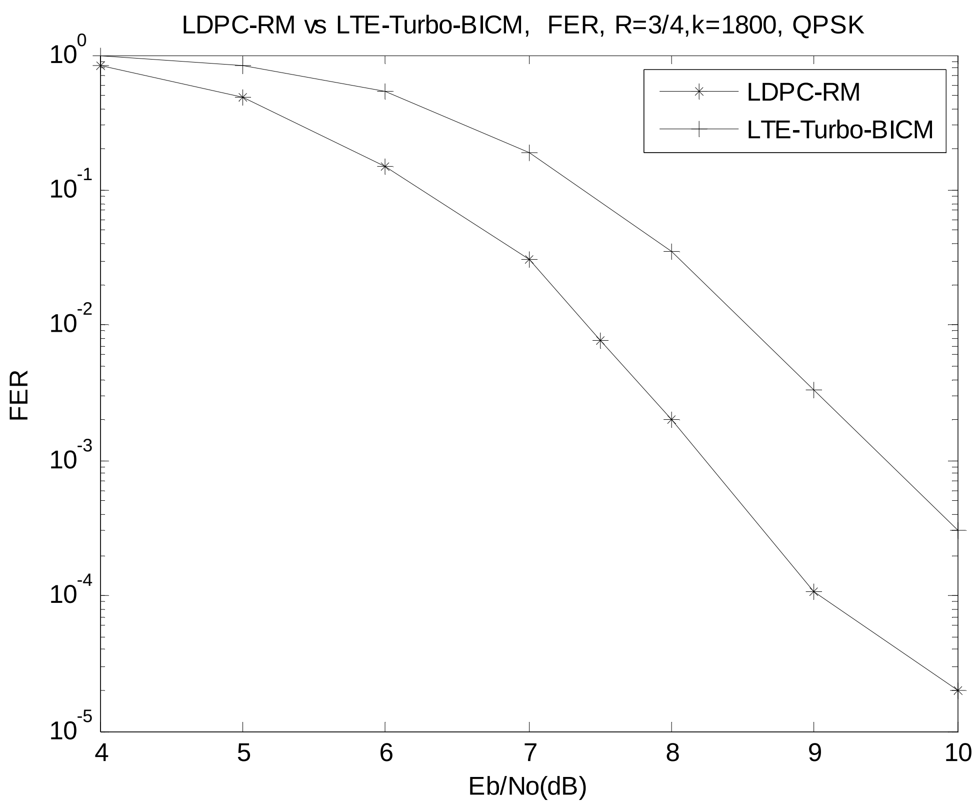

Fig.4 LDPC-RM vs LTE-Turbo-BICM (QPSK, r=3/4)

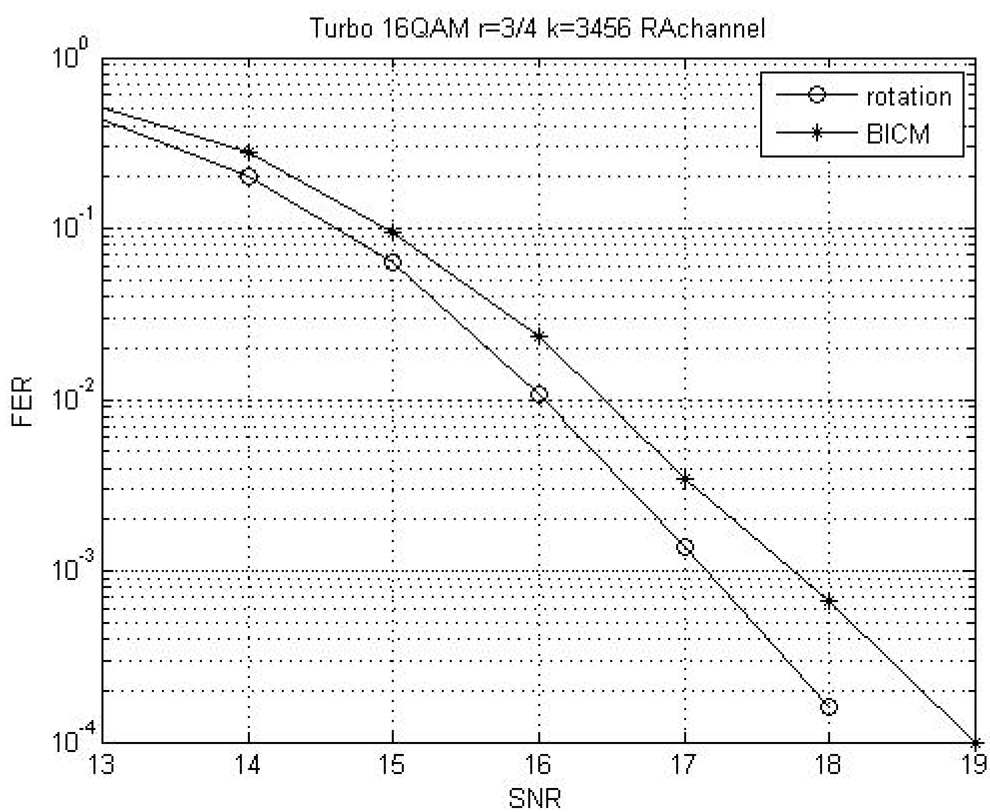

Fig.5 Turbo-RM vs Turbo-BICM on RA channel (16QAM, r=3/4)

Fig.4 compares our proposed LDPC-coded RM-QPSK-OFDM system with the conventional Turbo-coded BICM-QPSK-OFDM for TU channel. Fig.5 compares Turbo-coded RM-16QAM-OFDM system with the conventional Turbo-coded BICM-16QAM-OFDM for RA channel. It is easily seen that our proposed CRM-OFDM schemes are much superior to the conventional BICM-OFDM system. The optimum rotated angle works well on both channel types, TU and RA, which is very useful and robust.

4 Conclusions:

It is shown that the proposed CRM-OFDM scheme can significantly improve the performance of OFDM systems by fully exploiting the modulation diversity of rotated modulation, the time and frequency diversity of OFDM system, and the coding-gain of LDPC (Turbo) codes.

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Proposed Change

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11.13.1.5 Modulation

Modulation constellations of QPSK, 16 QAM, and 64 QAM are supported as defined for the WirelessMAN OFDMA reference system. The mapping of bits to the constellation point depends on the constellation-rearrangement (CoRe) version used for HARQ re-transmission as described in Section 11.13.2.2 and may depend on the MIMO stream. QAM Symbols are mapped to the input of the MIMO encoder. The coding-rotated-modulation OFDM schemes should be supported and the detailed schemes are FFS.

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