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**
Date Submitted	**2009-03-10**
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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 subcarriers. However, if the code rate increases, an OFDM system usually shows 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 Turbo codes all together.

2 Proposed coding-rotated-modulation OFDM scheme

The 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 modulated. A modulated symbol is decomposed to I (in-phase) component and Q (quadrature) component. A time-frequency two-dimensional (2D) interleaver is used to interleave the Q components. The interleaved Q components and the original I component are multiplexed into the new symbols. Then, OFDM modulation is performed, including adding CP (cyclic prefix) and IFFT (inverse fast Fourier transform) operations. In the receiver, OFDM demodulation is carried out firstly, including deleting CP and fast Fourier transform (FFT). For the OFDM-demodulated signals, the Q components are de-interleaved, and are combined with the I components into one complex symbol sequence. Then, the maximum-likelihood (ML) demodulation is used to produce the log-likelihood-ratios (LLRs) of the encoded bits from the rotated symbols, so the channel decoder can utilize the LLRs to decode the information bits.

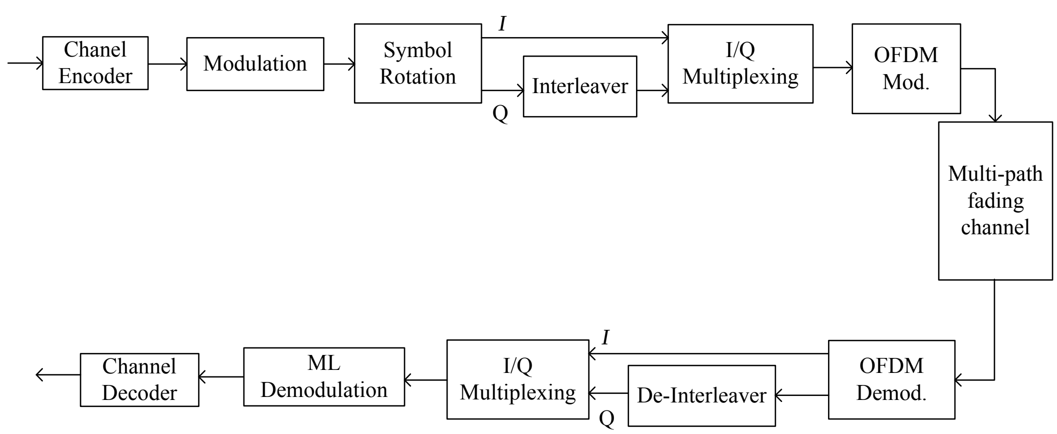

Fig. 1 Coding-rotated-modulation OFDM scheme

2.1 Rotated Modulation (RM)

As compared with the usual MPSK/QAM, the constellation rotated with some angle can obtain the so-called modulation diversity [1]. 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:

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

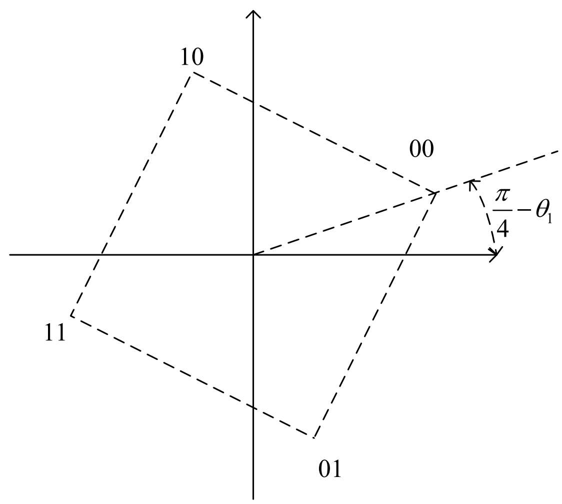

Fig. 2 Rotated-QPSK constellation

By adjusting θ_1, the optimum modulation diversity can be obtained to minimize bit error rate. Some derived optimum angles are as follows:

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

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

2.2 Time-frequency 2D-interleaver

The interleaver of Q components is based on time-frequency 2D interleaving. Consider a resource block with 2N subcarriers and 2M OFDM symbols. Let f1=(f2+N) % 2N, where f2=1,2,…,N. After interleaving, the 2M Q-component signals, occupying time-frequency units {(f1,1), (f2,M+1), (f1,2), (f2,M+2),…(f1,M), (f2,2M)}, are allocated to {(f2,M+1), (f1,2), (f2,M+2), …, (f1,M), (f2,2M), (f1,1)}, which is actually the right-cyclic-shift result of the original time-frequency units.

Assuming six Q-component signals ($q_1 q_2 q_3 q_4 q_5 q_6$) 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.

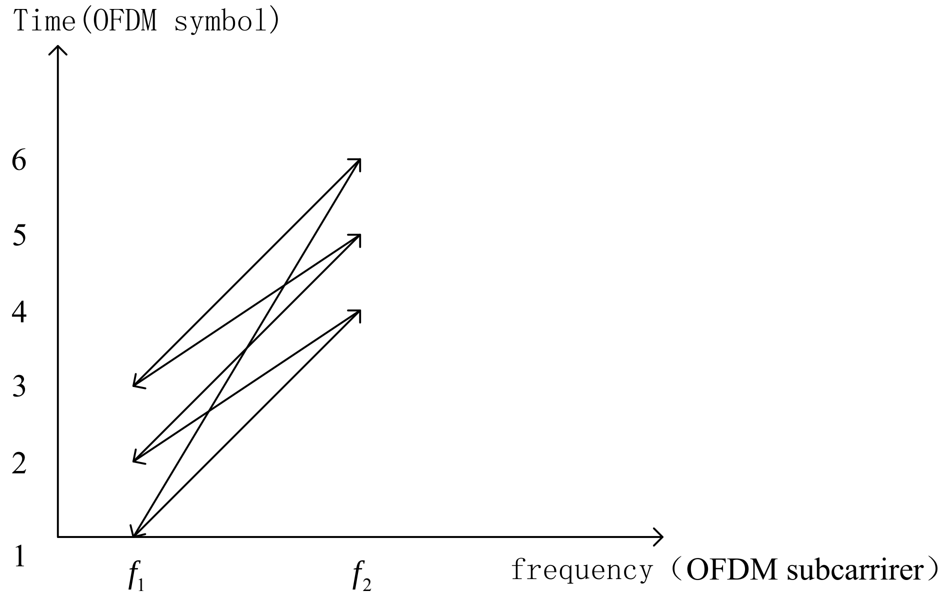

Fig.3 Time-frequency 2D interleaver

3 Performance evaluation

Simulations are carried out to compare the proposed CRM-OFDM with the conventional BICM-OFDM system. Turbo codes with generator $\begin{bmatrix} \frac{15}{13} \end{bmatrix}_8$ are studied in this scheme. The fading channel models are two kinds of six-delay-tap models, typical urban (TU) and Rural Area (RA) channels, which are defined in GSM standards. The maximum Doppler frequency shift f_D=56 Hz. The system parameters are listed in Table.1. The code rate is 3/4, QPSK and 16QAM with Gray mapping are studied.

Fig.4 compares the proposed Turbo-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 the proposed CRM-OFDM schemes are superior to the conventional BICM-OFDM system. The optimum rotated angle works well on both channels.

Table.I System configuration

Sampling rate t_s (= 1 / W)	0.0651 µsec.
FFT Size (= N_{FFT})	1024
OFDM symbol duration (= $N_{FFT} t_s$)	66.7 µsec.
# of CP (= N_{CP})	73
CP duration (= $N_{CP} t_s$)	4.75 µsec.
# of OFDM symbols per sub-frame	6 Data symbols
Sub-frame duration	500 µsec.
# of occupied sub-carriers	1000
# of occupied sub-carriers per user	200
# of pilot sub-carriers	24
# of info.bits per sub-frame (incl. tail bits)	1200 (R = 1/2), 1800 (R = 3/4)
Channel coding	Turbo
Coding rate (= R)	3/4
Decoding algorithm	Log-MAP (8 iterations)
Modulation	QPSK,16QAM,
Rotation dimension (= D)	2
Rotation angle for rotational OFDM	0.463648 0.244979
Channel model	TU and RA (f_D = 56 Hz)
# of receiving antenna	1
Channel estimation	Perfect

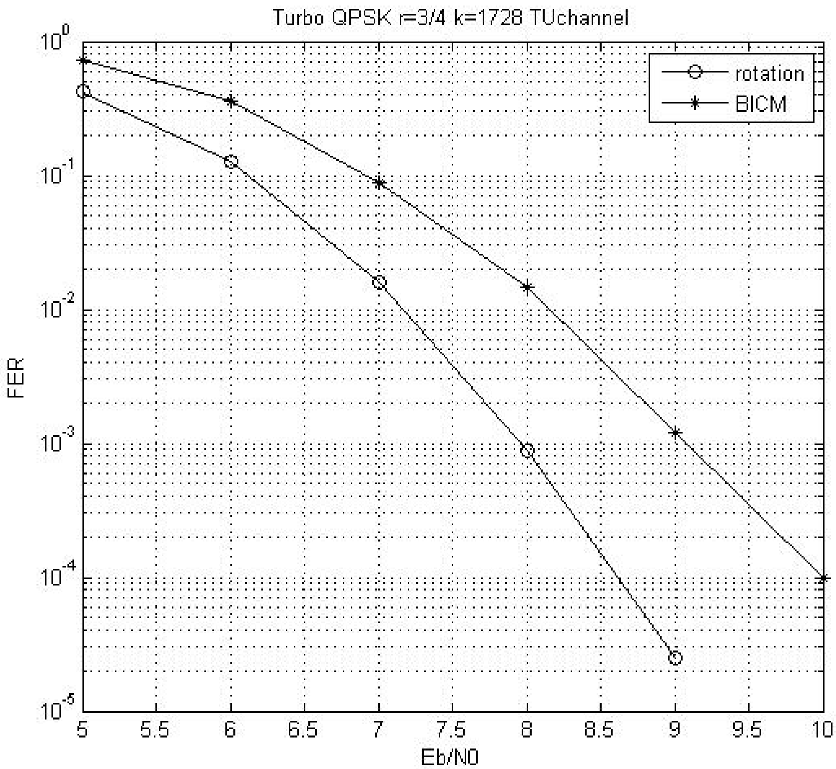

Fig.4 Turbo-RM vs Turbo-BICM (QPSK, r=3/4)

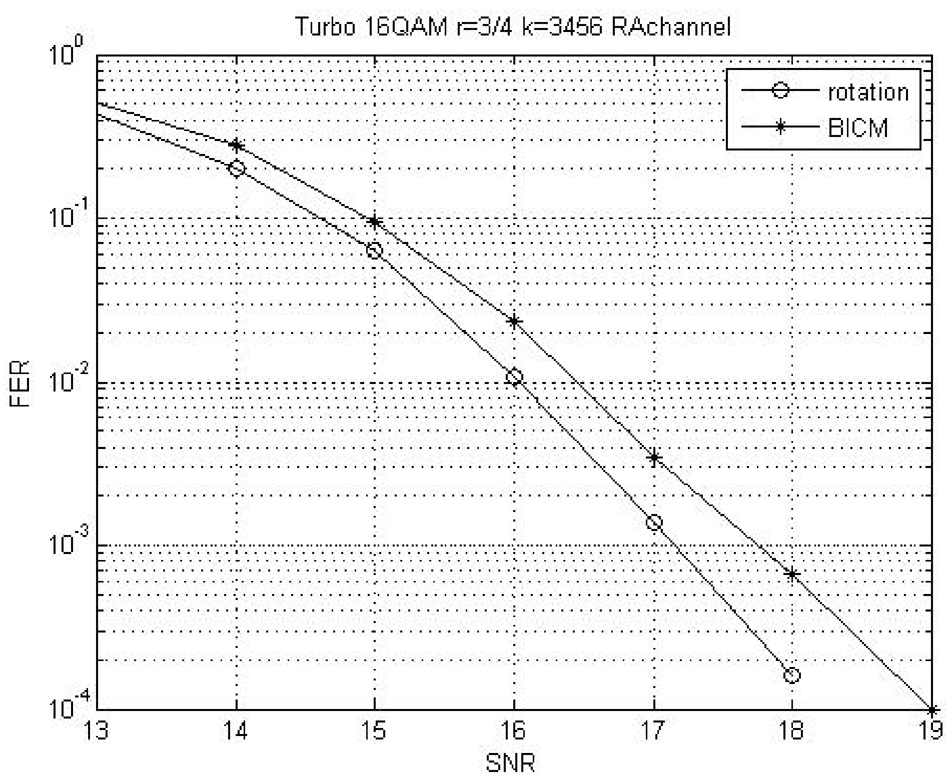

Fig.5 Turbo-RM vs Turbo-BICM on RA channel (16QAM, r=3/4)

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 Turbo codes.

Acknowledgement: This research is sponsored by the National Natural Science Foundation of China (grant No. 60702050).

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. Coding-rotated-modulation OFDM scheme should be supported, as shown in Fig. x.

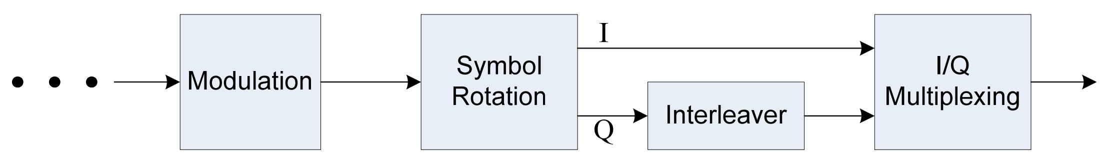

Fig. x Coding-rotated-modulation OFDM scheme

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6 References:

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3. Wu Zhanji, Model of independent Rayleigh faders, Electronics Letters, Vol. 40 No.15, 22nd July 2004, 949-951