Project	**IEEE 802.16 Broadband Wireless Access Working Group** <http://ieee802.org/16>	
Title	**Proposed Text of Coding-Rotated-Modulation OFDM System for the IEEE 802.16m Amendment**	
Date Submitted	**2009-03-10**	
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Re:	Comments on final draft of Channel Coding and HARQ Drafting Group: IEEE C802.16m-09/0510, "Proposed Text of Channel Coding and HARQ for the IEEE 802.16m Amendment".	
Abstract	Proposed Text of Coding-Rotated-Modulation OFDM System for the IEEE 802.16m Amendment	
Purpose	To be discussed and adopted by TGm for the 802.16m amendment.	
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Proposed Text of Coding-Rotated-Modulation OFDM System for the IEEE 802.16m Amendment

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1 Introduction

The conventional bit-interleaved coded modulation (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.

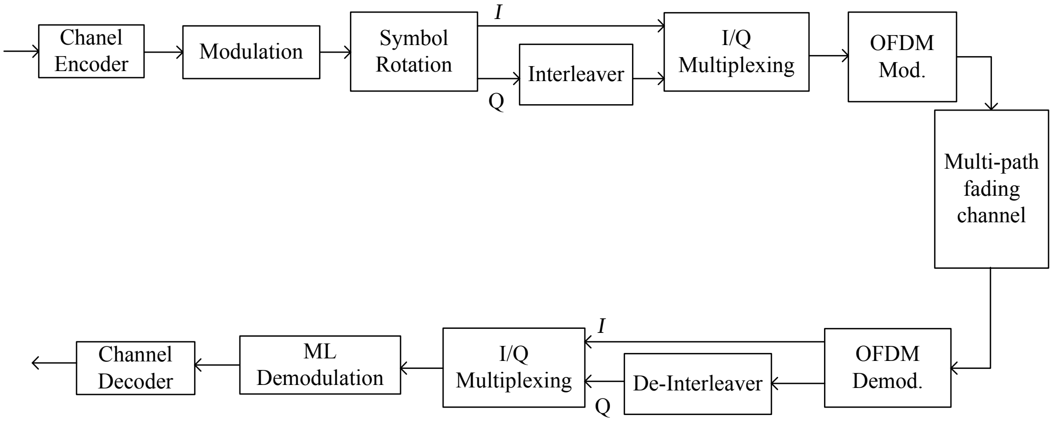

Fig.1 Coding-rotated-modulation OFDM scheme

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:

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

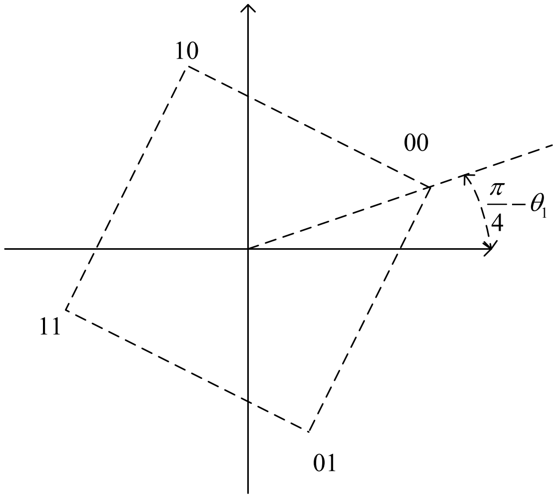

Fig.2 Rotated-QPSK constellation

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 ($q_1q_2q_3q_4q_5q_6$) 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.

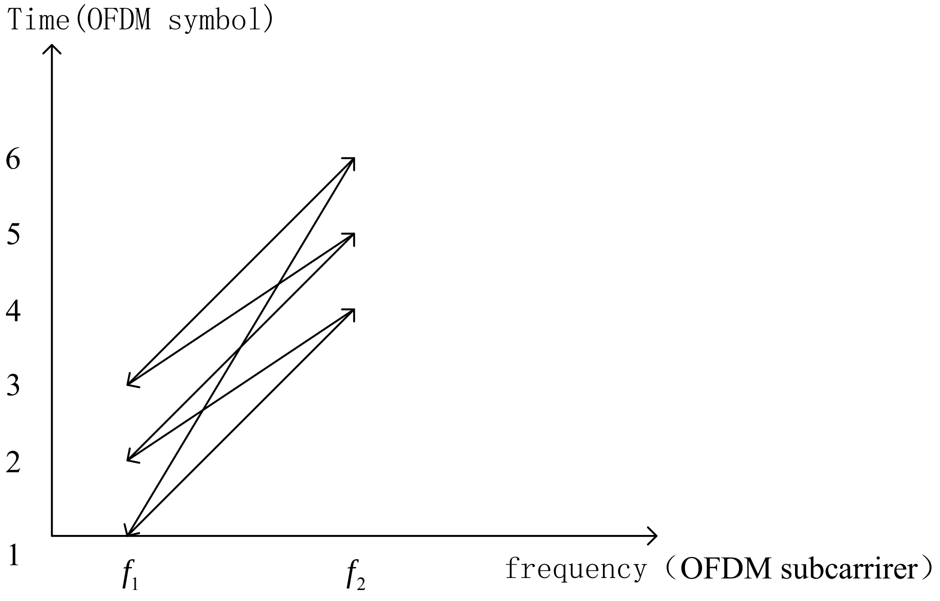

Fig.3 Time-frequency 2D interleaver

2.3 ML Demodulation

In the receiver, OFDM demodulation is firstly carried out. Then, the phase-compensation operation can be implemented as

$$r' = \frac{r \cdot h^*}{|h|}$$

where r is the FFT output, h is the channel coefficient in frequency domain. So, we can only consider the amplitude attenuation due to the frequency-selective effect of OFDM system, and do not need to consider the phase distortion. And then, the Q component is de-interleaved to composed new constellations. Afterwards, ML demodulation is used to produce the LLRs of the encoded bits from the rotated constellations. For example, assuming the transmitted rotated QPSK constellation S＝(S_I, S_Q) and the corresponding received constellation R＝(R_I, R_Q), as shown in Fig.4, we have the following formula:

$$R_I = H_I \cdot S_I + N_I$$
$$R_Q = H_Q \cdot S_Q + N_Q$$

where H_I and H_Q is the amplitude attenuation coefficient on I component and Q component of the constellation R, respectively. The 2D Q-interleaver ensures H_I and H_Q as independent as possible. N_I and N_Q is the independent identical distributed (i.i.d.) additive white Gaussian noise (AWGN) with zero mean and σ^2 variance per I/Q component, respectively. So, from Fig.4, we can see the reference constellation after Q-interleaving ($H_I \cdot S_I$, $H_Q \cdot S_Q$) is the scaled version of the transmitted constellation (S_I, S_Q).

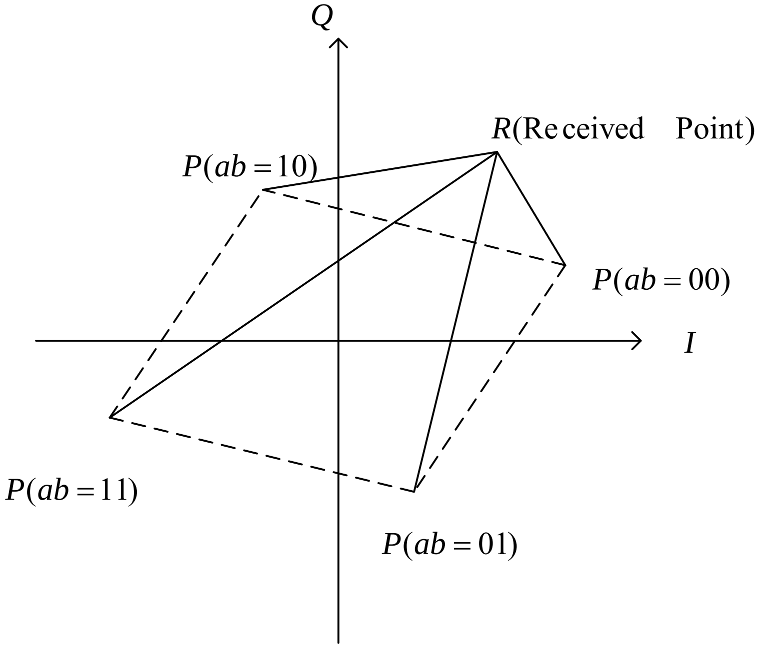

Fig.4 Received signal constellation and ML demodulation

Assuming equal a-prior probability of the transmitted rotated constellations *S*, the probability of received constellation (R_I , R_Q) should be in direct proportion to the Gaussian distributed probability density:

$$\mathrm{P}=\frac{1}{\sqrt{2\pi}\sigma}\exp\left(-\frac{\left(R_I-H_IS_I\right)^2+\left(R_Q-H_QS_Q\right)^2}{2\sigma^2}\right)$$

Therefore, the LLRs of (a,b) bits can be obtained as

$$LLR\left(a\right)=\ln\frac{P(a=0)}{P(a=1)}=\ln\frac{P\left(ab=00\right)+P\left(ab=01\right)}{P\left(ab=10\right)+P\left(ab=11\right)}$$

$$LLR\left(b\right)=\ln\frac{P(b=0)}{P(b=1)}=\ln\frac{P\left(ab=00\right)+P\left(ab=10\right)}{P\left(ab=01\right)+P\left(ab=11\right)}$$

3 Performance and complexity 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 system parameters are listed in Table.1. 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. We choose the following optimum rotation angle:

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

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

Fig. 5 and Fig. 6 compare the proposed Turbo-coded RM-QPSK-OFDM system with the conventional Turbo-coded BICM-QPSK-OFDM for RA and TU channel, respectively. It is easily seen that the proposed CRM-OFDM schemes are superior to the conventional BICM-OFDM system, and both cases can obtain over 1 dB SNR gain for FER=10^{-4}.

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)	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. 7 and Fig. 8 compare Turbo-coded RM-16QAM-OFDM system with the conventional Turbo-coded BICM-16QAM-OFDM for TU and RA channels, respectively. The code rate is 3/4. It also turns out that the proposed RM-OFDM schemes are superior to the conventional BICM-OFDM system. The optimum rotated angle $\theta_1 = \arctan\left(\frac{1}{4}\right)$ works well on both channels.

As for the complexity, in the transmitter, like the usual QAM/QPSK modulation, the rotated constellation can be set in advance and be implemented by a table, so it has no extra modulation complexity. For Q-interleaving, usual BICM also requires an interleaver so that modulation symbols can be interleaved to different time-frequency resource blocks of OFDMA, so rotated modulation has no extra complexity and delay as well. In receiver, the two-dimensional ML rotated demodulation is the same as that of usual QAM/QPSK, and the only difference lies in the amplitude attenuation of I component is not the same as that of Q component for the rotated demodulation. So, the rotated demodulation has no extra complexity as well. In a word, the transmitting and receiving complexity of rotated modulation is almost the same as that of usual QAM/QPSK. So, it is simple and efficient.

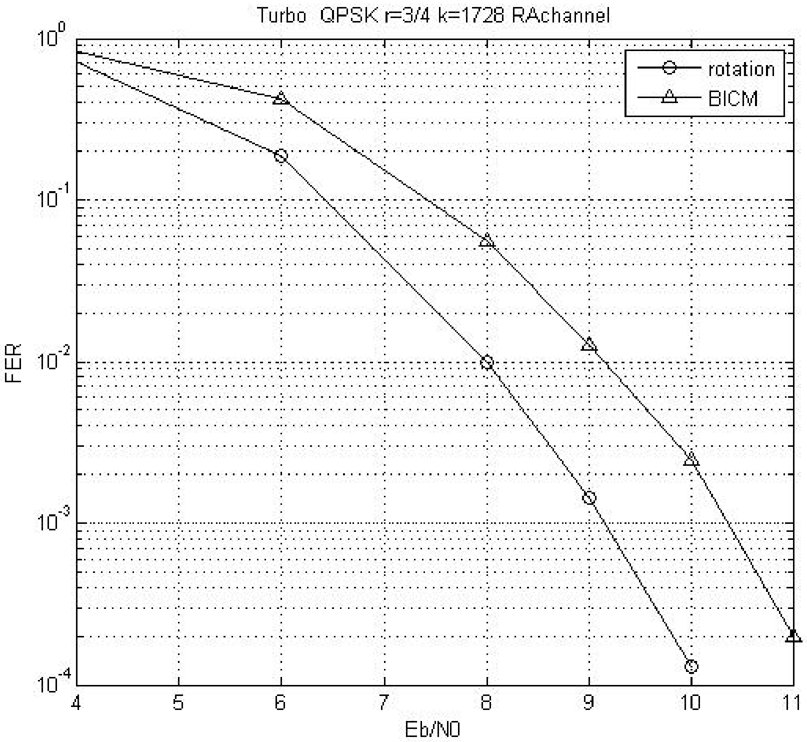

Fig. 5 Turbo-RM vs Turbo-BICM (QPSK, r=3/4)

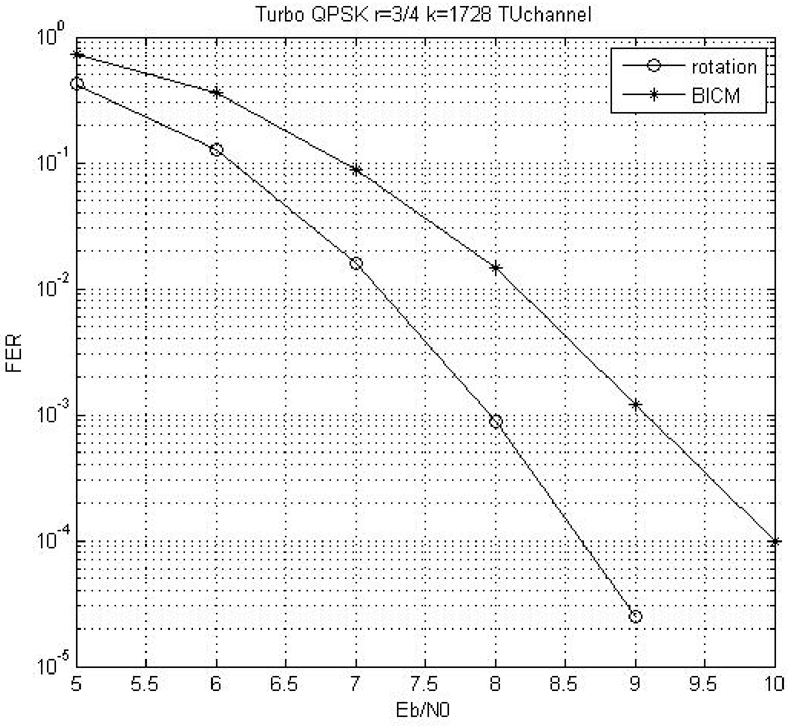

Fig. 6 Turbo-RM vs Turbo-BICM (QPSK, r=1/2)

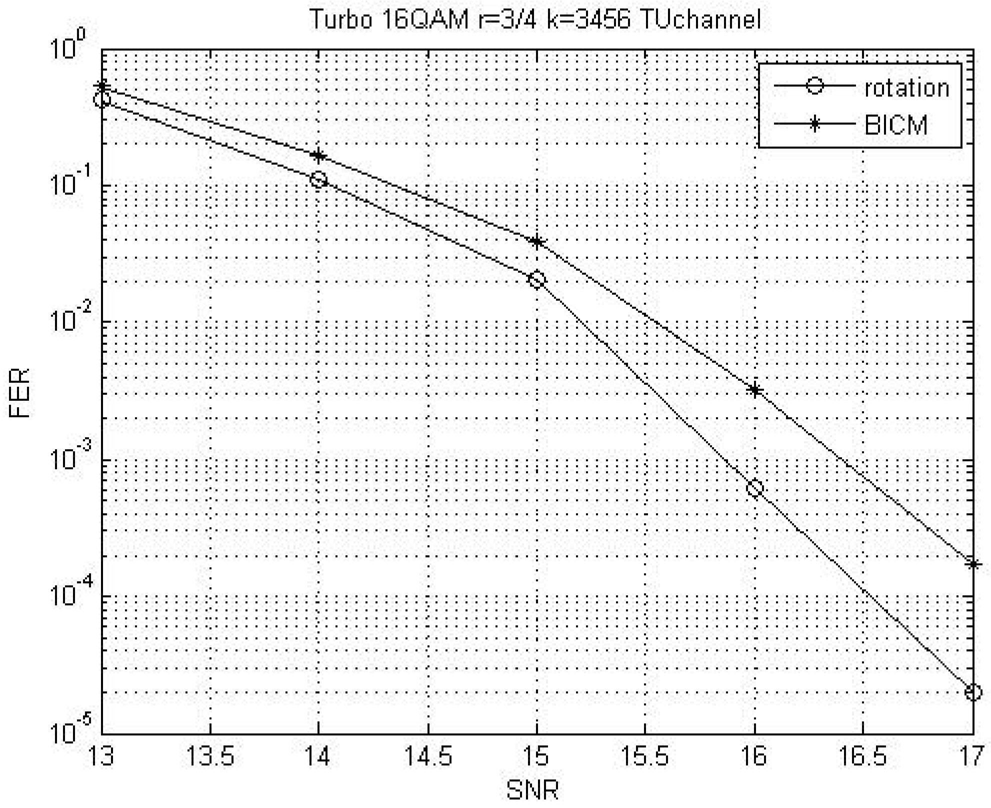

Fig. 7 Turbo-RM vs Turbo-BICM on TU channel (16QAM,r=3/4)

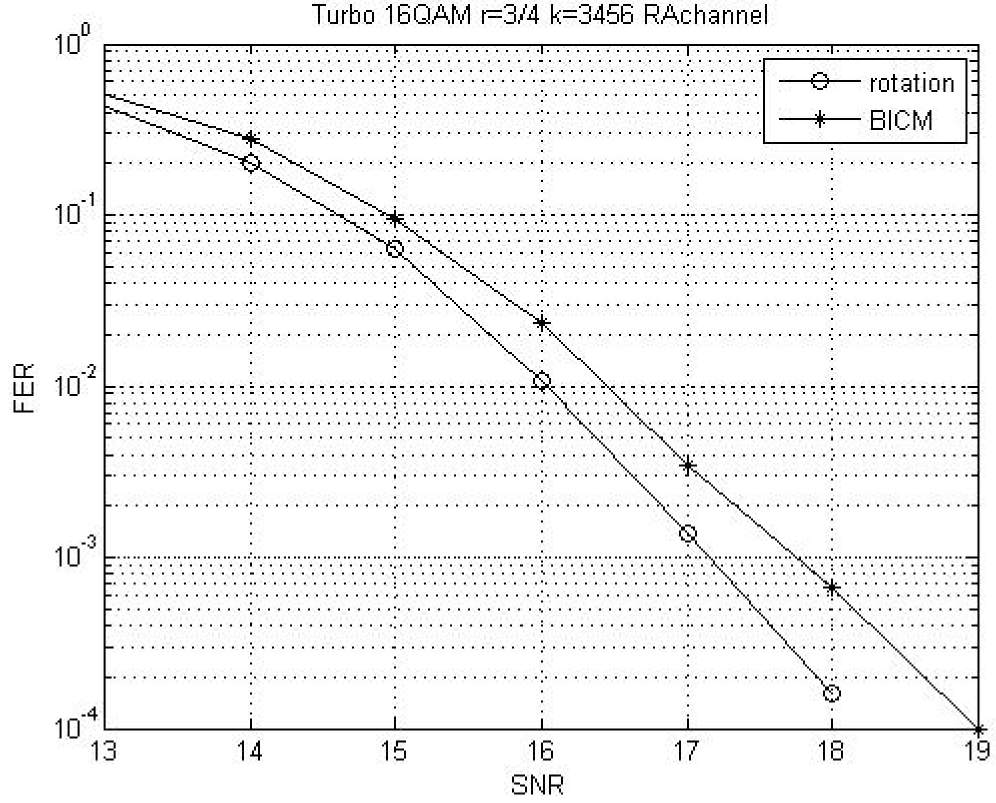

Fig. 8 Turbo-RM vs Turbo-BICM on RA channel (16QAM, r=3/4)

4 Conclusions:

The coding-rotated-modulation OFDM scheme is proposed. It takes full advantage of the modulation diversity of rotated MPSK/QAM modulation, the frequency diversity of OFDM system, and the coding gain of Turbo codes all together. Simulation results have turned out this scheme outperforms the conventional BICM scheme. Besides, we recommend the rotated angles for QPSK and QAM constellations. It is shown that the angles are independent of the fading channels. As for the implementations, the transmitting and receiving complexity of the proposed scheme is almost the same as the conventional schemes.

Acknowledgement:

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

5 Text proposal for inclusion in the 802.16m amendment

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15.X.1.5.1.10 Modulation

Coding-rotated-modulation OFDM scheme should be supported by IEEE 802.16m, as shown in Fig.x.1. After the data symbols are normally generated, they are rotated with a given angle, which depends on the used constellation. Then, the Q components (imaginary parts) of the rotated symbols are interleaved to maximize the modulation diversity. Finally, the I components and the interleaved Q components are multiplexed into one complex symbol sequence.

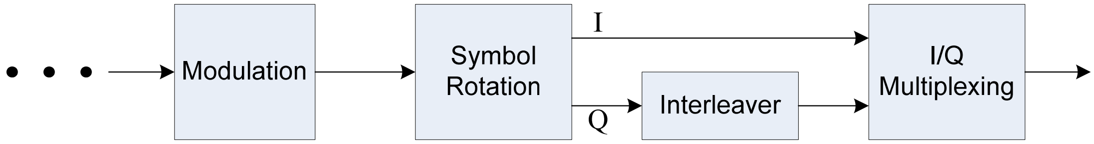

Fig.x.1 Coding-rotated-modulation OFDM scheme

15.X.1.5.1.10.1 Rotation Modulation:

A conventional two-dimensional constellation (A, B) becomes a new rotated constellation (X, Y) by rotating some angle θ_1, as shown in Fig.x.2. The formula is given by the following:

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

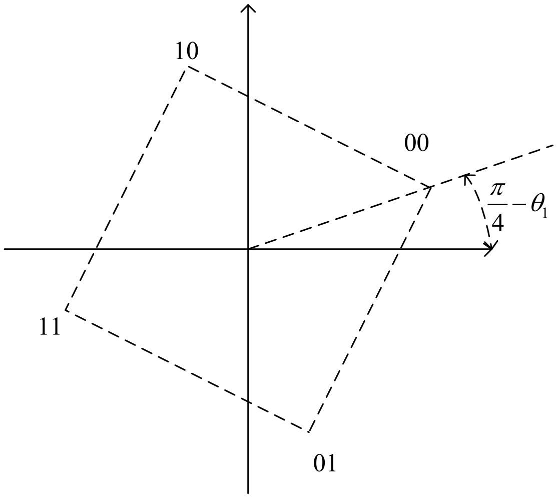

Fig.x.2 Rotated QPSK constellation

Some optimum rotation angles are given as follows:

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

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

For two-dimensional rotated 64QAM, $\theta_1 = \arctan\left(\frac{1}{8}\right) = 0.124355$

15.X.1.5.1.10.2 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)}.

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6 References:

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