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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 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 Turbo codes all together.

2 A novel coding-rotated-modulation OFDM scheme

A novel CRM(coding-rotated-modulation)-OFDM scheme is proposed, as 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 (Maximum-likelihood) demodulation is used to produce the LLRs (Log-likelihood-ratio) of encoded bits from the rotated constellations, so the channel decoder 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.

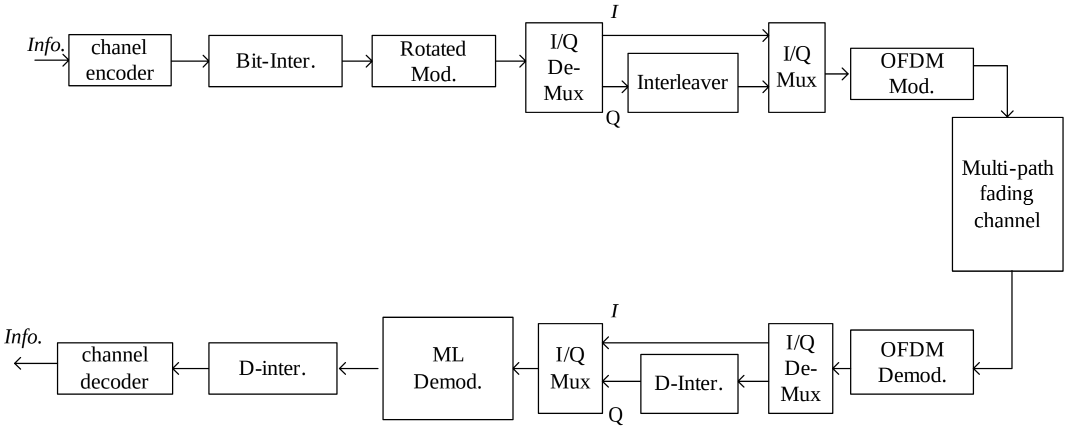

Fig.1 Coding-rotated-modulation OFDM scheme

2.1 Rotated Modulation (RM)

As compared with the usual MPSK/QAM, 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:

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

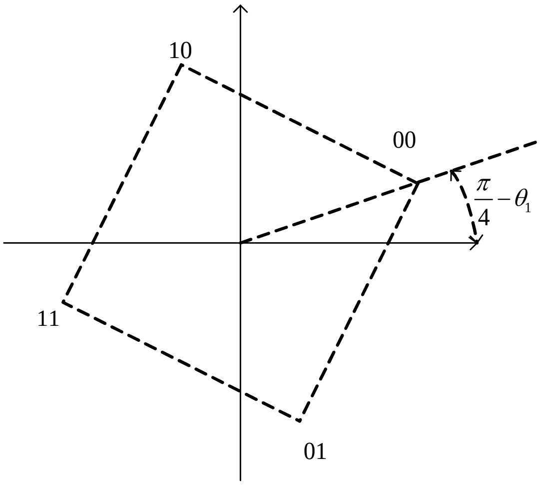

Fig.2 Rotated-QPSK constellation

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, $\theta_1 = \arctan\left(\frac{1}{2}\right) = 0.463648$.

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

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.

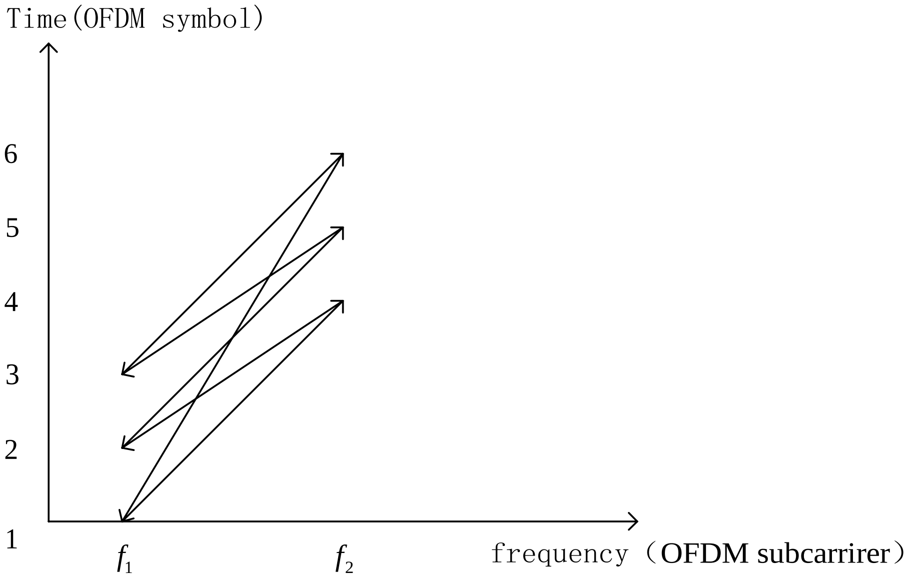

Fig.3 Time-frequency interleaver mapping

2.3 ML demodulation

In the receiver, OFDM demodulation is carried out firstly, including deleting CP, FFT and phase-compensation operations. The phase-compensation operation can be implemented as the follows:

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

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 (Log-likelihood-ratio) of 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 i.i.d. (independent identical distributed) AWGN (additive white Gaussian noise) $N(0,\sigma^2)$ with zero mean and σ^2 variance on I component and Q component of the constellation R, 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).

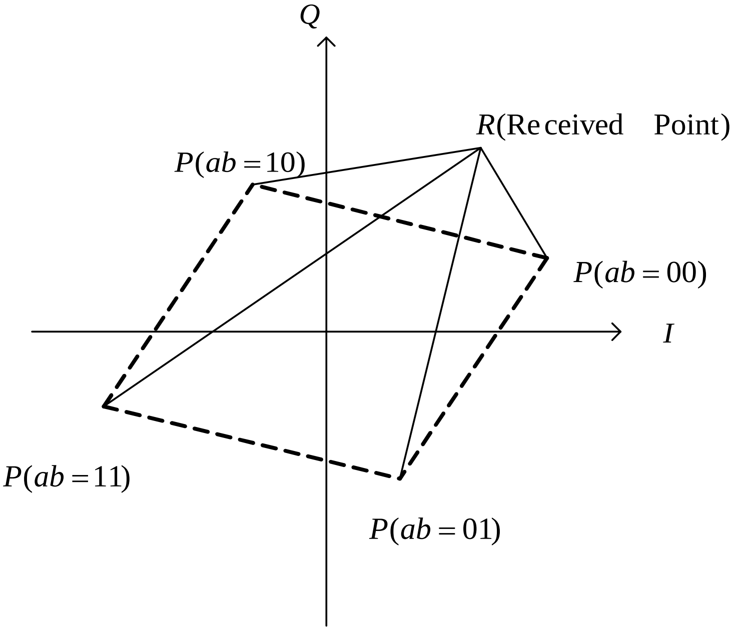

Fig.4 Received signal constellation and ML demodulation

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:

$$\mathrm{P} = \frac{1}{\sqrt{2\pi}\sigma}\exp\left(-\frac{\left(R_I - H_I S_I\right)^2 + \left(R_Q - H_Q S_Q\right)^2}{2\sigma^2}\right)$$

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

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

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

3 Performance and complexity evaluation

Simulations are carried out to compare our proposed CRM-OFDM with the conventional BICM-OFDM system. Turbo codes with generator $\begin{bmatrix}15\\ \hline 13\end{bmatrix}_8$ are studied in this scheme. The system parameters are listed in Table.1. The fading channel models are three kinds of six-delay-tap models which are defined in GSM standards with classical Doppler spectrum, TU, RA and HT environment. 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 our 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 our proposed CRM-OFDM schemes are much superior to the conventional BICM-OFDM system, and both cases can obtain over 1 dB SNR gain for FER=10^{-4}.

Fig. 7, Fig.8 and Fig.9 compares different-rotated-angle performances for TU, HT and RA channel model, respectively. Three figures are all like U-shape and turn out $\theta_1=\arctan\left(\frac{1}{2}\right)$ is the best rotated angle for two-dimensional rotated QPSK constellation. It is very useful that the optimum rotated angle is independent on the fading channel.

Fig.10 and Fig.11 compare Turbo-coded RM-16QAM-OFDM system with the conventional Turbo-coded BICM-16QAM-OFDM for TU and RA channel, respectively. Turbo codes are studied in this scheme, and the code rate is 3/4. It also turns out that our proposed RM-OFDM schemes are much superior to the conventional BICM-OFDM system. The optimum rotated angle $\theta_1=\arctan\left(\frac{1}{4}\right)$ works well on both channel types, TU and RA, which is very useful and robust.

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.

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	LDPC,Turbo
Coding rate (= R)	3/4
Decoding algorithm	Log_BP/ 50 iterations, Log-MAP/8 iterations
Modulation	QPSK,16QAM,
Rotation dimension (= D)	2
Rotation angle for rotational OFDM	0.463648 0.244979
Channel model	C.3.3 (Typical Urban) of f_D = 56 Hz, HT of f_D = 56 Hz,RA of f_D = 56 Hz
# of receiving antenna	1
Channel estimation	Perfect

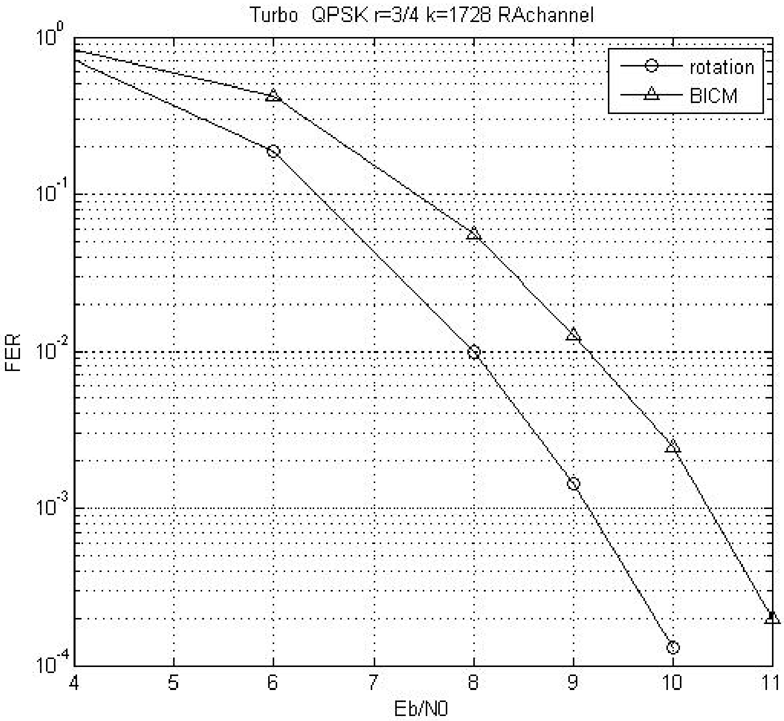

Fig.5 Turbo-RM vs Turbo-BICM (QPSK, r=3/4)

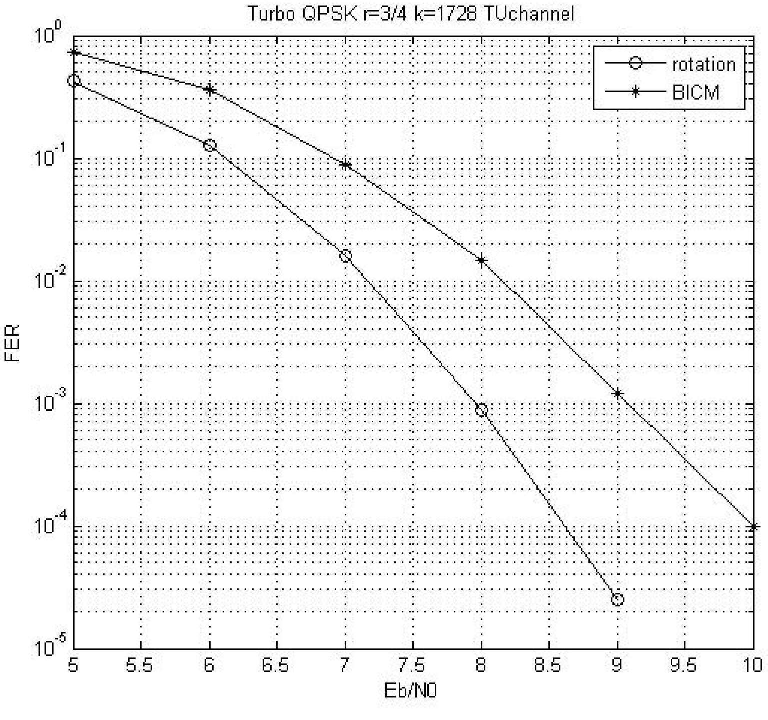

Fig.6 Turbo-RM vs Turbo-BICM (QPSK, r=1/2)

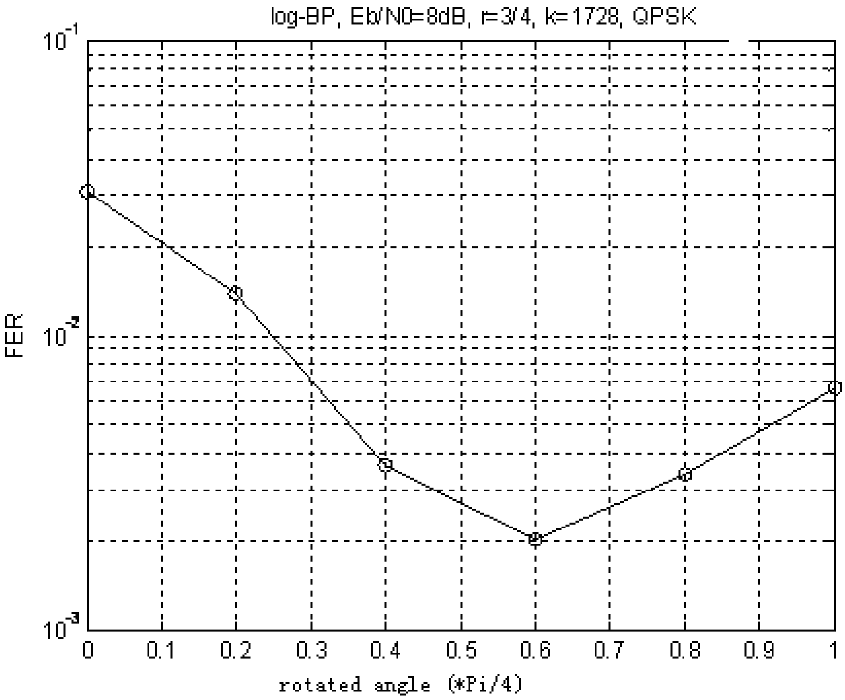

Fig.7 Different rotated-angle performance on TU channel

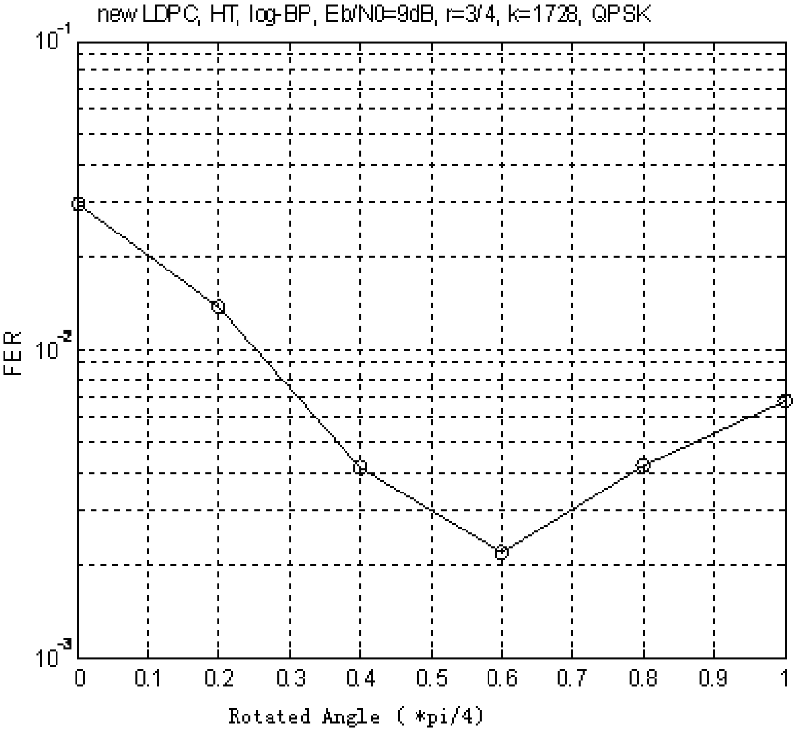

Fig.8 Different rotated-angle performance on HT channel

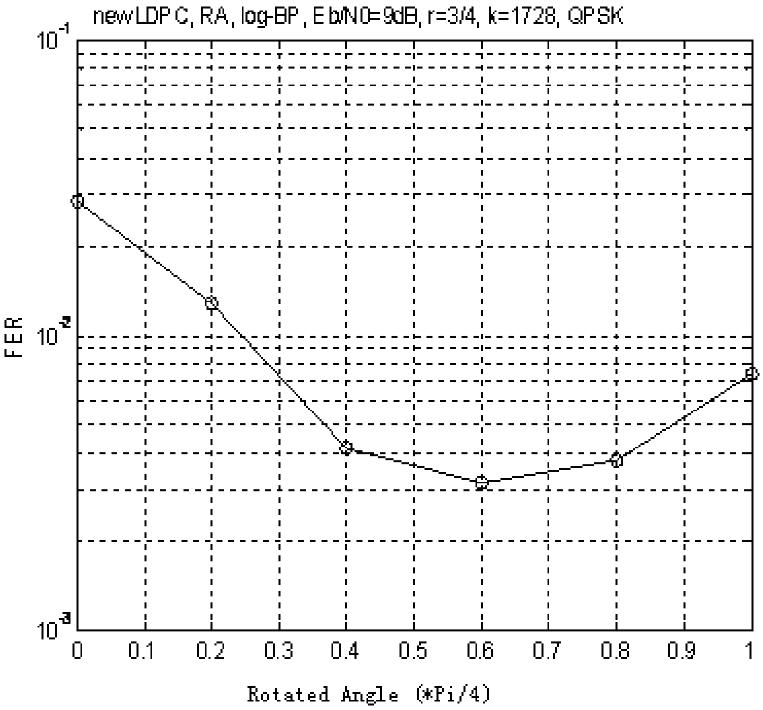

Fig.9 Different rotated-angle performance on RA channel

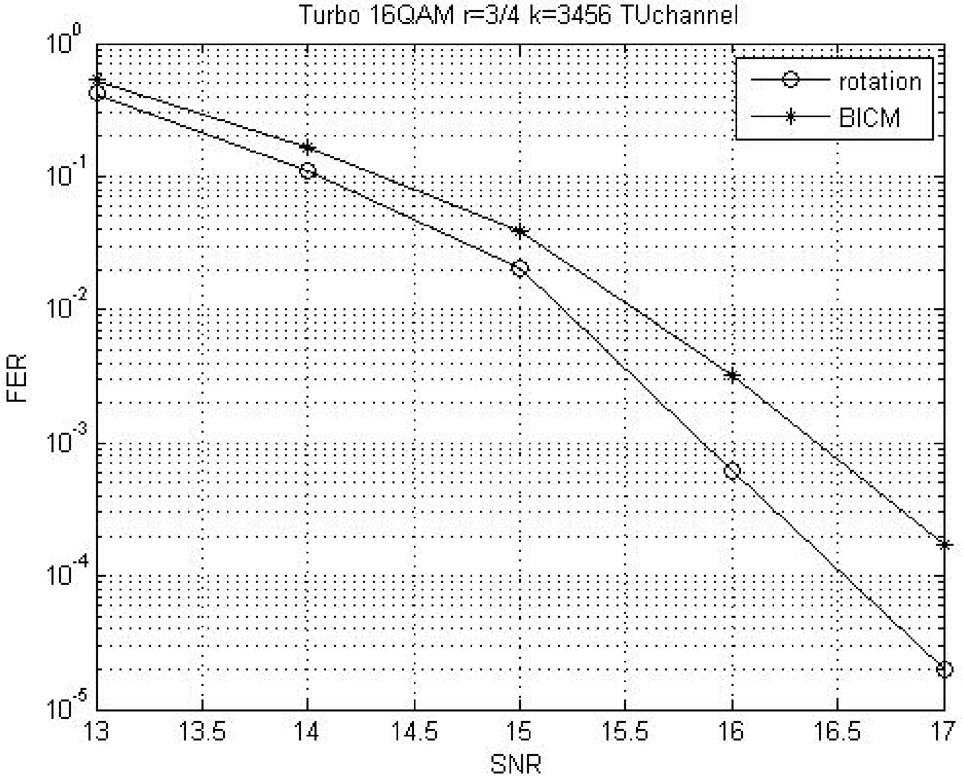

Fig.10 Turbo-RM vs Turbo-BICM on TU channel (16QAM,r=3/4)

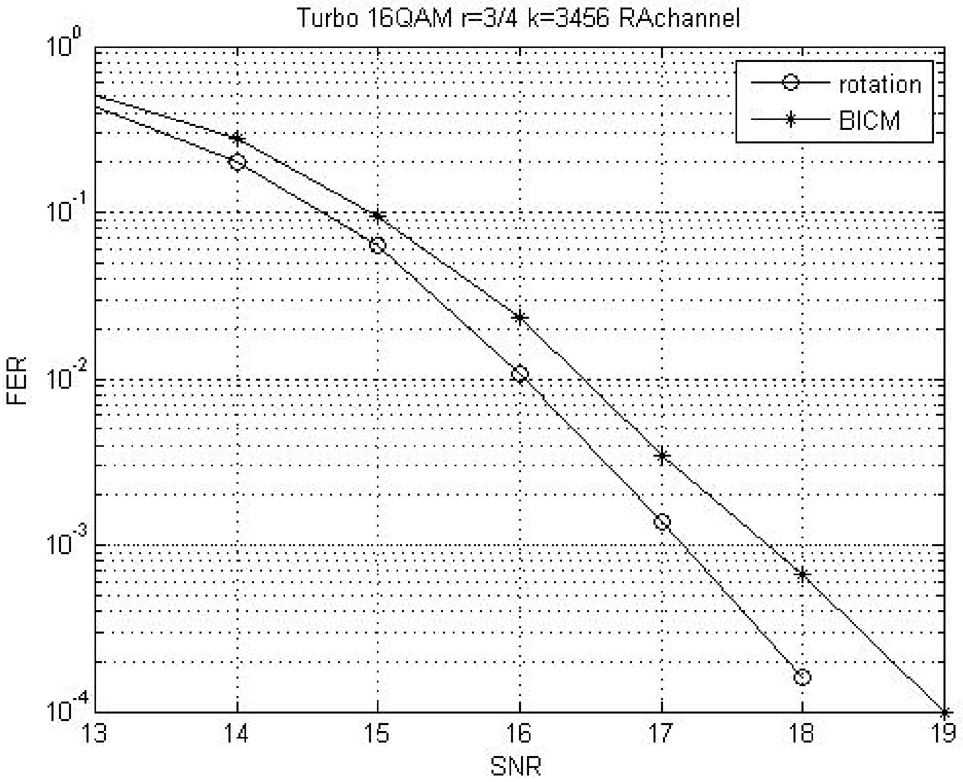

Fig.11 Turbo-RM vs Turbo-BICM on RA channel (16QAM, r=3/4)

4 Conclusions:

A novel CRM-OFDM system is proposed. Turbo codes are studied in this scheme. The new scheme 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 new coding-modulation scheme for OFDM system can significantly outperform the BICM scheme. Besides, we derive the optimum rotated angles for two-dimensional rotated QPSK/QAM and prove that it is independent on the fading channel, which is very useful and robust. As for the implementations, the transmitting and receiving complexity of two-dimensional rotated modulation is almost the same as that of usual QAM/QPSK. So, our proposed CRM-OFDM scheme is simple and efficient.

Acknowledgement:

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5 Text proposal for inclusion in the 802.16m amendment

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15.X.1.5.1.10 Modulation

CRM(coding-rotated-modulation)-OFDM should be supported by IEEE 802.16m, as shown in Fig.x.1. Firstly, information bits are sent into a channel encoder, and the coded bits are rotation-modulated. For the rotation-modulation, the point of the rotated constellation is obtained by applying the rotation matrix to the multidimensional QPSK/QAM constellation. The rotated constellations (complex signal) split into the in-phase (I) and quadrature (Q) Components (real signal). For Q components, a time-frequency two-dimensional interleave is used to maximize the time, frequency and modulation diversity. I components and interleaved Q components are multiplexed into one complex-signal sequence and then allocated into different chunks in the distributed OFDMA system.

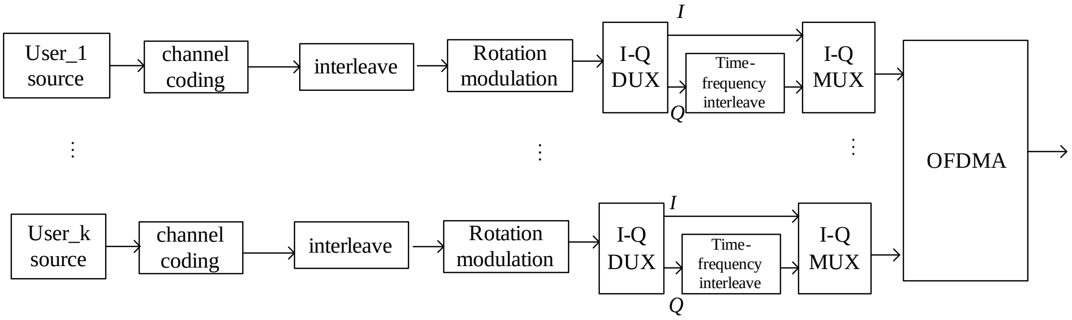

Fig.x.1 CRM(coding-rotated-modulation)-OFDMA

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:

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

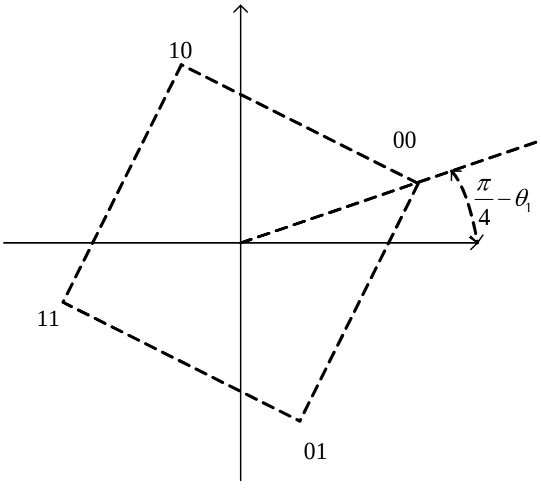

Fig.x.2 Rotated-QPSK constellation

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, $\theta_1 = \arctan(\frac{1}{8}) = 0.124355$

15.X.1.5.1.10.2 Rotated Constellations mapping into OFDM and a time-frequency 2D-interleaver

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. and it can be easily generalized to any 2N-subcarrier OFDM system with 2M OFDM symbols in time domain. Assuming 2M Q-component signals ($q_1, q_2, ..., q_{2M}$) take up the time-frequency resource blocks {(f1,1), (f2,M+1), (f1,2), (f2,M+2),…(f1,M), (f2,2M)}, after interleaving, they occupy {(f2,M+1), (f1,2), (f2,M+2), …, (f1,M), (f2,2M), (f1,1)}, which is the right-cyclic-shift result of the original resource blocks, where, f1=(f2+N) % 2N.

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6 References:

1. Matthew C. Davey, PHD Thesis: Error-correction using Low-Density Parity-Check Code, Gonville and Caius College, Cambridge, 1999
2. Wu Zhanji, Peng Mugen, Wang Wenbo, Efficient difference-based decoding implementations of LDPC, IEEE Communication Letter, May, 2008, Vol.12, No.5, pp:383-385
3. Wu Zhanji, Peng Mugen, Wang Wenbo, A new parity-check stopping criterion for Turbo decoding, IEEE Communication Letter, April, 2008, Vol.12, No.4 ,pp:304-306
4. Wu Zhanji, Model of independent Rayleigh faders, Electronics Letters, Vol. 40 No.15, 22nd July 2004, 949-951
5. J.Boutros, E.Viterbo, Signal Space Diversity: a power and bandwidth efficient diversity technique for the Rayleigh fading channel. IEEE Trans. Inform. Theory, bol.44. pp.1453-1467, July1998 .