A novel HARQ Scheme based on Frequency Diversity and Energy-MRC

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Abstract—In order to reduce the influence of multipath propagation on signal transmission in the OFDM wireless network, a novel HARQ scheme based on frequency diversity and Energy-MRC is proposed. This scheme takes the times of accurate transmission of previous data as reference value of present data transmission. When the data is transmitted, the position in which information sequence lives after constellation mapping is changed before IFFT. So each time subcarrier fading relativity of the same information sequence is small, and major frequency diversity gain is obtained. In the receiving terminal, energy of the same information sequence in many times of transmission is maximal ratio combined after FFT. Under Rayleigh fading channel environment, simulation experiment shows that this scheme can reduce effectively BER(Bit Error Rate), compared with HARQ scheme without frequency diversity and MRC based on channel impulse response power. This scheme is easy to realize, and complex channel estimation is avoided.

Index Terms— Frequency Diversity; Maximal Ratio Combining(MRC); Hybrid Automatic Repeat Request(HARQ); OFDM; Frequency Selective Fading

I. INTRODUCTION

HARQ (Hybrid Automatic Repeat Request) [1-7] technique is one of the important techniques to realize reliable transmission of high data rate in the wireless network. At present there are mainly three kinds of HARQ. Type I HARQ requests retransmitting data which is still error after error correcting. When the maximal times of transmission allowed is exceeded, the data is discarded and the next data is transmitted. Type II HARQ transmits different IR (Incremental Redundancy) information at retransmission, then IR information is merged with the above-received information and forms a code which has a stronger error correcting ability. Type III HARQ transmits an integral code including IR information at retransmission. At the receiving terminal, the error data and retransmission data are combined and decoded. In Type II and Type III HARQ, the data without accurately decoding is fully utilized at receiving terminal. The reliability of data transmission is raised effectively.

In the OFDM wireless network, frequency selective fading [8-17] is one of the important factors which influences signal transmission quality. In order to reduce the influence of multipath propagation on signal transmission, many HARQ schemes based on frequency diversity have been proposed. Literature [18] utilizes the subcarrier assignment pattern before IFFT at the transmitting terminal. Traditional MRC (Maximal Ratio Combining) is used after constellation inverse mapping. This scheme reduces the times of retransmissions, but does not consider the present channel state. Literature [19, 20] use interleaving to realize frequency diversity according to the present subchannel quality, and reduce effectively burst error code. In literature [21], according to the channel estimation state obtained at transmitting terminal, retransmission data is adaptive interleaving rearranged. The constellation rearrangement scheme and traditional Chase combining are used. The block error rate and transmission delay are greatly reduced. But literature [19-21] rely on accurate channel estimation, and feedback information of high quality is needed at transmitting terminal. The algorithm is very complex.

This paper proposes a HARQ scheme based on frequency diversity and Energy-MRC. This scheme takes the times of accurate transmission of previous data as reference value of present data transmission. When the data is retransmitted, the position in which information sequence lives after constellation mapping is changed before IFFT. In the receiving terminal, energy of the same information sequence in many times of transmission is maximal ratio combined after FFT. Under Rayleigh fading channel environment, simulation experiment shows that this scheme can reduce effectively BER (Bit Error Rate), compared with HARQ scheme without frequency diversity and MRC based on channel impulse response power. This scheme is easy to realize, and complex channel estimation is avoided.

II. HARQ SCHEME MODEL

The proposed HARQ system model is shown in Fig. 1. The focus of this paper is how to reduce the influence of frequency selective fading on signal transmission in the OFDM wireless network, thus raising the reliability of data transmission effectively. The OFDM wireless system in this paper is SISO structure. The channel encoding is CC (Convolution Code). The modulation pattern is MQAM. The channel model is Rayleigh channel. The additive noise is AWGN.

The major job steps of the proposed HARQ model are:
(1) if the CRC checking result of received data is correct,
the data is received at receiving terminal. The ACK (acknowledge) feedback message is sent to transmitting terminal simultaneously, and the next data will be transmitted; (2) when the CRC checking result of received data is incorrect and the times of transmission is less than or equal to the maximal times of transmission, the system will send NACK (non-acknowledge) message to the transmitting terminal. According to the proposed frequency diversity algorithm before IFFT, the position in which information sequence lives after constellation mapping is changed. In the receiving terminal, energy of the same information sequence in many times of transmission is maximal ratio combined after FFT. The combined information is carried on constellation inverse mapping, and is restored to data sequence.

III. PRINCIPLE OF THE ALGORITHM

Multipath propagation in wireless channel can lead to frequency selective fading. A deep fading phenomenon will occur at propagation zeros and places near them. According to the above analysis of literature [18-21], the paper proposes a novel frequency diversity and maximal ratio combining algorithm.

A. Frequency Diversity Algorithm

1) the Method of Changing the Position in which Information Sequence Lives

The paper uses cycle-translation method to change the subchannel position in which information sequence lives. An example of the method is shown in Fig. 2. Fig. 2 presumes that an OFDM symbol has nine information sequences after constellation mapping. In Fig. 2(a), the subcarrier corresponding to the first transmission information is $\omega_1$. At the first retransmission the cycle-translation number is 3. Nine information sequences are cycle-translated three subchannels towards left in OFDM symbol. In this case, the relation between information sequence and subcarrier is shown in Fig. 2(b).

At the second retransmission, $N_2$ is $\frac{S}{3}$, i.e. the cycle-translation number begins the cycle from zero again.

Because $M (M \leq M_{\text{max}})$, the times of the accurate transmission of previous data, roughly reflects present channel quality, this paper takes it as reference value of present data transmission, according to which information sequence’s cycle-translation number is confirmed.

At the $i$th ($1 \leq i \leq M$) transmission, the present data’s cycle-translation number is

$$N_i = (i-1) \cdot \left\lfloor \frac{S}{M} \right\rfloor_{\text{integer part}}$$

(1)

For example, when the data is in the first transmission, $M = 3$, $i = 1$, $N_1 = 0$; When the data is in the first retransmission, $N_2 = \left\lfloor \frac{S}{3} \right\rfloor_{\text{integer part}}$; When the data is in the second retransmission, $N_3 = 2 \cdot \left\lfloor \frac{S}{3} \right\rfloor_{\text{integer part}}$.

When the times of transmission of present data is more than $M$, i.e. $M < i \leq M_{\text{max}}$, the present data’s cycle-translation number

$$N_i = [i-1-M]_{\text{mod}M} \cdot \left\lfloor \frac{S}{M} \right\rfloor_{\text{integer part}}$$

(2)

i.e. the cycle-translation number begins the cycle from zero again.

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Especially $M$ is forced to be 2 when $M = 1$, thus cycle-translation number is avoided to be $S$ when present data needs retransmission.

3) Realizing Procedure of Frequency Diversity Algorithm

Frequency diversity algorithm of this paper gives an OFDM symbol example. In the OFDM symbol, the subcarrier after constellation mapping is named $X_p (0 \leq p \leq S-1)$. At the transmitting terminal, information sequence vector which is translated at the $i^{th}$ transmission is named $F_i$. In $F_i$, arranged sequence number of $X_p$ is $\{p+N\}_{\mod S}$. So

$$F_i = [X_{(p+N)_{\mod S}}, X_{(p+N+1)_{\mod S}}, \ldots, X_{(p+M-1)_{\mod S}}]$$

For example, $S = 9$, $M = 3$, $N_i = (i-1) \times 3$. When $i = 1$, $N_1 = 0$, $F_1 = [X_0, X_1, \ldots, X_3]$; When $i = 2$, $N_2 = 3$, $F_2 = [X_3, X_4, X_5, X_6, X_7, X_8, X_9, X_{10}, X_{11}, X_{12}]$. In this way, cycle-translation of information sequence towards left is realized, and the position in which information sequence lives is changed.

When the checking result of received data is incorrect and the data needs retransmission, $F_i$ at transmitting terminal corresponds to name $F_i'$ at receiving terminal. $X_p$ is named $X_p'$ in $F_i'$. For example, $F_2' = [X_3, X_4, X_5, X_6, X_7, X_8, X_9, X_{10}, X_{11}, X_{12}]$. $F_1'$ is named after $F_2'$.

4) Characteristic of Frequency Diversity Algorithm

Frequency diversity algorithm of this paper has three major characteristics. First, this paper takes the times of accurate transmission of previous data as reference value of present data transmission. On the one hand, feedback information of high quality isn’t needed at transmitting terminal and the algorithm is easy to realize. On the other hand, the algorithm ensures as far as possible that the position in which the same information sequence lives is different at every retransmission, so major frequency diversity gain is obtained. Second, when the maximal relative delay is less in multipath channel, i.e. adjacent propagation zero is far apart, frequency diversity algorithm of this paper avoid as far as possible that same information sequence places propagation zero many times. So subchannel information of small fading can be fully utilized when combining. Third, when retransmission time is short apart, for example in many ARQ agreement [22] the data retransmission starts immediately as soon as NACK is received, multipath condition of retransmission is unchanged or little changed. At this moment each time subcarrier fading relativity of the same information sequence is small, and major frequency diversity gain is obtained.

B. Energy-MRC Algorithm

In HARQ technique traditional MRC algorithm mostly relies on SNR (signal-to-noise ratio) [23-25] or channel impulse response power [26] to weighted combination. These algorithms need a large number of statistics and analysis for channel information and high-accuracy channel estimation [27-31]. But in the actual application channel estimation often exists deviation. The more accurate channel estimation is, the more complex the algorithm is. According to above proposed frequency diversity algorithm and received signal’s analysis for OFDM system, this paper proposes a novel MRC algorithm based on energy which is named Energy-MRC (i.e. EMRC).

According to the analysis of mathematics model for OFDM system [32, 33], the received signal which lives in each subcarrier at the OFDM receiving terminal is

$$R_n = H_n A_n Q_n + W_n \quad (n = 0,1,\ldots,S-1)$$

where $A_n$ is transmitted signal’s amplitude at each subcarrier; $Q_n$ which lives in the $n^{th}$ subcarrier is the transmitted signal that power is normalized; $W_n$ whose variance is $D_0$ is additive white Gaussian noise; $H_n$ which lives in the $n^{th}$ subcarrier is channel multiplicative factor.

$$H_n = \frac{1}{L} \sum_{f=0}^{L-1} h_f \exp(-j2\pi nf / S)$$

where $n = 0,1,\ldots,S-1$; $L$ is the number of path in multipath channel; $h_f (f = 0,1,\ldots,L-1)$ is the $f^{th}$ path coefficient of multipath channel. The amplitude of $H_n$ submits Rayleigh distribution, and $\frac{1}{L} \sum_{f=0}^{L-1} E(|H_n|^2) = 1$.

When the amplitude of $H_n$ submits mutual independence and the signal is transmitted with equal power at each subcarrier, instantaneous SNR of the $n^{th}$ subcarrier is

$$\gamma_n = \frac{|H_n|^2 A_n^2}{D_0}$$

According to Eq. (6), BER (Bit Error Rate) at each subcarrier is closely related to $|H_n|^2$. When $D_0$ is less, BER of the entire system is mainly decided by the subcarrier which suffers deep fading. At this moment, the energy of information sequence at every transmission chiefly suffers influence of multipath fading.

It is assumed that the times of actual transmission of present data is $\tilde{M}$. The transmitted $X_p$ corresponds to $\tilde{M}$ received sequences, $X_p' = a_p' + jb_p' \quad (1 \leq i \leq \tilde{M})$, which are before constellation inverse mapping. The energy of $X_p'$ is $E_p' = (a_p'^2 + b_p'^2)$. It is assumed that $X_p'$ which corresponds to transmitted $X_p$ is received sequences after Energy-MRC, i.e.
TABLE I. MULTIPATH CHANNEL PARAMETERS

<table>
<thead>
<tr>
<th>Tap</th>
<th>Relative delay (ns)</th>
<th>Average power (dB)</th>
<th>Relative delay (ns)</th>
<th>Average power (dB)</th>
<th>Relative delay (ns)</th>
<th>Average power (dB)</th>
</tr>
</thead>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
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<td>-0.7</td>
<td>50</td>
<td>-3</td>
<td>100</td>
<td>-4</td>
</tr>
<tr>
<td>2</td>
<td>190</td>
<td>-19.2</td>
<td>110</td>
<td>-10</td>
<td>200</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>410</td>
<td>-22.8</td>
<td>170</td>
<td>-18</td>
<td>300</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>190</td>
<td>-19.2</td>
<td>290</td>
<td>-26</td>
<td>400</td>
<td>16</td>
</tr>
<tr>
<td>5</td>
<td>310</td>
<td>-32</td>
<td>500</td>
<td>0</td>
<td>500</td>
<td>20</td>
</tr>
</tbody>
</table>

\[
X_p = \sum_{i=1}^{M} \frac{E_p}{E_p} = \hat{a}_p + j\hat{b}_p \quad (7)
\]

The proposed Energy-MRC algorithm fully utilizes major frequency diversity gain on the basis of frequency diversity. The specific weight of high quality signal is increased before constellation inverse mapping at multipath propagation. At the same time both a large number of statistics and analysis of channel information and high-accuracy channel estimation are avoided.

IV. SIMULATION RESULTS AND ANALYSIS

A. Simulation Assumption

The proposed HARQ scheme based on OFDM wireless network is simulated by MATLAB. In the simulation system, it is assumed that feedback channel of ACK/NACK message is ideal and the data retransmission starts immediately as soon as NACK is received. Every OFDM symbol is assumed to have 784 data subcarriers. The 16QAM is employed. The Doppler frequency is assumed to be 20 Hz. The maximal times of transmission is assumed to be 2. The CC is employed at rate 1/2. In the light of various multipath channel conditions and combining patterns, this paper compares performance of various transmission schemes by BER.

In consideration of stronger real-time of wireless communication, the focus of this simulation system discussion is that the times of transmission of previous data is \( M = 2 \). Then the reference times of transmission of present data is 2, and the cycle-translation number is \( 784/2 = 392 \). In the simulation results figure, “without HARQ” expresses that simulation system is without HARQ scheme; “proposed HARQ” expresses that the proposed frequency diversity algorithm is used at retransmission; “type I HARQ” expresses that the information sequence position is unchanged at retransmission: “HMRC” expresses the MRC algorithm is based on channel impulse response estimation; “EMRC” expresses the MRC algorithm is based on energy.

B. Simulation of HARQ Scheme without Channel Encoding and Decoding

In order to more objectively verify the proposed algorithm which does not involve channel encoding and decoding, this paper simulates the HARQ scheme without channel encoding and decoding at first. In many ARQ agreements the data retransmission starts immediately as soon as NACK is received. That is, multipath condition is unchanged at data retransmission. Figs. 3 and 4 are simulated results under the same multipath condition at data retransmission.

In Fig. 3, the multipath channel parameters are both M. 1225 outdoor to indoor and pedestrian test environment parameters at the first transmission and retransmission, (See table 1.) As shown in Fig. 3, (1) in the EMRC pattern, BER of the proposed HARQ has 2 dB gain between 12—14 \( \text{dB} \) as compared with type I HARQ; (2) Under the proposed frequency diversity algorithm at retransmission, BER of EMRC pattern has about 2\( \text{dB} \) gain between 10—12 \( \text{dB} \) as compared with HMRC pattern.

In Fig. 4, the multipath channel parameters are both COST207 rural terrain parameters at the first transmission and retransmission, (See table 1.) As shown in Fig. 4, (1) in the EMRC pattern, BER of the proposed HARQ has 1 dB gain between 17—19 \( \text{dB} \) as compared with type I HARQ; (2) When the information sequence position is changed at retransmission, EMRC curve intersects HMRC curve at 10 \( \text{dB} \). HMRC is a little better than EMRC when SNR is less than 10 \( \text{dB} \); EMRC is obviously better than HMRC when SNR is more than 10 \( \text{dB} \). BER of EMRC pattern has about 2 \( \text{dB} \) gain between 12—14 \( \text{dB} \) as compared with HMRC pattern.

The superiority of the proposed algorithm in Fig. 4 is obviously weak as compared with Fig. 3. According to channel parameters in table 1, the number of the tap of multipath channel is 4 in Fig. 3, and the maximal relative delay is 410ns; the number of the tap of multipath channel is 6 in Fig. 4, and the maximal relative delay is 500ns. When the number of the tap of multipath channel is many and the maximal relative delay is big, the increase of the number of propagation zero causes the increase of deep fading place. At this moment, deep fading place can’t be effectively avoided by changing subchannel position in which information sequence lives. By simulating many times, the proposed frequency
diversity algorithm is more suitable for the situation that both the number of the tap of multipath channel and the maximal relative delay are small.

In actual wireless communication, when retransmission time is short apart, multipath condition of retransmission possibly is a little changed. In Fig. 5, the multipath channel parameters are M. 1225 indoor office test environment parameters at the first transmission, the multipath channel parameters are M. 1225 outdoor to indoor and pedestrian test environment parameters at the first retransmission, (See table 1.) As shown in Fig. 5, (1) in the EMRC pattern, BER of the proposed HARQ has 2 dB gain between 13—16 dB as compared with type I HARQ; (2 ) when the information sequence position is changed at retransmission, BER of EMRC pattern has about 2 dB gain between 12—13 dB as compared with HMRC pattern.

In Fig. 5, since the maximal relative delay are little changed at retransmission, for example, the maximal relative delay of the first transmission is 310ns, the maximal relative delay of the first retransmission is 410ns, the performance in Fig. 5 and that in Fig. 3 is very close. The result shows that the proposed algorithm is effective in condition that the maximal relative delay is little change at retransmissions.

As shown in Fig 3, 4 and 5, HMRC curve tends to be smooth after about 15dB. The proposed EMRC curve falls along with SNR, which is obviously better than HMRC. The major reason is that channel impulse response estimated by pilot frequency little changes because of less noise after about 15dB. As shown in Fig4, when multipath channel is complex, HMRC is a little better than EMRC at low SNR. The major reason is that the proposed EMRC suffers greater influence by noise and deep fading at low SNR.

C. Simulation of HARQ Scheme with Channel Encoding and Decoding

The channel encoding is added in HARQ scheme of Fig. 6. The multipath channel parameters are both M. 1225 outdoor to indoor and pedestrian test environment parameters at the first transmission and retransmission, (See table 1.) The channel encoding employs CC with generator polynomials $G(561,753)$ at rate 1/2.
Decoding employs Viterbi algorithm. As shown in Fig. 6, (1) in the EMRC pattern, BER of the proposed HARQ has about 2 dB gain between 9-12 dB as compared with type I HARQ; (2) when the information sequence position is changed at retransmission, BER of EMRC pattern has about 2-3 dB gain between 7-11 dB as compared with HMRC pattern.

The BER is between $10^{-3}$ - $10^{-5}$ in the simulation system without channel encoding and decoding. The BER reduces greatly in system simulation with channel encoding and decoding. As shown in Fig. 6, the proposed algorithm is still better than other algorithms. When SNR is low, error correcting ability of CC is still exceeded although interweaving is added due to the common influence of deep fading and noise. At this moment the BER slowly reduces along with SNR. When SNR increases, BER reduces greatly in case that CC is within the limits of error correcting ability.

From the analysis results shown above, the proposed scheme is better than other algorithms. The proposed HARQ scheme is more suitable for the situation when both the number of the tap of multipath channel and the maximal relative delay are small. This HARQ scheme effectively reduces the influence of frequency selective fading on signal transmission in the OFDM system. The EMRC pattern avoids complex channel estimation.

V. CONCLUSIONS

The proposed HARQ scheme based on frequency diversity and Energy-MRC effectively obtains major frequency diversity gain by subcarrier assignment pattern of cycle-translation. At the receiving terminal, EMRC pattern fully utilizes frequency diversity gain, avoids complex channel estimation. The EMRC algorithm is easy to realize. Under the situation that both the number of the tap of channel multipath and the maximal relative delay are small, simulation experiment shows that this scheme can effectively reduce BER compared with HARQ scheme without frequency diversity and MRC based on channel impulse response power. The proposed HARQ scheme has actual application value to a certain extent.

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