2011 International Conference on Information Management and Engineering (ICIME 2011)
IPCSIT vol. 52 (2012) © (2012) IACSIT Press, Singapore
DOI: 10.7763/IPCSIT.2012.V52.44

The Research and Improvement of HARQ in TD-LTE Systems

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Abstract—This paper proposed a new HARQ scheme based on the traditional schemes to meet the need of LTE for data transmission with high speed and low system delay. When starting data transmission，the transmitter would select appropriate redundant information which depends on the redundant version information and the times of retransmission in the last time to transmit together with the original data, by doing this, the probability of one-time successful decoding was increased. According to the channel condition indicated by the CQI, the receiver decided whether to decode the data received currently or not. When the channel condition was bad, the complexity was decreased as well as the times of decoding. The result of simulation showed, by optimizing both transmitter and receiver, that the efficiency of data transmission could be improved and the transmission system delay would be decreased.

Keywords-TD-LTE;HARQ;redundant version;CQI

1. Introduction

On the field of modern wireless communication, the speed of data transmission is very significant as well as the accuracy of data. Some applications such as video and voice require high speed and stability, some other applications such as web and e-mail have requirements on the accuracy of data [1]. To meet the acquirement, the modern communication systems usually adopt the mechanism of retransmission.

Automatic Repeat-reQuest (ARQ) ensures the reliability of data transmission, but when the channel condition is bad, it will cause some delay, which cannot be tolerated by some application such as transmission of voice. Forward Error Correction (FEC) enables the real-time of transmission, but it needs additional bits as overhead to correct error, when the channel condition is fine, the system throughout will reduce due to the added error-correction bits. Hybrid Automatic Repeat-reQuest (HARQ) combines the advantages of both FEC and ARQ, so it provides more reliable decoding contrasting with single FEC system and higher throughput contrasting with single ARQ mechanism, with such features, HARQ is ranked as an important mechanism to ensure data transmission on the time-varying channels with reliability [1]-[2].

This paper focuses on the HARQ adopted in the TD-SCDMA Long Term Evolution (TD-LTE) system. In order to meet the requirements of TD-LTE system for data transmission with high speed and low system delay, this paper puts forward an improved HARQ scheme. By optimizing the mechanism on both transmitter and receiver, this scheme can reduce the times of retransmission when the channel condition is bad, it also avoids decoding processes which are unnecessary, the efficiency of decoding will be improved and the system delay will be reduced.

The rest of this paper is organized as follows. In Section Ⅱ, the basic classification and deficiencies of conventional HARQ will be presented. An improved HARQ scheme is described in Section Ⅲ. Simulation results are presented and discussed in Section IV. Section V concludes the paper.

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2. HARQ System Overview

2.1. Basic Classification

HARQ is a combination of ARQ with FEC. The mechanism of transmission and reception can be described as Figure 1. Firstly, the transmitter codes the data by FEC before sending it. Secondly, the receiver decodes the data packet by FEC after receiving it. If decoding is successful, the receiver sends an ACKnowledgement (ACK) to transmitter, otherwise sends a Negative ACKnowledgement (NACK). Finally, the transmitter sends a new packet if the ACK is received, or retransmits the packet. According to the contents of retransmission, the 3rd Generation Partnership Project (3GPP) proposed three kinds of HARQ schemes, including the HARQ-I, HARQ-II and HARQ-III [2].

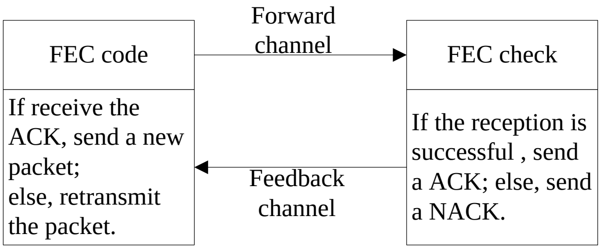

Fig. 1. Block diagram of HARQ principle.

HARQ-I is the traditional scheme, which only introduces FEC coding on the basis of ARQ, that a raw data packet adds Cyclic Redundancy Check (CRC) bits before the FEC encoding. The receiver decodes and checks the packet received. When it is wrong, the receiver will discard the wrong packet and send a NACK to transmitter which should retransmit the packet that is the same as last transmission. This HARQ scheme adopts a strategy that simply discards the wrong data, which does not take advantage of the useful information in the wrong packet.

HARQ-II scheme is also known as full Incremental Redundancy (IR). In this scheme, the checking bits are punched according to certain period after the information bits were encoded, then the transmitter in turn sends the bits according to the principle of rate-compatible. The receiver does not simply discard the wrong packet, but to combine the wrong packet with the received retransmission packet and encode it. In addition, the retransmission packet is not a simple replication of data which has been passed, but a combination of additional redundant information and the initial data. Each HARQ-II retransmission has different redundant information, the retransmitted data can not be decoded singly, on the contrary, it can be decoded using the combined data.

HARQ-III type is known as partial IR HARQ scheme. A strategy of each complementary deletion is adopted to encode the transmitted data in this scheme, each packet can be decoded singly, it also can be combined into a larger package of redundant information to decode. This scheme also adopts multiple Redundancy Version (RV), and each of RV is not the same as others. Therefore, the combined code can cover coding bits in the FEC, which makes the decoding information become more comprehensive and more conducive to decode properly.

2.2. Deficiencies of Traditional HARQ

Proven by practice, type II HARQ scheme is a more suitable type for high-speed, high-capacity mobile environment, so it is becoming a mainstream solution to TD-LTE systems. However, the transmission strategy of type II HARQ scheme is that the initial transmission includes data packet encoded by FEC and little redundant information, no matter what the condition of the channel is. The transmitter starts to retransmit the redundant information when the receiver fails to decode the original data. This mechanism is described as follows. Firstly, the transmitter selects the redundant information with lower version to send. Secondly, the version of redundant information updates as the times of retransmission increases. Finally, it ends when the receiver has the correct decoding or the times of retransmission exceeds the maximum number of retransmission. So when the channel is bad, each new packet would be transmitted many times for the receiver can get an ideal redundancy, which would increase the system propagation delay greatly, system throughput would be reduced [3]. The system block diagram is shown in Figure 2.

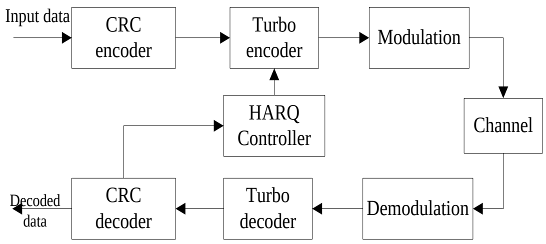

Fig. 2. HARQ system diagram.

In TD-LTE system, type II HARQ scheme generally adopts the combination of full IR model [4]. The mechanism of combination is described as follows: Firstly, the receiver combines retransmission with the packet that was not successfully decoded or checked, when receiving a retransmission. Secondly, the receiver checks the packet after successful decoding. If the decoding or the checking fails, then the receiver waits for the next retransmission.

In such cases, each retransmission may execute at least two times decoding processes which include much complex iteration, so that each retransmission will consume a large amount of time and capacity of systems. Especially in relatively poor channel quality cases, data may need to go through a few times retransmissions before it is correctly received, so the whole transmission process will waste a lot of system time and increase system power consumption.

3. The Scheme of Improved HARQ

3.1. Improvement of Transmission Mechanism

Considering the defects that the transmission of type II HARQ may increase system delay sharply when the quality of channel is poor, we propose a new HARQ scheme in which the transmission mechanism is improved accordingly. When we do the initial transmission, according to the number of previous retransmission and redundant information, the transmitter can predict the situation of this data transfer. Thereby, the transmitter can choose redundant information which is an appropriate version to send with the raw data, so the receiver can obtain an appropriate combination gain at the time of the initial reception, improving the successful rate of initial decoding, reducing the number of retransmission significantly. Instead of changing the overall architecture, we just need to modify the transmission controller [5], so this HARQ scheme can be realized easily.

The specific improve program is shown as figure 3:

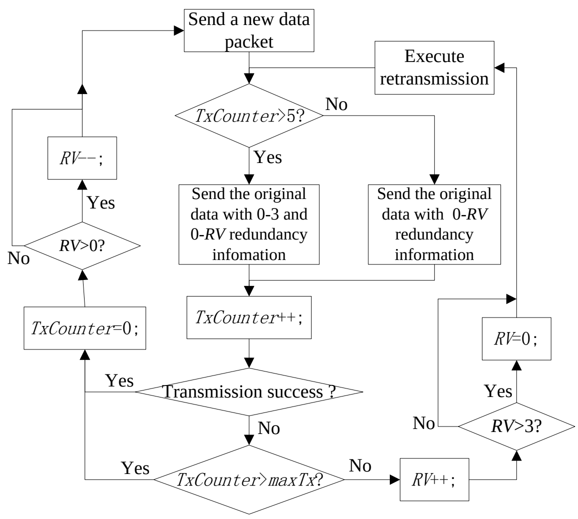

Fig. 3. Flow chart of the improved transmission controller.

1) The transmitter set a variable *RV*, which is used to record the version of redundant information of the previous successful transmission. In the system of TD-LTE, HARQ redundant information has four versions, 0,1,2,3. When the transmitter does the first retransmission, a low version of redundancy will be adopted, after that, if there are another retransmissions, the redundant version will add 1 [4].
2) Another parameter *TxCounter* is used to record the number of retransmissions of last successful transmission. Because of [6] suggest, in TD-LTE systems, that HARQ the maximum number of transmissions will up to 5, so generally the value of *TxCounter* is not more than 5.
3) When doing initial transmission, the transmitter judges whether the *TxCounter* is less than 5 (the number of redundant version add 1). If the *TxCounter* less then 5, the transmitter sends both the redundant information from version 0 to *RV* and the original information; else if the *TxCounter* more than 5, $RV > 0$, it sends both redundant information which is 2 times 0 to *RV* adding $RV + 1$ to 4, and the original information.
4) When the initial transmission fails, the transmitter will judge whether the *TxCounter* more than the *maxTx* (deployed by Radio Resource Control layer, or RRC) [6]. If the $TxCounter < maxTx$, the *RV* add 1, then the transmitter does the retransmission; else if transmission is successful, or the $TxCounter > maxTx$, it makes the $TxCounter = 0$, *RV* subtracte 1 (when $RV = 0$, *RV* unchanged), then it waits for the new data.

3.2. Improvement of Receptive Mechanisms

Although the optimization of HARQ transmission mechanism can improve the successful decoding rate and also decrease the number of retransmissions in system, in the case of the bad quality channel, the success of each data transmission may be through a number of retransmissions to complete. This process includes so much complex combining and decoding calculation that it will consume large amounts of system time and increase system power consumption. Therefore, we introduce the Channel Quality Indicator (CQI) [7] which can judge the packets received whether needs to be combined and decoded, so that the receiver can send feedback to transmitter timely and improve the efficiency of retransmission.

In TD-LTE systems, UE executes measurement periodically or aperiodically at idle state, at the same time , it reports the CQI information to eNode-B. Aperiodic measurements is executed by UE which was deployed by eNode-B, while the periodic measurements may be executed by UE spontaneously. Subframes reported for periodic CQI are satisfying [4]:

$$\left(10\times n_f + \lfloor n_s/2 \rfloor - N_{OFFSET,CQI}\right) \bmod N_P = 0 \qquad (1)$$

where N_p is the periodicity, $N_{OFFSET,CQI}$ is the offset ,which are all given in [4].

In this paper, we also introduce the Block Error Ratio(BLER) which is defined as [8]：

$$BLER \approx 0.2e[-1.5\gamma/(M-1)] \qquad (2)$$

where, γ is defined as the SNR, and is valid for$0 \le \gamma \le 30$dB, *M* is the modulation coding scheme used, and in this case it may take on real or integer values.

Specific improvement scheme shown in Figure 4：

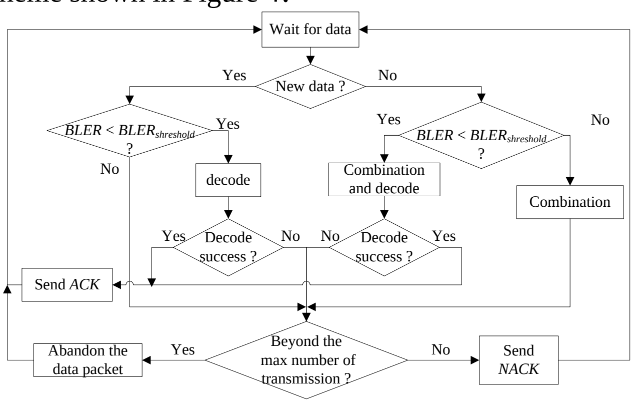

Fig. 4. Flow chart of the improved reception controller.

1) In the first step, the receiver judges the data packet received whether is initial transmission or retransmissions, it also compares the current measured value of *BLER* with a predetermined threshold $BLER_{\text{threshold}}$ value.

2) If the data packet is a initial transmission, the receiver decodes and checks (CRC) the packet when the current $BLER < BLER_{threshold}$. If decoding and checking are successful, the receiver sends an ACK to transmitter and skips to step 1), else skips to step 4).When $BLER > BLER_{threshold}$, it does not decoding and checking, but skips to step 4).
3) The data packet received is retransmission. If $BLER < BLER_{threshold}$, the receiver combines the packet with the data which is previously failed to decode, before decoding and checking it. If the decoding and checking are successful, it sends ACK to transmitter and skips to step 1); else, skips to step 4). When $BLER > BLER_{threshold}$, however, the receiver directly combines the packet with the data which previously failed to decode but does not decode and check before skipping to step 4).
4) The receiver judges whether the current number of transmissions exceeds a predetermined value of the maximum number of transmissions. If the current number of transmissions is less than the maximum number of transmissions, the receiver sends a NACK to transmitter and skips to step 1); else, the receiver discards the data packet before skipping to step 1).

4. Computer Simulations

4.1. Simulation Model

The improved HARQ scheme is given in Fig. 5.

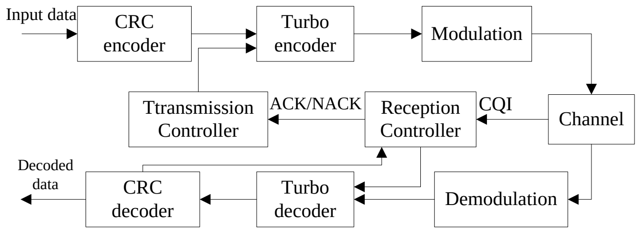

Fig. 5. System model of improved HARQ scheme.

As shown in Figure 5, this model includes transmitter, receiver, transmission controller and reception controller. In this paper, we assume that the maximum number of HARQ transmissions is 5, using a fixed modulation coding scheme. Other simulation parameters are showed in Table I.

TABLE I. SIMULATION PARAMETERS

Parameters	**Values**
Modulation	QPSK
Time duration	10ms(a subframe)
Carrier frequency	2GHz
Bandwidth	5MHz
MIMO configuration	1T2R
Path delay	[0 30 150 310 370 710 1090 1730 2510][9]
Channel model	AWGN/EPA5[9]
Cyclic prefix	Normal
Carrier spacing	15kHz
Mobile speed	65/110 Km/h

In this reception mechanism of improved HARQ scheme, whether it is necessary to decode the current packet is up to the value of *BLER*. So in the system, it is very crucial to determine the threshold value $BLER_{threshold}$ because it may significantly influence the entire system performance. This paper does not give a detailed discussion on the best value of *BLER* threshold and assumes $BLER_{threshold}$ = 25%. In different conditions, we compare the performance of the improved HARQ with the traditional type II HARQ in terms of system delay and throughput rate when SNR is varied。

4.2. Simulation Results

The results of simulation are showed by Figure 6 and Figure 7. The throughout rate η is defined as the ratio of the number of information bits in the frames to the number of all the bits transmitted by the transmitter when the receiver gets the correct data frames [10]:

$$\eta = \frac{N_{rec}}{N_{trans}} \tag{3}$$

where N_{rec} is the number of bits correctly received by receiver, N_{trans} is the number of bits actually sent by transmitter.

Figure 6 shows that the two HARQ schemes have little difference in the throughput rate. When the value of SNR is more than 3 dB, the improved HARQ scheme has a little advantage over type Ⅱ HARQ scheme in throughput rate. System delay is generally determined by the number of transmission. As observed from Figure 7, in the low SNR (-2 dB to 4 dB) channel conditions, the average number of transmission in improved HARQ is 2 times less than which in type Ⅱ HARQ. Considering the strategy used to improve the reception, some of the retransmission may be due to misjudgment of BLER. Additionally, the time consuming in the improved HARQ feedback process which does not include decoding and checking process must have some degree of reduction compared to which in type Ⅱ HARQ. So compared to the type Ⅱ HARQ scheme, especially in low SNR channel, the performance of system delay in this new HARQ scheme has been significantly improved.

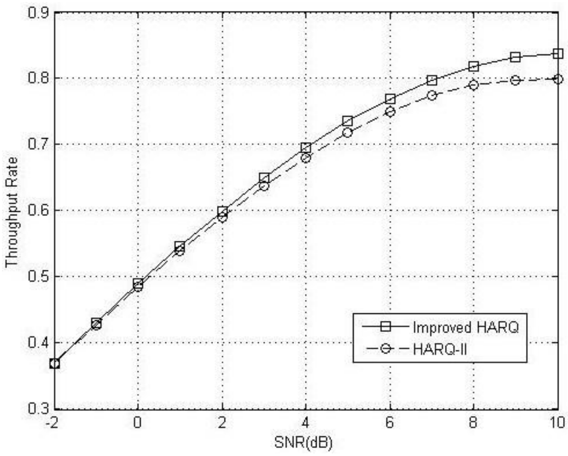

Fig. 6. Throughput rate comparison of the improved HARQ with type II HARQ, under AWGN channel.

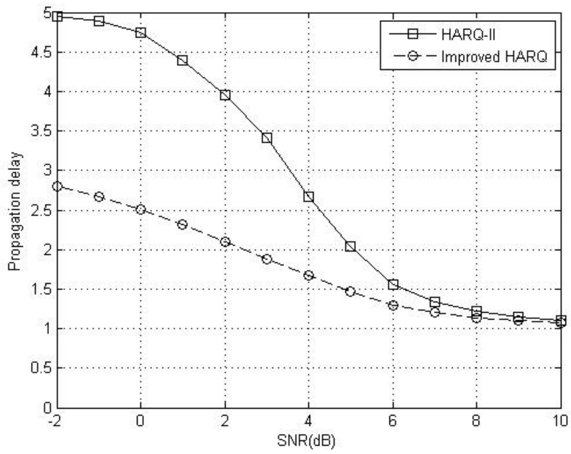

Fig. 7. Propagation delay comparison of the improved HARQ with type II HARQ, under AWGN channel.

5. Conclusion

This paper mainly focuses on the research of HARQ scheme in the TD-LTE system. The HARQ sending and receiving mechanism is improved for large propagation delay and poor performance of HARQ Ⅱ at adverse channel circumstances. Simulation results have shown that the throughput rate of the new scheme has a slight improvement compared to the type Ⅱ HARQ scheme, and the system delay has a significant decrease under low SNR. The improved HARQ scheme doesn’t change the main process, only changes the sending and receiving controllers. Thus, this HARQ scheme did not increase the complexity of the system, it is easy to implement.

6. Acknowledgment

This work is supported by Major Project of National Science and Technology in Development of TD-LTE Wireless Integrated Test Instrument, and under Grant no.2009ZX03002-009.

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