Hybrid ARQ Schemes: Problems and Perspectives

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Abstract - **The diversity of Hybrid Automatic Repeat Request (HARQ) schemes is determined by their intensive development. In the paper is made attempt to classify HARQ systems. The problems are introduced on base of their description in a structural and an algorithmic direction.**

Keywords - **ARQ, HARQ I, HARQ II, HARQ III, RB-HARQ**.

I. Introduction

The development of modern communication systems is based on active development of Hybrid Automatic Repeat Request (HARQ) systems. There are two main techniques for error control in data communication systems: Forward-error correction (FEC) and Automatic repeat request (ARQ) [1, 7].

Improving the characteristics of communication channel with FEC systems is achieved by adding additional information to data transmitted. Typically block codes, convolutional codes or turbo codes are used in the FEC system**.**

Automatic repeat request (ARQ) is used in nonstationary channels with high noise level. In ARQ a cyclic redundancy check (CRC) code is applied for error detection. In case of errors the ARQ system sends a request for retransmission of erroneous data [14].

Throughput in ARQ systems is calculated using the follwing expression [1]

$$T_r = E[T] = \frac{1}{1-P_r}, \quad (1)$$

where *Pr* is probability for retransmission of received packets.

Using ARQ schemes cause increasing the effectiveness of throughput of the physical channels [14].

The sum of probabilities is equal to one [16]:

$$P_e^i + P_{ARQ}^i + P_c^i = 1, \quad (2)$$

where i represent the i^{th} retransmission, P_e^i resulting in a block error P_{ARQ}^i is probability of retransmission and P_c^i is correctly decoded the packet.

The aim is to reduce losses from transmission of additional information for the purposes of protocol interaction in the channel level. This approach is applicable only in the cases of duplex channels.

The combination of both FEC and ARQ techniques are known as HARQ and it is applied in modern data communication systems. If there are insignificant errors in the HARQ system works as pure FEC system. Otherwise, it is run the functions of the ARQ system.

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II. Analysis of HARQ Shemes

Traditional HARQ schemes are designed to improve performance of data communication systems that are under the influence of interference.

According to the operation mode, there are three basic types of HARQ systems:

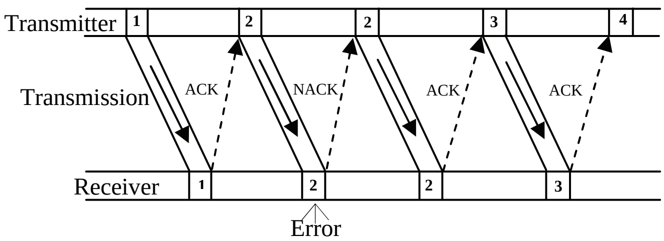

Fig.1"Stop and wait" ARQ scheme.

"Stop and wait" scheme is shown on Fig.1**.** In this system operating mode for the transmission of a block or codeword is required (ACK or NACK) acknowledgement of the previous word. Next codeword is not sent until the previous is not received correctly. Buffering of one packet is required.

The Basic "Stop and wait" scheme disadvantage is the reduced throughput.

"Go-back – N" scheme. The system requires buffering of more than one packet. In the case of NACK acknowledgement all subsequent packets are ignored. The process continues until correcting the missing packet.

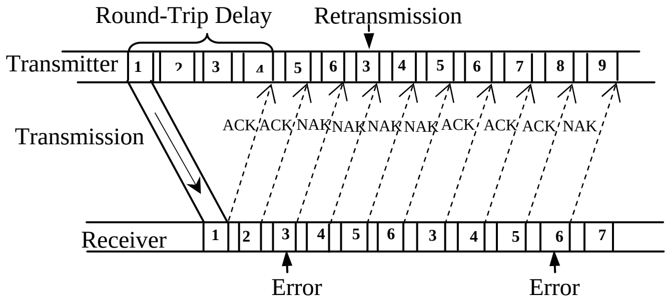

Fig. 2"Go-back – N" ARQ scheme.

"Selective repeat" ARQ scheme. The process of work in this system is that only the missing packets are transmitted.

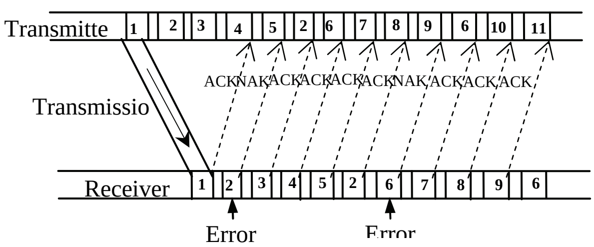

Fig. 3 "Selective repeat" ARQ scheme.

HARQ systems are used to increase the efficiency and the throughput of digital systems. These systems provide higher reliability than a FEC system and have higher throughput compared to an ARQ system.

There are three types of HARQ systems:

A. Type-I HARQ

Type-I HARQ scheme is used for simultaneous error detection and error correction [16].

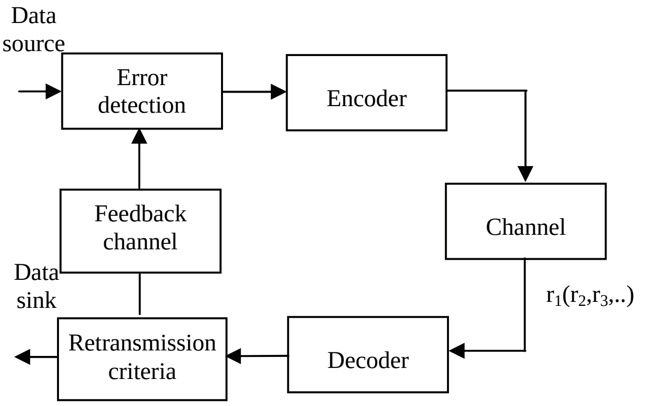

Fig. 4 General HARQ scheme

In this scheme two codes are used: one code for detection and other for error correction. Upon receiving of the packet containing errors the receiver first tries to correct it. If the correction failed, the packet is rejected and is retransmitted. In this system the code rate is fixed. This disadvantage can be avoided by optimizing the channel conditions. Type I HARQ is suitable for systems in which the constant noise and interference in the channel are present. In mobile channels, where the bit error rate changes, this scheme has following disadvantages:

- If the channel is very noisy it is possible the correcting capability of code to be insufficient;
- frequency of retransmission is increased and the throughput of the HARQ system is reduced;
- Type I HARQ provides a higher throughput of the ARQ scheme;
- limitation of throughput because of adaptive state changes in the channel.

B. Type II HARQ

In Type II HARQ the buffer memory is required.

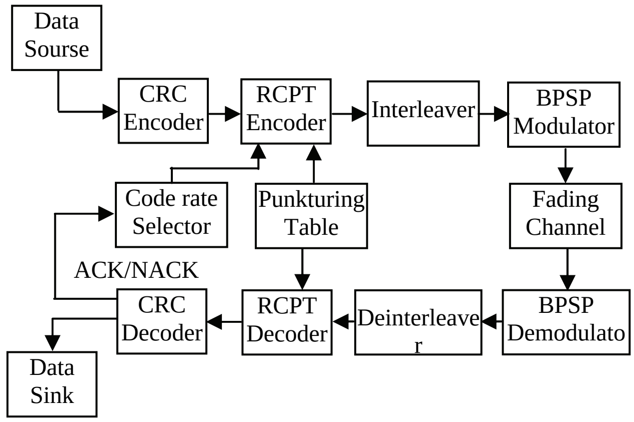

Fig. 5 Type II HARQ scheme

There are two basic systems of Type II HARQ.

- Chase combining;
- Incremental redundancy;

The general idea in Chase combining is following [2]:

- sending a number of copies for each packet of encoded data;
- enables the decoder to combine many parts of copies;
- decoding by measuring the signal-to-noise ratio of a prior decoding.

The essence of the Type II HARQ with incremental redundancy consists in the following:

- the received word is stored in a buffer in the case of errors;
- NACK is sent to the transmitter;
- the transmitter transmittes an additional number of encoded bits to check the original message and an attempt is made to correct the errors.

The main disadvantages of this scheme are:

- additional number of code symbols are sent with the packet which increase the size of transmitted information. A retransmission format depends on the applied strategy and the code for recovery of errors;
- a buffer with a large size is required which increases the cost of the system;
- greater complexity in decoding compared to type I HARQ.

The advantages are:

- better adaptation to the channel characteristics;
- outperform the Chase algorithm at high retransmission rates;
- throughput improves compared to Type I HARQ.

C. Type III HARQ

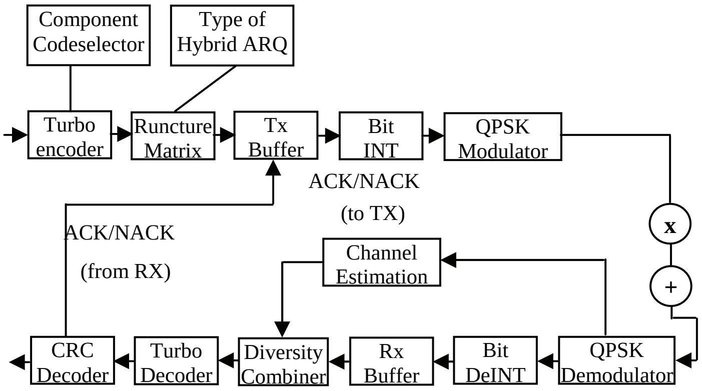

Fig. 6 Type III HARQ scheme

Type III HARQ is based on self-decoding and the source of information is needed for information extracting. The system has adaptable structure and determines an adaptive amount of additional information. At satisfactory channel conditions FEC code is used. The scheme also can be combined with incorrect data stored. According to the incremental redundancy used the schemes could be divided into two groups:

- with one version of the incremental redundancy (soft combining of the incremental redundancy);
- with several versions of the incremental redundancy (packets with detected errors are stored. The decoder combines the copies according to the ratio of signal to noise).

The main disadvantages of this scheme are:

- amount of redundancy information is increased in noisy channels;
- complex algorithms for coding and decoding are required in the above cases;

Type III HARQ has lower throughput than Type II HARQ in good channel conditions.

The advantages are:

- the throughput is improved compared to type I HARQ;
- the efficiency is improved compared to Type II HARQ[11];
- Type III HARQ has adaptive structure, i.e. it reduces the amount of redundancies to a minimum.

D. Reliability-Based HARQ

System model of Reliability-Based HARQ is shown in (fig. 7) [4]

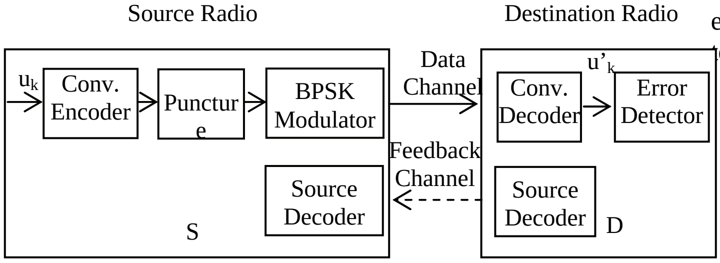

Fig. 7 System model for HARQ with convolutional codes

HARQ protocol is used in the model. This protocol which incorporates reliability information of data is called Reliability-Based HARQ. Bits are selectively retransmitted to the receiver in Reliable-Based HARQ. This is based on the estimated reliability of bits. Typically soft–input/soft-output decoding algorithms are used in the Reliable-Based HARQ. One of the possible algorithms is the maximum a posteriori probability (MAP) algorithm and its approximations [4]. In the log- MAP for every information bit u_k logarithm of the posteriori input probability is calculated by [15]

$$L(u_k) = \log\left(\frac{P(u_k = +1|y)}{P(u_k = -1|y)}\right), \tag{3}$$

where y is produced the codeword with noise.

The probability of bit error for an information bit can be estimated as the minimum of a posteriori probabilities, which is given by

$$P_b = \frac{1}{1+e^{|L(u_k|y)|}} \tag{4}$$

The performance of different RB-HARQ schemes can then be compared with the channel capacity. Presented a technique to approximate the word error probability given log-likelihood ratios provided for the information bits. No error detecting code is needed when using the word error probability as a reliability criterion for retransmissions. The estimation can be improved by applying subblock by subblock decoding. The word error probability can be used as a reliability measure for ARQ protocols to decide whether a frame or codeword can be considered reliable enough to be accepted. The exact bit error probability for u_k can be calculated using the magnitude of the corresponding log-likelihood ratio

$$P_{b,k} = \frac{1}{1+e^{|\tilde{u}_k|}}, \tag{5}$$

The average bit error probability P_b of the whole word can be obtained as

$$P_b = \frac{1}{K}\sum_{k=1}^{K} P_{b,k}, \tag{6}$$

This technique has the ability to improve performance and minimize the amount of retransmited bits. In recent years, more widely application the soft decoding founds, because exists a possibility to use interactive decoding. There are three techniques for reliability estimation [3,16]:

- log-likelihood ratios;
- determination the likelihood of the error bits;
- estimation of the error by using the reliability information.

The main disadvantages of this scheme are:

- according to [11] amount of additional information has increased significantly. To achieve a high reliability more complex algorithms are required;
- this type of system requires more memory which is required to maintain the combination of transmitted and retransmitted packets;
- the bad channel conditions and convolutional codes are extended time for analysis [14].

The advantages of this scheme are:

- the volume of calculations or decoding time is reduced [15];
- RB-HARQ is used interactive feedback to achieve higher reliability and performance.
- using convolutional codes in this systems are decreased the size of the retransmission requests.

III. CONCLUSION

The development of HARQ systems is passed different stages: first- HARQ with different modes of transmission - "Stop and Wait", "Go-back-N" and “Selective Repeat"; second - HARQ Type I, Type II, Type III and third- current RB-HARQ systems. This is due to the following:

- the intensive development of theoretical elaborations of efficient algorithms for encoding and decoding.
- the development of the technological base for the transmission, processing and storing of information.

Generally, the development of HARQ systems is expected in the following areas:

- new achievements in the field of coding and decoding of information,
- the elaboration and implementation of fast and efficient decoding algorithms,
- increasing of the reliability of transmission and accepting of information in the above two directions,
- evaluation the performance of RB-HARQ for fading channels and compare it with the performance of conventional HARQ techniques.
- examination the effect of node density on the interference power and overall system performance.

Finally, to achieve significant results in the communication the joint development of four main HARQ systems is required.

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