ALGORITHM FOR COORDINATING THE PROCESSES OF THE PHYSICAL AND DATA LINK LAYERS OF THE NETWORK

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Abstract. In this article, an algorithm for coordinating the processes of the physical and data link layers of the data communication network has been developed. The processes of performance of the retransmission protocols (ARQ and HARQ) used in the physical and data link layers of network are coordinated. A mathematical model for determining packet delay is proposed by coordinating retransmission protocols at the physical and data link layers in the data communication network.

Keywords: *coordination, ARQ, HARQ, FEC packet delay, retransmission, radio resource.*

Here, RLC is a radio channel control layer, and one of the main protocols of this layer is the Automatic Repeat Request (ARQ) protocol. Media Access Control (MAC) is a sublayer used at the data link layer for media access control. One of the main protocols used in this step is the Hybrid Automatic Repeat Request (HARQ) protocol.

HARQ is a combination of high-speed forward error correction (FEC) and error control with ARQ (requesting). In standard ARQ, redundant bits are added to the transmitted data using an error detection (ED) code, such as a cyclic redundancy code (CRC). Recipients who receive a corrupted message request a new message from the sender. In Hybrid ARQ, the original data is encoded using FEC, and check bits are sent immediately with the message or sent on request only when the receiver detects an error message. The FEC code is chosen to correct the expected set of all possible errors, while the ARQ method is used as a feedback to correct errors that cannot be corrected using only the check bits sent in the original transmission. As a result, hybrid ARQ performs better than traditional ARQ under poor signal conditions.

The simplest version of HARQ is HARQ type 1, which adds ED and FEC information to each message before transmission. When a block of encoded data is received, the receiver first decodes the error correction code. If the channel quality is good enough, all transmission errors should be corrected and the receiver can receive the correct data block. If the channel quality is poor and all transmission errors cannot be corrected, the receiver detects this condition using an error detection code, then the received coded data block is rejected (lost) and retransmitted by the receiver, just like ARQ is asked [1].

In a more sophisticated form of HARQ, type II, the message generator alternates between message bits as well as error-detecting check bits and only FEC check bits. When the first transmission is received without error, the FEC check bits are never sent. Also, if there is no error, two consecutive transmissions can be combined to correct the error [2].

To understand the difference between type 1 and type 2 hybrid ARQ, it is necessary to consider the size of the data added by ED and FEC the error detection process usually adds only a few bytes to the message, which is only incremental. On the other hand, FEC can double or triple the message length with check bits. In terms of throughput, standard ARQ typically consumes a few percent of the channel capacity for reliable error protection, while FEC typically consumes half or more of the entire channel capacity for channel enhancement.

In standard ARQ, for an error to be detected, the transmission must be received without error on any transmission. In Type 2 hybrid ARQ, the first transmission includes only data and error detection (no different than standard ARQ). If the data received without error, it is considered completed. If the data is received in error, the second transmission includes FEC check bits and error detection. If received without error, it is considered completed. If an error is received, an attempt can be made to correct the error by combining the data from both transmissions.

Only type 1 hybrid ARQ wastes channel capacity under strong signal conditions. Hybrid ARQ type 2 does not, because the FEC bits are transmitted only when necessary in subsequent retransmissions. In strong signal conditions, Type 2 hybrid ARQ performs as well as standard ARQ. In poor signal conditions, Type 2 hybrid ARQ performs as well as standard FEC with good sensitivity.

At the data link layer, frame retransmission processes are performed in the two sublayers listed above. The first sublayer describes the operation of the HARQ protocol, and the second sublayer describes the operation of the ARQ protocol. The first sublayer is placed inside the second sublayer. In the MAC and RLC sublayers, the functions of correct reception of packets, failure to detect errors and retransmission, as well as generating packet service time based on HARQ and ARQ protocols are defined. Using the generating functions, the average value, dispersion and coefficient of variation of the packet service time are determined. To calculate the average delay time of packets at the data link layer, the type of queueing system is selected taking into account the coefficient of variation of the packet service time. The analysis of the delay time of packets at the data link layer of data transmission networks is carried out for different values of the arrival rate of packets and the probability of P_b bit error at the physical layer of the network. For the stable operation of the data link layer of the network, the threshold values of the packet arrival rate are determined for the probability of bit error P_b given in the first chapter at the physical layer of the network.

Packet transmission in the MAC sublayer is based on the HARQ protocol, which has a combination of packet retransmission and noise-immunity coding techniques with error detection. Upon receiving a frame containing uncorrected errors by the channel decoder, the receiver discards the received frame and requests retransmission. The number of frame retransmissions can be unacceptably high in the presence of large radio interference or high noise levels. To limit the resulting time delays, HARQ is typically configured to limit the maximum number of retransmissions, after which, if the number of retransmissions equals the threshold, the packet is considered irreparably damaged and dropped. However, an upper sublayer of the receiving protocol stack, RLC, may detect a problem, and the lost packet is re-requested through the underlying ARQ protocol scheme.

The specific features of the work are as follows:

• The average time of serving an ARQ level package containing the HARQ level is determined based on the time-probability graph and generating functions;

• to calculate the average delay time of packets, the sample model type of queueing systems is selected taking into account the coefficient of variation of the packet service time;

• to calculate the time-probability characteristics of packet service, the bit error probability achieved after the signal-code construction is taken into account.

To solve the given task, first of all, a generalized model of the operation of the data link layer and a methodology for solving the specified task are developed. After that, the models for determining the average time of packet service at the HARQ and ARQ levels and the model for determining the average delay time of packets in the system are developed.

In the system, the average delay time of the packets is considered in relation to the transmitted frame at the data link layer. The average frame time of data link layer is estimated based on the HARQ and ARQ re-query protocols.

I. Materials and Methods

Assume that the incoming ARQ is a Poisson stream with packet flow rate λ (packet/TTI) and no packet queuing. The M/G/1-type Queueing System (QS) model can then be used to estimate packet latency. The average waiting time of a queued packet is determined by the Pollaczek-Hinchin formula:

$$W_2 = \frac{\lambda \bar{T}_{s2}^{\,2}(1+v_2^{\,2})}{2(1-\rho)} \qquad (1)$$

here, $\rho = \lambda/\mu_{s2} < 1$ - system utilization;

$\mu_{s2} = n_{HARQ}/\bar{T}_{s2}$ is the service speed of ARQ packets and n_{HARQ} is the number of parallel HARQ processes.

Most data link layer protocols support reliable data transmission by retransmitting failed transmissions. Unsuccessful transmissions are provided with acknowledgment (ACK) and non-acknowledgment (NACK) messages based on ARQ protocols. ARQ mechanisms apply to both wired and wireless connections, but are particularly important for wireless media because of the large nature and magnitude of errors in wireless environments.

The concept of ACK/NACK to indicate that a data frame has been successfully received is used by data link layer protocols. Such protocols do not assign sequence numbers to the feedback, but instead establish a feedback for individual transmissions using precise timing relationships between the transmitter and receiver. This is often called synchronous communication. The advantage of this approach is that short signals can be sent more often, but the transmission resources can be more reserved for feedback. However, if each ACK or NACK is a single bit, the achievable coding efficiency is limited or impossible. Therefore, there is a risk of the receiver misinterpreting such a single bit. Interference and noise in the communication channel further increase the probability of errors, and achieving a very low error rate can consume a lot of resources to compensate for the worst frames. Therefore, if very low error rates are required, the transmission of such a signal is also expensive, as this can only be achieved by increasing the transmission power or repeating the information. However, not every piece of information can be updated or retransmitted because it must be synchronized in time with the corresponding data transmission.

Another class of protocols uses either control messages (status messages). Such mechanisms are often used for window-based ARQ protocols. Feedback data frames may include sequence numbers and a checksum so that the integrity of the data frames can be maintained. Incorrectly received frames are not used and are discarded. Retransmission is used to ensure that frames are received correctly. It should be noted that such feedback blocks do not require any time alignment with the corresponding data frames due to sequential numbering of retransmitted data frames and reference to them in feedback blocks. This type of feedback mechanism has the advantage of being very reliable; however, they are generally much slower compared to synchronous ACK/NACK feedback mechanisms.

Therefore, there is a need for integrated retransmission protocols that provide the performance of conventional ACK/NACK protocols and ensure the integrity of specific data frames. The advantage of this is that such integrated relay protocols can be implemented in the same protocol class and are based on the same protocol data units, protocol state, and logic. Therefore, this section proposes an algorithm for a coordinated model of HARQ and ARQ protocols.

HARQ uses a transmission method called "stop and wait", according to which the transmitter (transmitter) transmits a data packet and then waits for confirmation (ACK or NACK) of the transmitted packet from the receiver. On the one hand, this protocol simplifies the design of the operating system, but on the other hand, it reduces its throughput due to the waiting time between the moment the transmitter sends the packet and receives the confirmation. To avoid this negative effect, it is proposed to use several HARQ processes running in parallel. In parallel HARQ operation, one process transmits data while the others wait for confirmation.

There are 8 HARQ processes fixed in the uplink channel, each of which is assigned a specific subframe. Thus, each HARQ process transmits a data packet (initial or repeated) once every 8 ms. The number of parallel HARQ processes on the downlink channel is variable, but cannot exceed 8. In this case, unlike uplink, asynchronous mode is used.

The use of several parallel HARQ processes causes a violation of the order of reception of data packets by the receiver. On the receiver side, original sequence recovery is provided by the ARQ protocol (for 4G-LTE) and PDCP protocol (for 5G networks) in the RLC sublayer.

The ARQ protocol implemented in the RLC sublayer is activated if the error is not cleared to repeat the unrecovered HARQ data.

The classic ARQ mechanism, or "Automatic Re-Request", involves an automatic request to retransmit a corrupted frame when errors are detected. In this case, the damaged frame is discarded and retransmission of the same frame is requested. In this regard, the problem of trying to minimize retransmissions arises. The more efficiently the retransmission protocol is organized, the more rationally the radio resources are used.

In the figure below, a coordinated algorithm of the HARQ and ARQ protocols used for feedback at the data link layer is proposed. As can be seen from the algorithm presented in Fig. 2, this algorithm results obtained from the model and algorithm give the same value and efficiency. At first, all variables and constants used in the ARQ and HARQ protocols are declared. In this algorithm, in order to more clearly reflect the nature of the work, in addition to the main variables used in the mathematical model, the following additional variables are included: M^* - the number of allowed retransmissions according to the HARQ protocol; $N^*$is the number of allowed retransmissions according to the ARQ protocol; P_{Rv} – the probability of receiving the frame based on the HARQ protocol; P_{Rv_ARQ} - the probability of receiving a frame based on the ARQ protocol. After announcing the variables, the RLC sublayer forms a frame based on the required parameters of the ARQ protocol and transmits it to the MAC sublayer. In this sublayer, the FEC parameter is added to the frame based on the HARQ protocol and transmitted to the receiver through the physical layer. P_b is the probability of a bit error in the physical layer of the signal received from the communication channel, and this parameter was used in our algorithm to calculate the characteristics of the HARQ protocol. After the signal with bit error probability P_b is received as a frame by the MAC sublayer, the frame reception probability P_{Rv} is checked based on the HARQ protocol. The frame is received in three cases, that is, in the case of correct reception ($P_{Rv} \geq p_{crv1} z^{T_{rt1}}$), in the case of detection of an error in the frame, and in the case of the presence of an error but not detection ($P_{Rv} < p_{crv1} z^{T_{rt1}}$ – for both cases) can be accepted. If the frame is correctly received based on the HARQ protocol, it is passed to the next RLC sublayer. After that, the probability of correct reception of the frame P_{Rv_ARQ} is calculated based on the ARQ protocol in this sublayer and evaluated in the classifier (CS). If the frame is correctly received, then $\bar{T}_{s2}$ is the average time of frame service and μ_{s2} is the service rate. Otherwise, the ARQ frame is re-requested until the ARQ frame is correctly received and N^* is the number of retransmissions allowed by the ARQ protocol, due to the fact that an error is detected based on the ARQ protocol or an error is present but could not be detected. If the number of retries exceeds the allowed value, the frame is dropped.

If the MAC sublayer detects an error in a received frame based on the HARQ protocol or cannot detect an error due to the presence of an error, then the frame is retransmitted up to the number of retransmissions allowed by the HARQ protocol M^*. Otherwise, it is discarded and requeried through the ARQ step.

In this algorithm, the parameters of the HARQ and ARQ protocols are organized on the basis of the P_b bit error probability obtained from the physical layer, so that as a result, the HARQ protocol and the ARQ protocol organize processes in a mutually compatible manner, and the average frame service speed and average service time is improved.

In order to explain this algorithm in a more understandable form, in the following its program sequence is presented.

Algorithm.

1: **begin**

3: form an ARQ frame based on the flow λ;

4: Formation of HARQ protocol by adding FEC parameter to ARQ frame;

5: **If** $P_{Rv} \geq p_{crv1} z^{T_{rt1}}$ **then** $P_{Rv\_ARQ} = 1 - P_{el\_1}$

 6: **If** $CS > p_{crv2} z^{T_{rt2}}$ **then** $\bar{T}_{s2}$, μ_{s2} are calculated

 7: **else**

  8:**If** $N > N^*$ **then end**

  9: **else** $N = N + 1$ **and go to** 3;

 10: **else** due to p_{ed1}, p_{ue1}, the frame is dropped and re-requested

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11: **If** $M > M^*$ **then** the frame is discarded **go to** 3

12: **else** $M = M + 1$ **and go to 4;**

The algorithm in the given software approach consists of a total of 12 steps, in which the above-mentioned sequence of processes is implemented. Since the mathematical calculations and formulas used in the proposed algorithms are given in the mathematical model, they are explained in the form of a sequence of executed processes. When creating a real algorithm program, it is necessary to include all mathematical expressions in the program.

II. Results

The developed algorithm is an algorithm coordinating the operation of ARQ and HARQ protocols used at the data link layer, in which attention was paid to the error-free transmission of frames, thereby reducing the number of retransmissions and increasing the speed of service (Fig. 3).

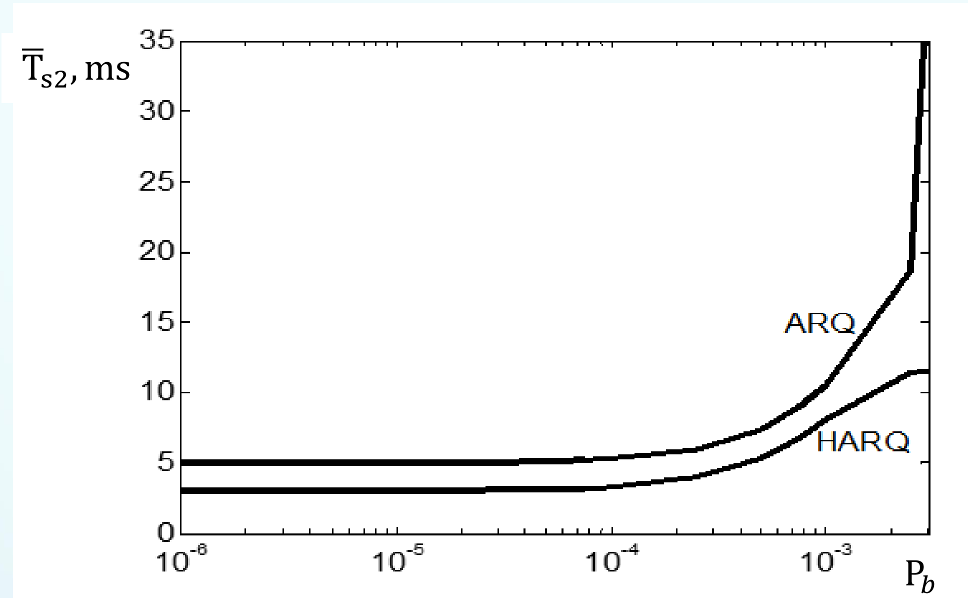

Fig. 3. A graph dependancy of the average service time of a HARQ packet versus the bit error probability.

III. Conclusion

This article focuses on the coordination of data transfer protocols used at the channel level of the network. In addition, coordination of the processes at the physical and channel levels of the network was carried out, the results were obtained and analyzed. A model of coordination of the processes of working protocols of data transmission networks at the channel level has been developed. In this case, the issue of mutual coordination of the operation of HARQ and ARQ protocols used for feedback processes at the channel level was resolved.

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