Performance Analysis of Dual-mode Selective Repeat ARQ Mechanism in Fading Channel Environments

Seong-Soo Park¹, Young-Jae Song², and Dong-Ho Cho³,³
¹Dept. of Mobile Network, ETRI, ²Dept. of Computer Eng., KyungHee Univ., ³³Dept. of Electrical Eng., KAIST.

Abstract - In this paper, we propose DSR(dual-mode selective repeat) ARQ which performs error recovery based on retransmission mechanism in fading channel environments. DSR mechanism supports two different modes such as normal transmission and recovery mode. When transmission buffers are full due to waiting packets, sender performs duplicate retransmission for the first frame of transmission buffer. From performance analysis for data transmission, DSR mechanism shows better performance than conventional SR mechanism in the fading channel environments.

I. Introduction

Error control is usually divided into two methods such as ARQ method and FEC method. ARQ method provides reliable data transmission by retransmission, and FEC method provides reliable data transmission by correcting errors of received data. In ARQ method, ACK is transmitted when successful packet transmission is performed, and NAK is transmitted when errors occur. When an NAK response is received, the packet is retransmitted. Among these ARQ methods, GBN(Go-back-N) and SR(Selective Repeat) mechanisms are usually used[1,2].

For the efficient data transmission in wireless network, hybrid ARQ mechanism using selective retransmission mechanism with multicopy mechanism is proposed[3]. This mechanism switches from SR mode to MC(multicopy) mode when n times transmission errors per data frame occur. This method shows better transmission performance than the Go-back-N mechanism or other existing hybrid mechanisms in high error rate environments. Extending this method, hybrid ARQ method in which IP packet are transmitted in SR mode, and errored packets are retransmitted in MC mode after all IP packets are transmitted is suggested. Also, transmission performance is analyzed in AWGN channel and fading channel environments[4,5].

In this paper, we suggest a new data link layer protocol for effective transmission of continuous data frames in the environments with limited sending and receiving buffers, and analyze its performance. In section II following this introduction, problems of existing data link layer protocols for previous study in wireless environments are described.

A new transmission mechanism proposed in this study and mathematical analysis for proposed protocol are described in section III. Also, simulation results and discussions are expressed in section IV. Finally, conclusions are made in section V.

II. Problems of Existing Data link Protocol for Mobile Data Service

GBN and SR protocols perform error recovery using the retransmission mechanism. When an error occurs in a sent data frame, the receiver detects an error and requires the retransmission of data frame. While GBN mechanism performs the retransmission of all frames after the errored data frame, SR can recover error just by retransmitting the errored data frame. The size of sending and receiving buffers(W) and RTD(round-trip delay) are important parameters determining the performance of these sliding window protocols. RTD is the interval between the point when a sender starts the transmission of a data frame and the point when the response for sent data frame is received. Therefore, when W≥RTD, data transmission can be performed constantly. Thus, the environments ensuring W≥RTD is considered in the performance study of most ARQ methods for data transmission. Performance study of ARQ methods for wireless data transmission requires careful consideration about the characteristics of wireless channels and the relation between buffers and the recovery mechanism. However, in existing studies, the errors of feedback information in wireless environments were not considered[3,4,5], and limited sending and receiving buffers were not considered either[6,7].

In this paper, we propose the methods to recover feedback information when there are feedback errors, and to recover errors rapidly through duplicate retransmission when buffers are full in the wireless data link transmission in the case of using...
limited size of buffers.

III. Proposed DSR ARQ protocol

1. DSR ARQ protocol

Transmission protocols for wireless data service should supply the mechanism to recover rapidly and effectively the errors of sent data frames and feedback information caused by poor channel environments in the case of using limited sending and receiving buffers. In this paper, the performance improvements of data link layer protocol by rapid recovery of error frames and the transmission of feedback information are introduced. Errors of feedback information cause the retransmission of relatively heavy data frames. Having feedback responses include the acknowledgement responses to the previous data frames up to (k-1)-th one can solve this problem. However, in the case that both ACK and NAK mean the response to the sent frames up to (k-1)-th data frames, it takes long time to recover when buffers are full due to continuous errors. That is, when buffers are full, while first errored frame is recovered by recovery mechanism through retransmission mechanism, the retransmissions of other errored frames are not performed. Therefore, in order to make the retransmission possible, NAK responses to error frames should include the acknowledgement response to only one frame. Also, when sending and receiving buffers are full, data frame transmission needs to be performed so that those buffers are usable. The dual-mode SR ARQ transmission mechanism proposed in this paper in the consideration of all these matters is shown in Figure 1.

![Figure 1. Dual-mode SR ARQ protocol](image)

In Figure 2, senders are operating in normal mode and recovery mode. In normal mode, senders operate in the window mechanism based on SR ARQ, and don't perform any response when feedback information is lost. Then, frame sequence number of ACK responses includes acknowledgement responses to previous frames. Thus, lost feedback information can be recovered. Unlike ACK responses, NAK responses mean the acknowledgement response to the only current data frame, and senders immediately retransmit the corresponding frames. When transmission buffers are full, due to continuous loss of feedback information or continuous errors of frame, transmission of new frames is suspended until ACK acknowledgement responses is received. Because the ACK acknowledgement response to the first frame of transmission buffers is not received. Therefore, the senders perform the retransmission of this frame and waits for the acknowledgement response. In the proposed DSR ARQ, senders perform the duplicate retransmission of the corresponding frames during the round-trip delay. If there are other data frames for which a NAK response is acknowledged in a window section, senders perform the retransmission of these frames as well to ensure rapid recovery.

2. Mathematical analysis of DSR ARQ mechanisms

In the GBN mechanism, when the recovery of w pieces of feedback information is performed, the number of new data frames (Y) that should be retransmitted owing to the error of feedback information and the number of duplicate data frames (Z) which are retransmitted owing to feedback information error are described in ref.[8]. Also, the analysis of GBN and SR mechanism is performed in ref.[8].

In the case that the ACWNAK response includes the meaning of the response for the (k-1)-th frame in SR mechanism, it is impossible to receive the response for the later frame errors until the current retransmission for error frame is finished completely. In the proposed DSR ARQ mechanism, ACK frame means confirmation response for the previous frames, but NAK frame means the response for the present frames. Therefore, when the transmitter receives NAK response, it performs retransmission for the present data frames even though the error recovery for previous frames is in process. That is, error recovery for feedback information is applied to only ACK response. If the feedback information or data frame gets continuous errors, the limited sending and receiving buffers get full. In this case, the existing SR mechanism performs the same recovery as the GBN mechanism for the first frame of buffers. The number of duplicate transmission data frames until the buffers get full is given by

$$
\sum_{i=1}^{G-1} P_d (1 - P_d^{i-1}) = \frac{1 - P_d}{P_d} \sum_{i=1}^{G-1} P_d (1 - P_d^{i-1})
$$

Then, the retransmission caused by the feedback information errors until the buffers get full is
expressed by
\[ Z(1 - P_d) \sum_{i=0}^{Q-1} P_d^i = (1 - P_d^Q)Z \]  \hspace{1cm} (3)

Also, the number of retransmission frames caused by transmission errors when the buffers are full is described as
\[ P_d^Q + \sum_{i=0}^{Q-1} P_d^i + (1 - P_d) \sum_{i=1}^{\infty} P_d^i \]
\[ = P_d^Q + P_d^2 + \frac{(1 - P_d)P_f}{1 - P_f} \]  \hspace{1cm} (4)

When the transmission buffers are full, performing duplicate transmission for the first data frame of the transmission buffers is based on the recovery of SR mechanism. Therefore, the same number of transmission overheads as \( K \) is added in the duplicate transmission mode for the only first retransmission of data frames. In general, only the same number of overheads as the number of retransmission is applied. Thus, the average number of transmission data frames in the proposed DSR protocol \( N_{DSR} \) is described from equation (2), (3), and (4) as follows.
\[ N_{DSR} = 1 + \frac{P_d^Q (1 - P_d^Q)}{1 - P_d} + (1 - P_d^Q)Z 
+ \frac{P_d^2 (1 + KP_d + \frac{P_d^2}{1 - P_d} + \frac{(1 - P_d)P_f}{1 - P_f})}{1 - P_f} \]
\hspace{1cm} (5)

IV. Simulation result and analysis

1. Simulation environments

In this paper, we simulate the performance of data link layer protocol, considering the transmission error rate of data frames, the error rate of feedback information, the size of transmission buffers, and the delay time before receiving ACK in the wireless link. The assumption used in this paper are as following:

- The time needed to transmit one data frame is the same as one frame transmission time regardless of the size of data frame.
- Transmission buffer size \( \geq K \).
- The size of response frame is 20 octet.

The pertinent channel models are needed to analyze reliable communications system. We have to consider burst error characteristics such as fading in mobile communication systems. Rayleigh fading is a special case of multipath fading, and receiving signal power is weaker than reflection signal power. Thus, Rayleigh fading is used to analyze performance evaluation for worst case in mobile communication system. In this case, to improve transmission performance, signal recovery technique using the diversity method is considered. Also, in this paper, we use channel property of QPSK modulation method to simulate performance evaluation of data link protocols. In this case, BER is as follows[5].
\[ p = \frac{1}{2} \left( 1 - u \frac{\sum_{k=0}^{k-1} (2k) \left( \frac{1 - u^2}{4 - 4u^2} \right)}{\sqrt{1 - u^2}} \right) \]
\hspace{1cm} (6)

Here, \( u = \frac{SNR}{(1 + SNR_f)} \) is average signal to noise level per channel. Signal to noise level per bit \((Be/No)\) is given by.
\[ \frac{E_{fb}}{N_o} = \frac{L \cdot SNR_f}{2} \]
\hspace{1cm} (7)

Here, \( L \) is the number of MCR path.

Each mobile station transmits data frames to the base station, and the base station transmits the response. Applying the error rate of channel to each transmission frame generates the error of data frames. If any error occurs, the recovery is performed by retransmission mechanism. We didn't consider the processing delay for the data frame process, and suppose that there is no terminal mobility.

2. Results analysis

The transmission performance of data frames is influenced by the channel error property, the delay time before the response frame, and the size of transmission buffers used in data communication. Figure 2 shows the transmission performance of data frames vs. \( Eb/No \) in Rayleigh fading channel.

![Figure 2. Transmission performance of data frames vs. \( Eb/No \)](image-url)
limitation of buffers and response time. DSR(dual-mode SR) means the modified SR mechanism that has two transmission modes shown in this paper. As shown in this figure, ARQ protocol using SR strategy generally has better performance than GBN ARQ protocol. However, in the case that Eb/No increases, the performance difference increases. If the transmission buffers get full because of the continuous errors of specific frame in SR strategy, the retransmission for recovery is performed based on SAW or GBN. Thus, performance degradation occurs. However, when the transmission buffers get full, in proposed DSR ARQ protocol, the continuous repetitive retransmission is performed for the first frame of transmission buffers, and this enables prompt recovery.

Figure 3 shows the comparison of transmission performance versus the size of the transmission buffers.

As shown in Figure 3, the size of transmission buffers doesn't give much influence to transmission performance in the case that the error rate of channel is low. In other words, if the error property of channel is good, the transmission buffers that can receive only a little more data frames than data frames receiving during the response waiting time are needed and the performance of data transmission is guaranteed. However, if the error rate of channel increases, big amount of transmission is needed. Therefore, we should consider the error rate of channel and the size of data frame to decide the size of the sending and receiving buffers. In order to guarantee the same performance, DSR needs small amount of buffers compared to SR. This is possible because the prompt error recovery is done during the recovery mode through the repetitive retransmission for the errored frames.

Figure 4 shows the transmission performance vs.

As shown in this figure, if the Eb/No increases, the transmission performance is increased by reduction of error frame. Also, the difference of transmission performance for frame size is decreased. In the channel environment that bit error rate is high transmission performance for data frame is better compared with large data frame.

In order to evaluate reliable transmission performance of upper layer data frame, we assume that the size of each datalink frame was 20 octet. In this case, the transmission performance of data frame for upper layer is shown Figure 5.

As shown in this figure, when upper layer data frame is smaller, better performance in infection channel environment could be obtained. That is, if radio channel has high bit error rate, to guarantee transmission performance, size of data frame must be reduced. Thus, in the implementation of data transmission protocol, we have to consider channel environments.
among the several signals. Figure 6 shows
transmission performance for the number of signal
path.

![Figure 6. Transmission performance for the number of signal path](image)

As shown in this figure, if the number of signal path is increased, transmission performance is increased. That is, diversity method is needed for effective transmission of data frame in Rayleigh fading channel environments.

V. Conclusion

As the mobile communication service becomes generalized, the needs for the mobile data service are increasing. For the efficient data service, we need to offer an efficient mechanism in order to recover the transmission errors that happen in the wireless transmission link. Generally, for the reliable data transmission, we use the retransmission mechanism based on ARQ as well as the data recovery strategy through FEC. The recovery mechanism caused by the retransmission of data frames makes the transmission delay caused by retransmission inevitable, and enough buffers for resequence are needed. At this time, FEC mechanism cannot avoid overheads that happen by inserting error correcting code into the transmission data.

This paper proposes DSR ARQ mechanism that performs the error recovery based on retransmission for data service. DSR strategy supports two kinds of transmission modes that consist of normal transmission mode and recovery mode. In the normal transmission mode, ACK response includes the confirmation response to the previous frames, and NAK response includes only the meaning of response for the present frames. Also, we improve the performance by performing the continuous repetitive retransmission for the errored frames in order to prevent the performance decrease occurring when the sending and receiving buffers are full.

According to analysis result of the transmission performance for data frames in rayleigh fading channel, DSR mechanism shows superior transmission performance to SR mechanism. Also, DSR mechanism needs smaller amount of buffers than SR mechanism in view of guaranteeing the same transmission performance.

References