Adaptively Delay Retransmission Scheme for SR ARQ in Wireless Data Networks

Yi Wu, Zhisheng Niu, Junli Zheng *, Tamio Saito **
* State Key Lab on Microwave and Digital Communication,
Tsinghua University, Beijing, China.
** Fujitsu Research and Development Center, China
E-mail: wuy@atm.mdc.tsinghua.edu.cn, niuzhs@tsinghua.edu.cn

Abstract

A novel adaptively delayed retransmission scheme for SR ARQ in fading channel is proposed for wireless data communications, by which the link layer protocol and the physical channel are considered together for a successful deployment of effective error control strategies. Specifically, at link layer, when an information frame is corrupted, it is not retransmitted immediately but delayed for a dynamic interval to avoid deep fading period of wireless channel. To determine the dynamic delay value, an adaptive fading channel prediction algorithm is also proposed. Numerical results show that it achieves higher performance compared with the previous retransmission schemes in Rayleigh fading channels.

Keywords: SR ARQ, wireless data networks, Rayleigh fading channel

1. Introduction

As digital radio techniques are applied to the modern mobile and portable communication systems, data transmission becomes more practical. Since data service is very sensitive to the errors encountered in a radio channel, the traditional mobile communication systems are facing many challenges in such wireless data networks. In voice predominated mobile communications, the physical layer of the radio transmission technology provides the frame error rate (FER) of the order of 10^-2, which is usually suitable for voice communications. However, this error rate is too high for data transmission which may require the FER less than 10^-4 [2]. To reduce the error rate from physical layer, reliable link layer protocols such as automatic repeat request (ARQ) schemes are widely used.

Among ARQ schemes, Selective Repeat (SR) scheme is most efficient and has been widely used in practical mobile systems (e.g., IS-99 [1]). Since the maximum number of retransmissions of ARQ is generally limited (say 3 in IS-99), it leads to a semi-reliable transmission and does not completely survive from wireless loss. To solve this problem, some related research has been presented in the literature. For example, references [2, 3] discussed a multiple copies retransmission scheme (MCR), which proposed to send multiple copies of the lost frame at each retransmission. Furthermore, considering the burst nature of wireless channel, we have suggested a delayed multiple copies retransmission scheme (DMCR) in [4], by which a fixed delay is inserted between the successive copies of the lost frame. However, all these existing schemes are based on retransmission of multiple copies which improves reliability at the cost of throughput. Accordingly, they result in the overburden of network traffic during the data transmission.

In this paper we propose a novel adaptively delay retransmission (ADR) scheme with channel prediction. In the ADR scheme, retransmission is delayed for a dynamic interval in order to avoid the deep fade period of wireless channel. The delay of each retransmission is determined with the cooperation of a suggested adaptive channel prediction scheme.

The purpose of our work is to complement the well-documented work in this radio transmission technology (RTT) area by providing some new retransmission schemes of link layer with respect to the fading channel and investigate the performance improvement of data communication using some “basic” protocols. This means that the channel coding used is assumed to be for error-detection only and the channel throughput is normalized with reduction due to overhead coding. Also no interleaving scheme is included. We consider only practical ARQ protocols that can be implemented in real-time applications.

The rest of the paper is organized as follows. In Sec. 2, a brief introduction to the channel prediction process is presented. In Sec. 3, the proposed adaptively delay retransmission (ADR) scheme is described in detail. The numerical results and performance analysis are discussed in Sec. 4. Finally, conclusions are summarized in Sec. 5.

2. Prediction of Channel State

In our investigation, we consider the Rayleigh fading channel with a fading rate specified by the maximum Doppler frequency. Note that shadow fading is not considered because it is generally slow enough and can be mitigated by some other means.
in practical applications. It has been widely investigated that the Rayleigh fading can be modeled as a deterministic sinusoidal process with time-varying parameters and predicted with satisfied accuracy [5], [6]. With such view, we apply the adaptive channel prediction algorithm as follows.

Since the channel fading is much slower compared to the symbol rate, the sampling rate of fading channel can be kept very low. So the transmitter only sends the training symbols at a low sampling rate, which brings quite little overhead of network. By receiving the training symbols, the receiver gets the channel samples \( f_k \), which is the fading gain \( f(t) \) sampled at the sampling rate. To predict the future fading signals, we employ spectral estimation followed by linear prediction and interpolation. The estimates of the future samples can be obtained based on \( p \) previous samples \( f_{n-1}, f_{n-2}, \ldots, f_{n-p} \):

\[
\hat{f}_n = \sum_{i=1}^{p} a_i f_{n-i} 
\]

where \( a_i \) \((i=1 \ldots p)\) are the weight coefficients of the linear prediction.

Denote by \( \hat{f}^{(k)} = [f_{k-1}, f_{k-2}, \ldots, f_{k-p}]^T \) the past channel measurements vector. In the sense of least mean square error, the optimal weight coefficients vector \( \hat{a}^* \) is obtained by Wiener solution [7]:

\[
\hat{a}^* = [a_1^*, a_2^*, \ldots, a_p^*]^T = R^{-1}d
\]

where \( R = \mathbb{E}[\hat{f}^{(k)}(k)\hat{f}^{(k)T}] \) is the correlation matrix, and \( \tilde{d} = \mathbb{E}[f_k(\hat{f}^{(k)T})] \) . It is known that the optimal weight coefficient vector can be obtained iteratively by the weight-update equation, i.e.

\[
\tilde{a}_{k+1} = \tilde{a}_k + \mu \tilde{f}^{(k)} e_k
\]

where \( e_k \) is the prediction error for channel sample \( f_k \), and \( \mu \) is the step size which decides the converging rate. As shown in (3), by adaptively updating the weight coefficients vector \( \tilde{a} \), the future channel fading samples can be predicted by (1). The rate of adaptive updating is controlled by prediction error so that the prediction algorithm can obtain sufficient accuracy.

Setting appropriate threshold of the fading amplitude, the channel is divided into two states: “GOOD” and “BAD”. When the prediction module predicts that the channel fading amplitude exceeds the threshold in the future, it assumes that the channel will be in GOOD state. Otherwise the channel is predicted to be in BAD state. It will be seen in next section that our adaptive delay retransmission (ADR) scheme just depends on the channel state information obtained by the prediction module.

3. Adaptively Delay Retransmission Scheme

Actually the new scheme we investigate is the improved version of the NAK-based SR scheme defined in IS707 [3]. When an information frame is corrupted or lost at the receiver, NAK frames will be sent back to the transmitter. Since the NAK frames are generally much short and over-protected by strong coding, their loss probability keeps quite low compared to the information frames. Therefore, the backward channel is assumed to be error free for simplicity.

Suppose that the transmitter sends an information frame (I-frame) with sequence number \( i \), denoted by \( I(i) \). If the receiver receives any \( I(j) \) \((j>i)\) before receiving \( I(i) \) or finds unrecoverable errors in \( I(i) \) by channel decoding, it assumes that \( I(i) \) has been corrupted. Then according to the conventional SR ARQ scheme, the receiver sends NAK message back to the transmitter asking for the retransmission of the lost frame \( I(i) \).

As we know, in wireless channel the frame errors usually occur in burst caused by the correlated fading nature. So when the receiver detects an erroneous frame and requires the retransmission with the NAK message sent back to the transmitter, it is very possible that the retransmitted frame will fall in the same fading period and be corrupted again. To improve the reliability of retransmissions, we propose an adaptively delayed retransmission scheme by holding the retransmission for a delay so that the deep fading period of wireless channel can be avoided. Apparently, the delay needs to be adaptive depending on the variation of physical channel. That means we need to get the channel state information after the next round trip time (RTT), i.e. in the next receiving period, by the channel prediction module described in Sec. 2.

Note that since the uplink channel and the downlink channel are generally unsymmetrical, the channel prediction should be executed at the receiver. Thus in practice, we suggest that the adaptive delay is implemented at the receiver while sending NAK messages.
A typical example of the adaptive delay implementation is illustrated in Fig. 1. The channel is sampled at fixed intervals and the fading prediction is performed with a range of round trip time (RTT). When the receiver detects a corrupted information frame $I(m)$, if it is predicted that the retransmitted frame $Ir(m)$ will fall in the GOOD channel state in the next receiving period, then the NAK$(m)$ message is sent back. Otherwise, the corresponding NAK message is delayed until the prediction shows that the channel turns to the GOOD state after RTT.

The receiver triggers a timer for the NAK it sends back. When the timer expires before any correct copy of the lost information frame is received, the receiver assumes it is lost again and will turn to the next retransmission. Note that after retransmissions of maximum times, the residual probability of frame aborting has been kept very low so that the upper layer protocols could recover the residual transmission errors, if necessary.

4. Performance and Discussions

In experiment we investigate high speed data network with long frame transmission, assuming data rate is 1Mbps and frame length is 1000 bits. The roundtrip time of the wireless link is set as 6ms (transmission duration of 6 frames). The maximum number of retransmissions is 3. At the receiving side the channel is sampled at the rate of 1kHz. This overhead affects the throughput only by 0.1%.

We consider the data link transmission over a Rayleigh fading channel with a fading rate specified by the maximum Doppler frequency $f_{D\text{max}}$. As we observe the channel from the viewpoint of link layer, the frame error process is provided by the physical layer. Assume that the Rayleigh fading envelope is generated by Jake’s model [8] and constant over a frame. Also assume that BPSK modulation is used. Denote the frame length by $L$ bits, the instantaneous frame error rate (FER) is

$$P_f = 1 - (1 - P_b)^L.$$  \hspace{1cm} (4)

where $P_b$ is the bit error rate given by:

$$P_b = \frac{1}{2} \text{erfc} \left( \frac{\sqrt{E_b} - N_0}{\sqrt{E_b}} \right),$$  \hspace{1cm} (5)

where $[|f(t)|]$ is the amplitude of the complex fading gain $|f(t)|$, $E_b/N_0$ is the bit energy-to-noise density averaged over the fading process, and $\text{erfc}$ is the complementary error function. With the requirement of frame error rate, the appropriate threshold for $[|f(t)|]$ can be determined from (4) and (5) in order to divide the channel states.

In the evaluation model, as the round trip time is 6ms and the sample interval is 1ms, the range of channel prediction module is determined to be 6 samples. The performance of the fading prediction implemented in the ADR scheme is shown in Fig. 2, where the normalized mean square errors of the prediction are adopted as the measure.

As the performance evaluation, we consider the frame aborting probability defined as the residual frame error probability after retransmissions of maximum times, and the channel throughput efficiency defined as the mean number of frames that are received correctly during a frame time under the full load condition. The full load condition is the situation that a sender always has frames to transmit. For comparison, we study the performance of the proposed ADR scheme and the previous retransmission schemes such as original SR, MCR and DMCR schemes together. We apply the exponential rule for multiple copies in MCR and DMCR for its superiority been studied in [2] and [4].

Fig. 3 shows the frame aborting probability of the four schemes in Rayleigh fading channel with a maximum Doppler frequency of 10Hz. The channel throughput efficiency of the various retransmission schemes versus average $E_b/N_0$ in the fading channel is shown in Fig. 4. Apparently, the proposed ADR scheme keeps the lowest frame aborting probability in almost all $E_b/N_0$ channel conditions, which is due to the capability of avoiding the deep fade by adaptively delay retransmissions with channel prediction. While in the other schemes, the probability of retransmitted copies falling into the bad fading period is quite large especially in lower $E_b/N_0$ channel. Since the proposed ADR scheme obtains much lower frame aborting probability with only single copy for every retransmission, the throughput efficiency is greatly improved in all channel conditions as the result. If the required channel quality is defined as the minimum $E_b/N_0$ at which the throughput efficiency is more than 0.8, the gain with the ADR scheme is about 6dB relative to the other three kinds of retransmission schemes.

Table I shows the disadvantage of the ADR scheme. Actually, the proposed ADR scheme gets the performance improvement at the cost of time delay. However, according to the adaptively delay scheme depending on the prior information of physical layer obtained by channel prediction, the delay time of the ADR scheme is smaller than the DMCR scheme, and the difference with the other schemes decreases greatly with higher $E_b/N_0$. At extremely high $E_b/N_0$ channel conditions, the ADR scheme even has no disadvantage on delay time at all, while with the advantage in both the frame aborting probability and the throughput efficiency. This benefits from the achievement of the prior information of physical layer by channel prediction. The mean delay time of the original SR scheme and the MCR scheme is much smaller at low $E_b/N_0$ channel conditions, which is because that the maximum number of retransmissions is limited as small as 3 in our simulation. On the other hand, it is inevitable that the frame aborting probability of the
SR scheme and the MCR scheme is unendurable large at the low $E_b/N_0$ channel conditions. And in order to get the less frame aborting probability, the limited number of retransmission times has to be increased which also will enhance the correctly receiving delay time.

5. Conclusions

In this paper, we have studied a novel adaptively delay retransmission (ADR) scheme for mobile data networks in Rayleigh fading channel. Numerical results of simulation have demonstrated the performance improvement of this promising scheme.

The main advantage of this scheme is that with the method of adaptively delay retransmission, the retransmitted information frame can avoid the error burst period according to the general correlation properties of wireless fading channel. This feature brings great performance improvement on frame aborting probability and channel throughput efficiency. It shows that the improved ADR scheme can be a highly recommendable candidate of ARQ protocol for wireless data communications.

6. References


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