논문 2010-47IE-2-9

무선 통신망에서의 적응 프레임 길이 제어 방식의 성능 분석

(Performance Analysis of Adaptive Frame Size Control Scheme in Wireless Networks)

김 응 인*

(Eung In Kim)

요 약

본 논문은 무선 데이터 네트워크에 적용 가능한 적응 프레임 길이 제어 방식을 가진 데이터 링크 프로토콜을 제안한다. 무선 데이터망은 수시로 변화는 에러 환경에 놓여 있다. 이런 에러 환경에서도 잘 적용할 수 있는 가변 프레임 제어 방식을 제안하고 그 성능을 분석하였다. 2상태 마코프 모델을 이용하여 채널 환경을 모델링하였다. 수치해석방식을 통하여 새롭게 제안한 방식이 다양한 종류의 에러환경에서도 좋은 성능을 발휘할 수 있음을 보여 주었다.

Abstract

This paper suggests a new data link protocol with an adaptive frame length control scheme for wireless data networks which is subject to errors that occur with time variance. We analyze the proposed scheme under a two-state markov block interference(BI) model. Numerical results show that the proposed scheme can achieve high throughput performance for both dense and diffuse burst noise channels.

Keywords: data link protocol, adaptive frame length, wireless channel model, ARQ, Markov model

I. Introduction

In a wireless network, mobile stations experience reflection, diffraction and scattering, which cause burst errors to occur frequently. Therefore, in order to provide reliable transmission of packet data in such an environment, an efficient data link protocol is required, even though slight service delays could occur[1~2]. Error recovery schemes to cope with wireless channel noise have been investigated extensively. Conventional error recovery methods are based on automatic repeat request(ARQ) re-transmission schemes. Other approaches are related to the hybrid ARQ(HARQ), in which an automatic repeat request scheme is combined with forward error control(FEC)[3~5]. In the ARQ and HARQ schemes, a fixed frame length is usually used, which is designed with the worst channel condition and the overhead required per frame in mind. The data link protocol designer chooses a frame length that is small enough to transmit information when the error status is the worst. So, when channel conditions are good, the previously fixed frame length would be relatively small, because larger frames could be transmitted without error. By contrast, in burst error channels, a longer frame is more easily contaminated by fading than a shorter one, resulting in the inefficient use of channel capacity. If the frame length could be chosen adaptively in response to the

---

* 정회원, 용인송담대학 정보통신과
(Department of Information and Communications, YongIn SongDam College)
접수일자: 2010년5월3일, 수정완료일: 2010년6월7일

dynamically varying wireless data channel, maximum throughput could be achieved under both noisy and non-noisy error conditions.

Recent research[7~15] has demonstrated that adaptation of packet length can improve the throughput performance under widely varying channel conditions of wireless communication. Chien established that with an adaptive frame length control with error control, processing gain and equalization would be applied to the radio system's energy savings[7]. Choi considered a class of adaptive error-control schemes in the data link layer for reliable communication over wireless links in which the error-control code and the frame length are chosen adaptively, based on the estimated channel state/condition[8]. By contrast, Ci proposed an optimal frame size predictor, taking into account collisions and frame errors[9, 14]. Vitsas derived simple equations for optimum values of window size and frame length for maximum link layer throughput as a function of BER at Infrared Data Association(IrDA) link access[10]. However, these approaches usually adjust the frame length in response to feedback information, such as bit error rate(BER) or frame error rate(FER) from the radio receiver at the destination. The BER is an important measurement of wireless channel, but BER alone could not reflect well the influence of the wireless channel burstiness. For better performance, we need more information from the receiver to reflect the channel burstiness well, since burstiness can vary under the same average BER. We use the duty cycle of noisy bursts as a parameter to represent the channel burstiness. In this paper, we propose an adaptive frame length control scheme for the data link layer that will reduce the burst error effect and improve performance over wireless networks.

II. Noisy Channel Model

1. Markov Channel Model

We model the wireless data channel as a two-state Markov process. This traditional Gilbert error

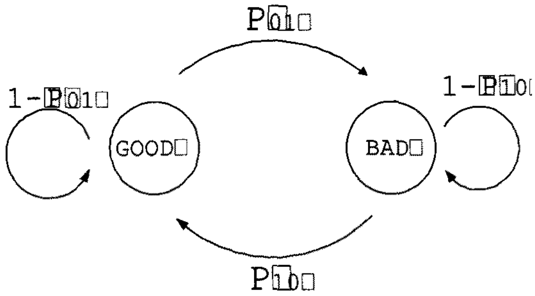


그림 1. 2-상태 마르코프 모델
Fig. 1. A two-state Markov model.

modelling approach is not identical to a real wireless error channel, but it has the advantages of simplicity and manageability[3, 6].

In a two-state Markov model, the states are classified as GOOD and BAD, which have Bq and B_n BER respectively, and $B_n > Bq$. The BAD state is a channel situation in which it is difficult to receive the packet frames properly, and B_n and Bq values depend on the channel environments. We assume that the state transitions occur with probabilities p_{01} and p_{10}, respectively, whenever each bit is transmitted, as shown in Fig. 1. For the Markov channel model, the average burst length is the expected value of the random variable X, where P(X = n) is the probability of staying in the BAD state for exactly n time bits.

Thus, we have

$$P(X=n)=(1-p_{10})^{n-1}p_{10} \tag{1}$$

Also, the average burst length N_b(average duration of the bad state) is given by

$$\begin{aligned} N_b &= \sum_{n=1}^{\infty} nP(X=n) \\ &= p_{10}\sum_{n=1}^{\infty} n(1-p_{10})^{n-1} \\ &= p_{10}\frac{1}{p_{10}^2} \\ &= \frac{1}{p_{10}} \end{aligned} \tag{2}$$

The average duration of the GOOD state, G_b is derived identically, since the model is symmetrical and (1-p_{01}) for state 0 is equivalent to (1-p_{10}) for state 1. Therefore,

$$G_b = \frac{1}{p_{01}} \tag{3}$$

Then, from (2) and (3),the average BER is described as follows.

$$\begin{aligned} B_{av} &= \frac{G_b B_q + N_b B_n}{G_b + N_b} \\ &= \frac{p_{01} B_q + p_{10} B_n}{p_{01} + p_{10}} \end{aligned} \tag{4}$$

And, the duty cycle of the noisy bursts which is the probability of being in the BAD state, P_{dc} is given by

$$\begin{aligned} P_{dc} &= \frac{N_b}{N_b + G_b} \\ &= \frac{p_{01}}{p_{01} + p_{10}} \end{aligned} \tag{5}$$

An alternate form for P_{dc} can be obtained as follows

$$\begin{aligned} P_{dc} &= \frac{p_{01}(B_n - B_q)}{(p_{01} + p_{10})(B_n - B_q)} \\ &= \frac{B_{av} - B_q}{B_n - B_q} \end{aligned} \tag{6}$$

Four parameters, N_b, B_{av}, P_{dc}, and B_n/B_q decide the two-state channel model. Here, $B_n/B_q(=v)$ denotes the high-to-low BER ratio.

2. Two-state Block Interference(BI) Model

Of the four parameters, three parameters, N_b, P_{dc} and v characterize the burstiness of the channel, with p_{01} and p_{10} describing the time variation of the channel behavior. In this paper, we use the approach proposed by Lugand et al[3] as a burst noise model. We will reduce the number of degrees of freedom by proposing a model for the noise bursts that can be dense(low duty cycle P_{dc} and high intensity, i.e., large high-to-low BER ratio) or diffuse(large duty cycle and low intensity).

Now the burst channel model is completely described by B_{av}, P_{dc} and N_b. In particular, when P_{dc} = p_{01} = 1- p_{10}, this channel model becomes the two-state block interference(BI) channel model proposed by McEliece and Stark[11]. The BI model is completely determined by P_{dc} and B_{av}. So, we assume that the wireless channel is modelled by a two state Markov BI model. In this model, the burstiness is determined by the proper value of P_{dc}. The higher the value of P_{dc}, the less burstiness occurs.

Ⅲ. Numerical Analysis of the proposed adaptive algorithm

Considering the error status of the wireless channel, the frame length of the data link layer is usually decided when the service connection is established. But, during the service period, the status of the wireless data channel varies dramatically. So, optimum throughput is not obtained with fixed frame length. In order to reduce the number of re-transmissions and conserve channel resources, an adaptive frame length control scheme is required.

1. FER

From the Markov model shown in Fig. 1, we can obtain the portion of time each Markov state spends in equilibrium, as follows

$$[\lambda_1\, \lambda_2] = [\lambda_1\, \lambda_2]\begin{bmatrix} 1-p_{01} & p_{01} \\ p_{10} & 1-p_{10} \end{bmatrix} \tag{7}$$

Here, the time portion of the good state(λ_1) is p_{10}, while p_{01} is the time portion of the bad state(λ_2). If a frame with n bits is transmitted over the channel, the frame error probabilities of the two states are $1-(1-Bq)^n$ and $1-(1-B_n)^n$, respectively. So, the frame error rate(FER) of the channel is described.

$$\begin{aligned} & fer(n) \\ & = \lambda_1(1-(1-B_q)^n)+\lambda_2(1-(1-B_n)^n) \\ & = (1-P_{dc})(1-(1-B_{av}P_{dc})^n) \\ & + P_{dc}(1-(1-\frac{B_{av}}{P_{dc}}+(1-P_{dc})B_{av})^n) \end{aligned} \qquad (8)$$

As shown in (8), the FER depends on the average BER(B_{av}), the duty cycle of noisy bursts(P_{dc}) and the frame length transmitted (n).

2. Numerical Analysis

Formulating the relationship between the throughput and the channel model parameters (B_{av} P_{dc}), we use the following definitions. Let the total amount of information to be transmitted be N bits and the frame length be n bits, while the header length of each frame is h bits. The transmitter sends the data at a transmission rate of M bps. The propagation delay of the wireless channel is assumed to be t_p seconds. Then, the number of frames to be transmitted is $\frac{N}{n}$ and each frame has $n+h$ bits. If we let S be the number of missing frames when N frames are transmitted over the channel, the random variable K has a binomial distribution. Then, the probability of missing k frames when $\frac{N}{n}$ frames are transmitted, $P[S=s]$ is described with FER(= $fer(n)$) which is given by (8).

$$P[S=s]=\begin{pmatrix} \frac{N}{n} \\ k \end{pmatrix} fer(n)^s(1-fer(n)^{\frac{N}{n}-s}) \qquad (9)$$

The number of average missing frames is derived from the expectation of random variable K. Since the number of transmitted frames is $\frac{N}{n}$ and the probability of frame error is $fer(n)$ the expectation of S, $E[k]$ is given by

$$E[s]=\frac{N}{n}fer(n) \qquad (10)$$

Here, $E[s]$ means the average number of frames contaminated during the transmission over the channel. So, we need to re-transmit s frames that were not received properly. And we know that s frames should be re-transmitted again if s frames out of the re-transmitted s frames were also destroyed during the re-transmission. If we let the total elapsed time caused by all re-transmissions be T_r, then T_r is given by

$$T_r=\frac{N(n+h)}{Mn}\frac{fer(n)}{1-fer(n)} \qquad (11)$$

We let T_f be the absolute time needed to transmit $\frac{N}{n}$ frames. Then, $T_f=t_p+\frac{N}{n}\frac{n+h}{M}$. Hence, the total transmission time ($T_t = T_f + T_r$) of N data bits when the frame length is n, including re-transmission, is given by

$$T_t=t_p+\frac{N(n+h)}{Mn}\frac{1}{1-fer(n)} \qquad (12)$$

If we define the throughput as $\frac{data\,bits\ received}{total\ elapsed\ time}$, the throughput ($\sigma$) is formulated as

$$\sigma=\frac{N}{t_p+\frac{N(n+h)}{Mn(1-fer(n))}} \qquad (13)$$

From (13), we know that the throughput depends on the FER, frame length and header length. And, the FER depends on three parameters: frame length, average bit error rate, and the duty cycle of noisy bursts, as shown in the previous subsection. The optimum frame length can be calculated analytically under the wireless error channel determined by B_{av} and P_{dc}, since we can obtain the frame length that maximizes the throughput performance. Fig. 2 shows the relation between the optimum frame length and the average BER when the duty cycle of noisy bursts (P_{dc}) is 0.25. When the BER is low, the optimum frame length is large. By contrast, the optimum frame length becomes small when the BER is high.

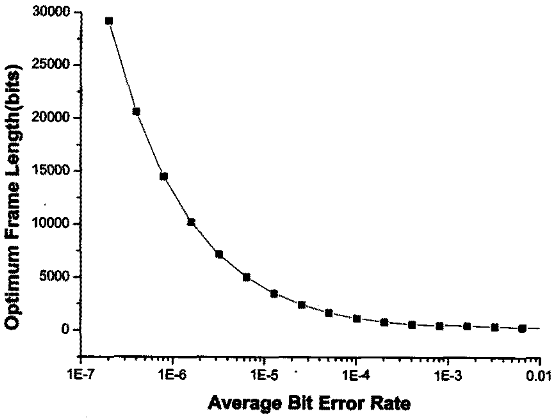


그림 2. $P_{dc} = 0.25$ 인 경우의 최적 프레임 길이와 비트에러율
Fig. 2. Optimum frame length vs. bit error rate when $P_{dc} = 0.25$.

Ⅳ. Results and Discussion

We assume that the burstiness of the wireless channel is diffuse(large duty cycle and low intensity), or dense(low duty cycle and high intensity). These terms were first introduced by Massey[12]. Firstly, fixed length frames from 10ms to 60ms with 3ms header are transmitted through diffuse and dense channels with different average BERs. In addition, frames with adaptively controlled length are delivered under the same channel conditions in order to compare previous schemes with the proposed scheme. The optimum frame length at the transmitter is calculated analytically to maximize the throughput for given error environments (P_{dc}, B_{av}).

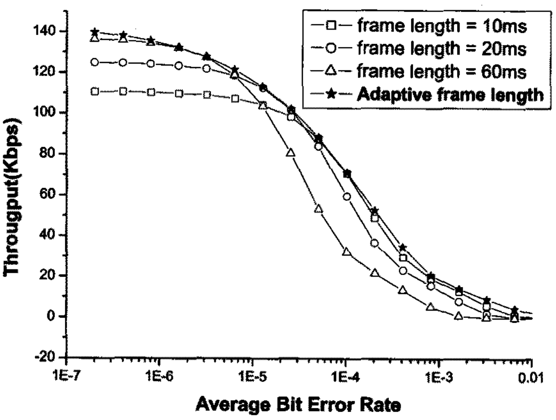


그림 3. $P_{dc} = 0.25$ 인 경우의 처리율과 비트에러율
Fig. 3. Throughput vs. BER when $P_{dc} = 0.25$.

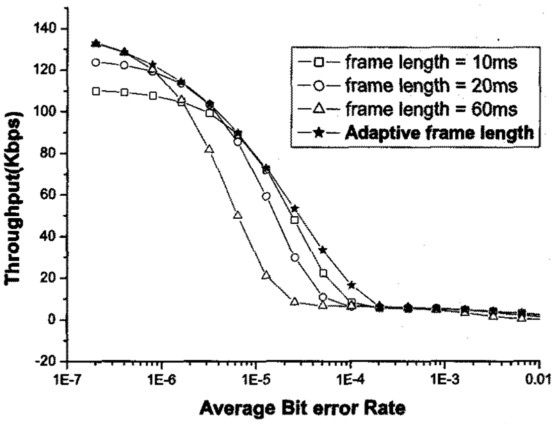


그림 4. $P_{dc} = 0.05$ 인 경우의 처리율과 비트에러
Fig. 4. Throughput vs. BER when $P_{dc} = 0.05$.

Fig. 3 shows the throughput performance versus the average bit error rate when a noisy burst has a fixed duty cycle(P_{dc} = 0.25). This figure is a graphical representation of the relationship between throughput and BER, described in eq.(13). When the frame length is fixed, the performance varies according to the average BER, whose range is from 10^{-7} to 10^{-2}. In the case of higher BER, we know that a shorter frame length shows better throughput performance. By contrast, a longer frame length shows good performance when the channel error is low. The 60ms frame length performs better than the 10ms frame length when the BER is 10^{-6}. By contrast, a frame length of 10ms is the optimum when the BER is 10^{-3}. However, throughout the entire channel error variation, the adaptive frame control scheme operates well, and shows maximum throughput. Fig. 4 shows that the proposed scheme could also be applied to the dense burst error channel.

Ⅴ. Conclusions

In this paper, we have studied a data link layer protocol with adaptive frame length. We have proposed a scheme that adaptively controls frame length based on the error status of a wireless data channel. We modelled the wireless data channel as a two-state Markov block interference model. We analyzed numerically the proposed frame length control scheme for both noisy and non-noisy error environments. We found that better performance could be achieved by using the newly proposed scheme, compared with a scheme using a fixed frame length.

참 고 문 헌

[1] S. Lin, D. J. Costello Jr., "Error Control Coding: Fundamentals and applications", Englewood Cliffs, Addison-Wesley, 1983.

[2] S. Lin, D. J. Costello Jr., M. J. Miller, "Automatic-Repeat Request Error-Control Schemes," IEEE Communications Magazine, pp. 5-17, Dec. 1984.

[3] L. R. Lugand, D. J. Costello Jr., R. D. Deng, " Parity Retransmission Hybrid ARQ Using Rate 1/2 Convolutional Codes on a Nonstationary Channel," IEEE Trans. on Com., Vol.37, No.7,pp. 755-765, July 1989.

[4] S. Kallel, "Analysis of memory and incremental redundancy ARQ schemes over a nonstationary channel," IEEE Trans. on Com., Vol.40, No.9, pp. 1474-1480, September 1992.

[5] Qinqing Zhang, Saleem A. Kassam, "Hybrid ARQ with Selective Combing for Fading Channels," IEEE Journal of Selected Areas in Comm., Vol.17, No.5, pp. 867-880, May 1999.

[6] A. Konrad, Ben Y. Zhao, Anthony D. Joseph, Reiner Ludwig, "A Markov-Based Channel Model Algorithm forWireless Networks," U.C Berkeley Technical Report, UCB/CSD-01-1142, May 2001.

[7] C. Chien, M. B. Srivastava, Rajeey Jain, P. Lettieri, Vipin Aggarwal, R. Sternowski, "Adaptive Radio for Multimedia Wireless Links," IEEE Journal of Selected Areas in comm., Vol. 17, No.5, May 1999, Page(s): 793 - 813

[8] Sunghyun Choi, Kang G. Shin, "A Class of Adaptive Hybrid ARQ Schemes for Wireless Links," IEEE Trans. on Vehicular Tech., Vol. 50, No.3, May 2001, Page(s): 777 - 790

[9] Song Ci, Hamid Sharif, .An link adaptation scheme for improving throughput in the IEEE 802.11 wireless LAN,. Local Computer Networks," 2002. Proceedings. LCN 2002. 27th Annual IEEE Conference on, 6-8 Nov. 2002 Page(s): 205 -208

[10] V. Vitsas, A. C. Boucouvalas, "Optimization of IrDA IrLAP link access protocol," IEEE Trans. on Wireless Comm., Vol. 2, No.5, Sept. 2003, Page(s): 926 - 938

[11] R. J. McEliece,W.W. Stark, "Channels with block interference," IEEE Trans. Inform. Theory, Vo.IT-30, No.1, pp.44-53, Jan. 1984.

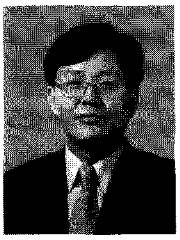
[12] J. L. Massey, "Coding techniques for digital communications. notes for a tutorial session," IEEE Int. Conf. Commun., Seattle, Jun. 1973.

[13] Y. Hou, M. Hamamura, S. Zhang, "Performance Tradeoff with Adaptive Frame Length and Modulation in Wireless Network," IEEE Computer Society, CIT'05, 2005.

[14] S. Ci, H. Sharif, K. Nuli, "Study of an Adaptive Frame Size Predictor to Enhance Energy Conservation in Wireless Sensor Networks," IEEE JSAC.,Vol. 23, No.2, Feb., 2005.

[15] S. Panichpapoborn, "Adaptive Frame Length Selection Scheme for RFID Object Identification," IEEE PIMRC'07, 2007.

저 자 소 개



김 응 인(정회원)
1984년 경북대학교 전자공학과 졸업(학사).
1986년 경북대학교 대학원 전자공학과 졸업(석사)
2004년 한국과학기술원 전자전산학과 졸업(박사).
1986년 3월~1996년 2월 KT 연구소 연구원
1996년 3월~현재 용인송담대학 전자공학과 교수
<주관심분야 : 이동통신, 음성신호처리, 정보보안>