A Parity-Bit Based Rate Adaptation Scheme for the IEEE 802.11a Wireless LANs

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Abstract—**In this paper we present a simple rate adaptation scheme by taking advantage of the information of the parity-bits in the SIGNAL field of the IEEE 802.11a [1] standard. Using this mechanism, the receiver can notify the transmitter to adapt to a higher or lower data rates according to the current wireless channel condition. The goal of our scheme is to find the most efficient transmission mode with acceptable quality. Finally, we will use a physical layer (PHY) simulation platform to investigate the performance of the proposed scheme.**

I. INTRODUCTION

Due to the growing demand of accessing the Internet service anywhere, wireless LANs have become important in recent years. Currently, wireless LANs cards sold in the market have three types: the IEEE 802.11a [1], 802.11b [2], 802.11g [3] standard. IEEE 802.11b [2] modulates the data using spread spectrum to support 2 Mb/s to 11 Mb/s data rates in the 2.4 GHz band. A newer modulation technique called Orthogonal Frequency Division Multiplexing (OFDM) is adopted by the IEEE 802.11a [1] and 802.11g [3] standards. It provides eight different data rates ranged from 6 Mb/s to 54 Mb/s in the 5 GHz band. The function of offering eight different data rates makes the IEEE 802.11a [1] capable of flexibly transmitting different data rates in the wireless environment.

Rate adaptation for the IEEE WLAN has strong impact on the efficiency and quality. Among the eight different data rates provided by the IEEE 802.11a [1] standard, the transceiver can select the most appropriate one according to the current wireless condition. For instance, it is reasonable to use a higher data rate for transmissions when the wireless channel environment between two stations is good enough. However, using a high data rate will cause higher error probability and increase retransmissions. On the other hand, if two stations communicate through a noisy channel environment, then the signal-to-noise ratio (SNR) measured at the station may be too low to use a higher data rate. In this situation a lower is desirable. Choosing a too low data rate will degrade the throughput because of transmitting the data inefficiently. As a result, a suitable rate adaptation algorithm is needed to achieve the best balance between efficiency and quality of transmissions.

In the literature, link adaptation schemes for WLANs have been discussed in [4]－[9]. However, most of them analyzes the problem from the aspect of Medium Access Control (MAC) layer without considering the effect in PHY specifications. Using the PHY specifications to discuss and solve the link adaptation problem has not been seen too much. This paper proposed a simple rate adaptation scheme that can be finished in the PHY layer.

We organize the rest of this paper as follows. Section II is the system overview. Physical layer (PHY) of the IEEE 802.11a, SIGNAL field, multipath channel profile, and channel estimation algorithm are described. The rate adaptation scheme is described and illustrated in Section III. The simulation results are presented in Section IV. Section V is the conclusion.

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II. SYSTEM OVERVIEW

A. PHY of the IEEE 802.11a

IEEE 802.11a uses OFDM to combat the distortion of the wireless channel. Rate 1/2 convolutional coding and bit interleaving are two major skills for Forward Error Correction (FEC). By puncturing the rate 1/2 convolutional coding, other coding rate including 2/3 and 3/4 are obtained. The modulation schemes defined in the standard are BPSK, QPSK, 16-QAM, and 64-QAM. The relationship between data rate, modulation skill, and coding rate are listed in Table I.

B. SIGNAL Field

SIGNAL field is defined between Physical Layer Convergence Procedure (PLCP) preamble and Data field of PLCP Protocol Data Unit (PPDU) frame format as shown in Fig. 1. SIGNAL field as shown in Fig. 2 is formed with five parts including rate field

TABLE I
EIGHT MODES OF THE IEEE 802.11a

Mode	Data rate (Mb/s)	Modulation	Coding rate
1	6	BPSK	1/2
2	9	BPSK	3/4
3	12	QPSK	1/2
4	18	QPSK	3/4
5	24	16-QAM	1/2
6	36	16-QAM	3/4
7	48	64-QAM	2/3
8	54	64-QAM	3/4

PLCP Preamble 12 Symbols	SIGNAL One OFDM Symbol	Data Variable Number of OFDM Symbols

Fig. 1. PPDU frame format

RATE (4 bits)					LENGTH (12 bits)													SIGNAL TAIL (6 bits)					
R1	R2	R3	R4	R	LSB										MSB	P	0	0	0	0	0	0	
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23

Fig. 2. SIGNAL field bit assignment

TABLE II
CONTENTS OF THE RATE FIELD

Rate (Mb/s)	R1-R4
6	1101
9	1111
12	0101
18	0111
24	1001
36	1011
48	0001
54	0011

(4 bits), reserved bit, length field (12 bits), parity bit, and SIGNAL tail field (6 bits). The rate field is filled with information according to Table II. The reserved bit is for future use. The length field represents the number of octets of data transferred between MAC layer and PHY. The parity bit is filled to let SIGNAL field to be even parity. Six zeros are set in SIGNAL tail field. SIGNAL field applies mode one shown in Table I with data rate 6 Mb/s, BPSK modulation, and 1/2 coding rate due to transmitting such important information mentioned above.

C. Multipath Channel Profile

We model our multipath channel as a finite impulse response filter [10] as shown in Fig. 3. The exponential decay black arrows mean average magnitudes. The gray arrows illustrate a random realization of the channel response.

The mathematical formula of the channel is described as follows:

$$h_k = N(0,\sigma_k^2/2) + jN(0,\sigma_k^2/2) \tag{1}$$

$$\sigma_k^2 = \sigma_0^2 e^{-kT_S/T_{RMS}} \tag{2}$$

$$\sigma_0^2 = 1 - e^{-T_s/T_{RMS}} \tag{3}$$

$$k_{\max} = 10 \times T_{RMS}/T_S \tag{4}$$

$N(0,\sigma_k^2/2)$ is a zero-mean Gaussian random variable with variance $\sigma_k^2/2$. σ_0^2 is selected to make $\sum_k \sigma_k^2 = 1$ and let the average received power be identical. T_S is the sample period. T_{RMS} is the root mean square (rms) delay spread of the channel response. $K_{\max}$ is the number of samples of impulse response of the channel.

D. Channel Estimation Algorithm

Channel estimation is an important process for the receiver to estimate the current quality of the channel. It is helpful to demodulate the data correctly if the proper channel estimation algorithm is performed.

The simple but efficient channel estimation algorithm we use is performed in the frequency domain and mentioned in [11]. It uses the two long training symbols defined in OFDM training structure shown in Fig. 4. Due to the contents of the two long training symbols are the same, it is desired to average them to estimate the channel quality.

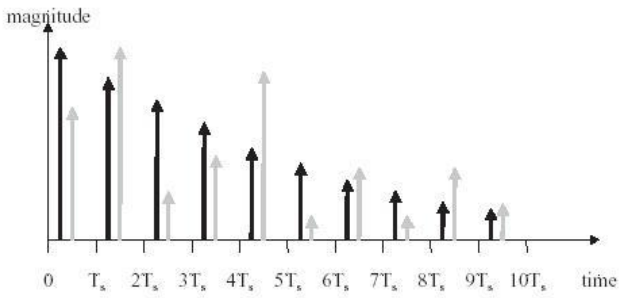

Fig. 3. Channel impulse response

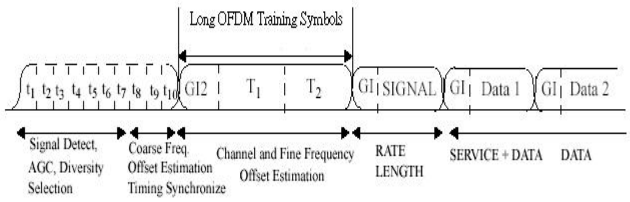

Fig. 4. OFDM training structure

The mathematical presentation of the channel estimation algorithm is described as follows:

$$R_{l,k} = H_k X_k + W_{l,k} \tag{5}$$

$$\hat{H}_k = \frac{1}{2}(R_{1,k} + R_{2,k})X_k^* \tag{6}$$

$$= \frac{1}{2}(H_k X_k + W_{1,k} + H_k X_k + W_{2,k})X_k^* \tag{7}$$

$$= H_k |X_k|^2 + \frac{1}{2}(W_{1,k} + W_{2,k})X_k^* \tag{8}$$

$$= H_k + \frac{1}{2}(W_{1,k} + W_{2,k})X_k^* \tag{9}$$

$R_{1,k}$ and $R_{2,k}$ equal to the product of the channel response H_k and the training symbols X_k plus noise sample $W_{l,k}$. The estimated channel response can be calculated by (6), (7), (8), and (9). According to the IEEE 802.11a standard, all amplitudes of the long training symbols equal to one.

III. RATE ADAPTATION SCHEME

Our rate adaptation scheme is based on checking the parity-bit of SIGNAL field shown in Fig. 2. As mentioned before, SIGNAL field is modulated with BPSK, which is the most reliable one to combat the distortion of the wireless channel among other modulation schemes in the eight PHY modes of the IEEE 802.11a. Thus, if we check the parity-bit of SIGNAL field and found it is not even parity that means there is some errors happened in the SIGNAL field, we conclude that the current channel condition is bad enough and should use a lower data rate for transmitting the original data one more time. However, if we found it is even parity that means correct transmission occurred, this can not mean the current channel condition is good enough to use a higher data rate for the next transmission.

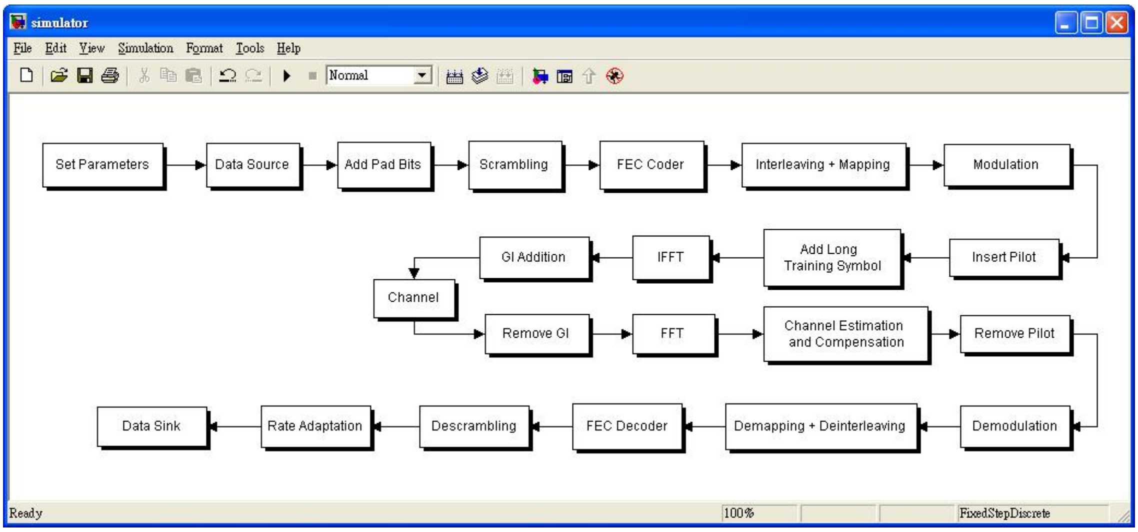

Fig. 5. PHY simulation platform

Thus, our rate adaptation scheme is to set a counter S which counts the successive times of successful transmissions of SIGNAL field. If the counter S reaches the boundary $S_{\max}$, the receiver will notify the transmitter to adopt a higher data rate in the next transmission and set the counter S to zero. On the other hand, if the counter S does not reach the boundary $S_{\max}$, the original data rate will be used for the next transmission. When there happens one transmission error, a lower data rate is going to be adopted by the transmitter and the counter S will also be set to zero. We illustrate our rate adaptation scheme as a flow chart shown in Fig. 6.

The important question is that for what value of $S_{\max}$ can achieve the best balance between efficiency and quality of transmissions. Our scheme is to choose the $S_{\max}$, which needs the shortest physical layer transmission time under an acceptable bit-error-ratio (BER) range. For our self-designed simulation platform, we send a picture which has 5184 bits through PHY specifications of the IEEE 802.11a standard. As a result, the acceptable bit-error-ratio (BER) range we define is lower than 5×10^{-2} according to our simulative experiments.

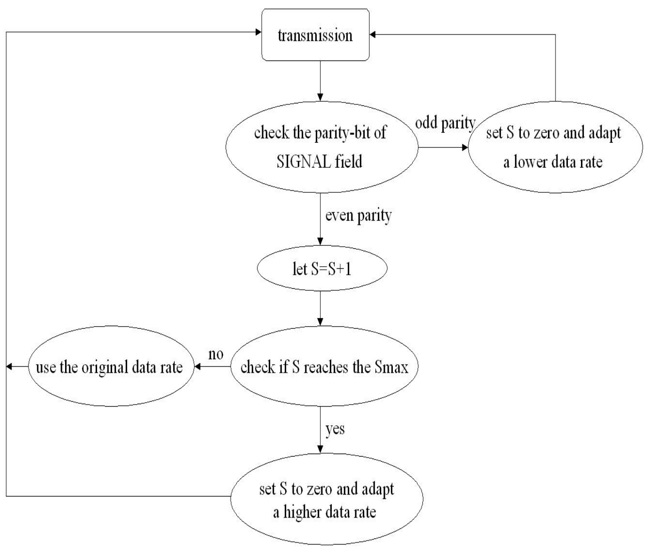

Fig. 6. Flow chart of the rate adaptation scheme

IV. SIMULATION RESULTS

We use the MATLAB[1] and Simulink[2] software to establish the platform shown in Fig. 5 for simulating our rate adaptation scheme. Some processes of PHY specifications defined in the IEEE 802.11a standard including add pad bits, scrambling, FEC encoding, data interleaving and mapping, modulation, insert pilot, add long training symbols, IFFT, GI addition, etc are performed. The multipath channel profile and channel estimation algorithm mentioned in system overview are also used for the platform. The root mean square (rms) delay spread of the multipath channel profile we simulate is 100 (ns).

As mentioned before, the data source of the simulation platform is a picture which has 5184 bits. We fragment the picture to 13 frames. No. 1 to No. 12 are the same size which is 400 bits. No. 13 is 384 bits. Thus, we will have total 13 PPDU frames transmitted through the channel. The LENGTH field of SIGNAL is filled with 50 or 48 octets according to the frame is 400 or 384 bits.

First we simulate our rate adaptation scheme with initial rate 6 Mb/s. An example of the transmitting procedure is shown in Fig. 7. The SNR and $S_{\max}$ used in the example are 10 and 3. Thus, we can see from Fig. 7 that after three successive times of successful transmissions the data rate is changed to a higher one. The best $S_{\max}$ with initial rate 6 Mb/s are listed in Table III. The average PHY transmission time versus SNR shown in Fig. 8 tells us that our rate adaptation needs less time than fixed rate to finish the transmission of the picture.

TABLE III
THE BEST $S_{\max}$ WITH INITIAL RATE 6 Mb/s

SNR	6	7	8	9	10	11	12
$S_{\max}$	4	3	3	3	3	3	2
SNR	13	14	15	16	17	18	19
$S_{\max}$	2	2	2	1	1	1	1

[1] MATLAB is a registered trademark of The MathWorks, Inc.
[2] Simulink is a registered trademark of The MathWorks, Inc.

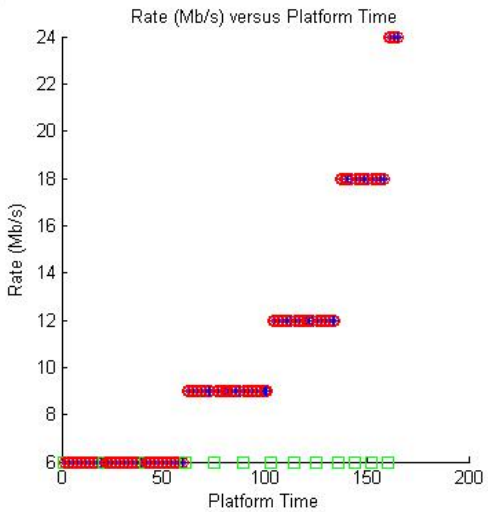

Fig. 7. Transmitting procedure with initial rate 6 Mb/s

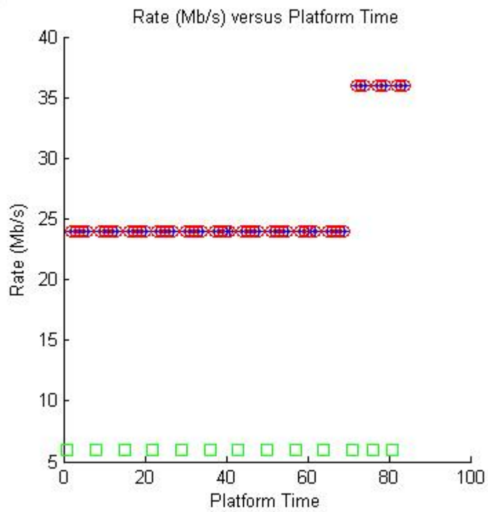

Fig. 9. Transmitting procedure with initial rate 24 Mb/s

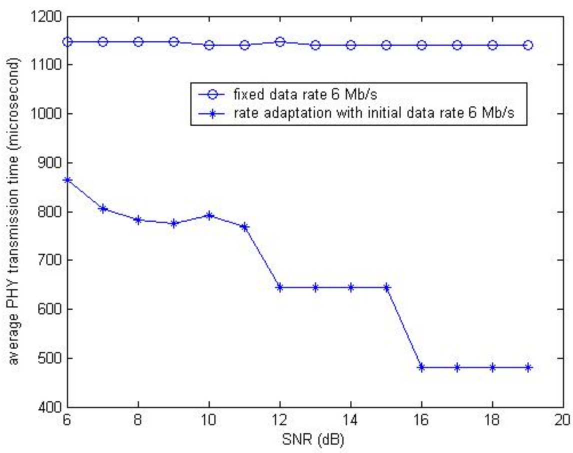

Fig. 8. Average PHY transmission time versus SNR with 6 Mb/s

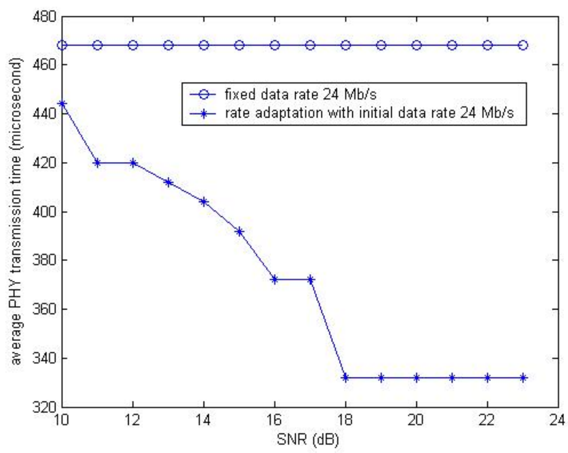

Fig. 10. Average PHY transmission time versus SNR with 24 Mb/s

Compared with the initial rate 6 Mb/s, we also simulate our rate adaptation scheme with initial rate 24 Mb/s. Fig. 9 shows one example of the transmitting procedure, and the SNR and $S_{\max}$ are both 10. Table IV shows the best $S_{\max}$ with initial rate 24 Mb/s. The average PHY transmission time of rate adaptation and fixed rate versus SNR are plotted in Fig. 10. Fig. 10 also demonstrates our rate adaptation scheme needs less time to transmit the picture.

In order to find how efficiency the rate adaptation scheme has. We set a parameter P equals to (F-R)/F×100%. F represents the average PHY transmission time of fixed rate. R represents the average PHY transmission time of rate adaptation. P is calculated and listed in Table V and VI. From the data listed in Table V and VI, we found that:

1. P increases as SNR increases. This is because higher SNR accepts higher data rates for transmissions. Higher data rates use less time to finish the transmission of the data.
2. For the same SNR range (e.g. 10~19), P with initial rate 6 Mb/s is always larger than that with initial rate 24 Mb/s. This can be observed from Fig. 7 and 9. From Fig. 7, about 2/3 of the total transmission time is spent on the transmissions using data rates higher than 6 Mb/s. From Fig. 9, about 1/6 of the total transmission time is spend on transmissions using data rates higher than 24 Mb/s.

From Tables III and IV, we found that under the same SNR range (e.g. 10~17) all $S_{\max}$ with initial rate 24 Mb/s are larger than that with initial rate 6 Mb/s. This is because lower data rates are more capable than higher ones to combat the distortion of the wireless channel. From Fig. 9, there are two data rates 24 Mb/s and 36 Mb/s for transmissions. In order to achieve the acceptable BER level, most of the transmission time must be spend on 24 Mb/s. But from Fig. 7, the data rates used for transmissions are less or equal to 24 Mb/s. Thus, it is reasonable to allocate about the same time on each data rate under the acceptable BER condition.

TABLE IV
THE BEST $S_{\max}$ WITH INITIAL RATE 24 Mb/s

SNR	10	11	12	13	14	15	16
$S_{\max}$	10	7	7	6	5	4	3
SNR	17	18	19	20	21	22	23
$S_{\max}$	3	1	1	1	1	1	1

TABLE V
COMPARISON OF AVERAGE PHY TRANSMISSION TIME
WITH INITIAL RATE 6 Mb/s

SNR	6	7	8	9	10	11	12
P (%)	25	30	32	32	31	33	44
SNR	13	14	15	16	17	18	19
P (%)	44	44	44	58	58	58	58

TABLE VI
COMPARISON OF AVERAGE PHY TRANSMISSION TIME
WITH INITIAL RATE 24 Mb/s

SNR	10	11	12	13	14	15	16
P (%)	5	10	10	12	14	16	21
SNR	17	18	19	20	21	22	23
P (%)	21	29	29	29	29	29	29

V. CONCLUSION

The parity-bit based rate adaptation scheme is simulated and investigated by our PHY simulation platform. According to the scheme, the best $S_{\max}$ that makes the PHY transmission time be shortest is selected. Simulation results suggest that the proposed rate adaptation scheme reduces the PHY transmission time of sending a picture under an acceptable BER range. Besides, the relation among the reduction time, the $S_{\max}$, the data rates, and the SNR is discussed.

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