A Study on Power Delay Profile Measurement using IEEE 802.11g based Long Preamble Signals for WLAN Systems at 2.4 GHz band

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***Abstract*—This paper proposes a measurement scheme for power delay profiles using IEEE 802.11g based wireless packets in the 2.4 GHz band. In the proposed scheme, first, a signal analyzer, which can save the received Ich and Qch signals, receives the OFDM based packets sent from a wireless access point to a mobile terminal. Second, positions of long preambles in the received IQ data are detected in the cross correlation process using a known long preamble signal between a transmitter and a receiver. Third, the power delay profile is calculated by averaging the channel impulse responses, which are estimated from the received long preamble signals. Computer simulations confirm that the proposed scheme can be expected to achieve almost the same performance with PN sequence based measurement schemes.**

I. Introduction

Recently, hot-spot services using wireless local area networks (WLANs) [1], [2] have been expanded throughout Japan. Many access points (APs) have been distributed at several locations in order to compensate for the reduction in the WLAN throughput due to an increasing number of network users [3]. Wireless packet communication with high data transmission rates can therefore be achieved in various places.

Although the number of network users may be small, the WLAN throughput sometimes decreases significantly when a mobile terminal (MT) connects to the AP. One of the reasons for this phenomenon is considered to be inter channel interference (ICI) from other APs, which causes a decrease in the signal to interference and noise power ratio (SINR). Moreover, the high propagation loss in the GHz band and multipath fading in the broadband transmission also cause the degradation of WLAN throughput. In the IEEE 802.11g WLAN system [4], [5], packets that are based on orthogonal frequency division multiplexing (OFDM) symbols are transmitted. The OFDM signals in the IEEE 802.11g are outputs of the inverse fast Fourier transform (IFFT) in which the FFT size is 64-point and there are 48 data and 4 pilot subcarriers. The bandwidth of each subcarrier is small, therefore the effect of inter symbol interference (ISI) can be avoided. However, packet errors due to ISI occur when the maximum delay time exceeds the time duration of the guard interval (GI), which is added to the head of the OFDM signal. Therefore, it is important to understand the statistical model of the multipath fading channel before constructing the WLAN environment.

In general, in order to investigate the statistical model of a multipath fading channel, the characteristics of the power delay profile (PDP) are measured at the various places [6]–[10]. A bi-phase modulated pseudonoise (PN) sequence [11] is often used because it is known in a transmitter and a receiver, and its auto-correlation function has a very high periodic peak. Channel impulse responses (CIRs) can be obtained by a cross correlation process using the received PN sequence, and the power delay profile is calculated by the averaging process of the CIRs. However, this takes a very long time and it is costly to build a PN based power delay profile measurement system because there is a long acceptance time duration for applications made to the Ministry of Internal Affairs and Communications (MIC) in Japan for experimental radio band usage. In addition, a flexible signal generator (SG) which periodically transmits arbitrary signals is expensive. In order to reduce the setup time and cost of the construction of a measurement system, we propose a power delay profile measurement using IEEE 802.11g based long preamble signals in the WLAN systems. In the proposed scheme, a signal analyzer (SA) saves transmitted data packets sent from the wireless AP to the MT, and its in-phase channel (Ich) and quadrature-phase channel (Qch) data are analyzed to estimate CIRs. Finally, the power delay profile can be obtained after the CIRs are averaged.

The remainder of this paper is organized as follows. Conventional and proposed system models of the power delay profile measurement are presented in section II. In section III, the proposed scheme of the delay profile measurement using IQ data of long preamble signals in the IEEE 802.11g packets is described. Analysis of computer simulation results are reviewed in section IV. Finally, we conclude the proposed measurement scheme in section V.

II. System Models

Figure 1 shows (a) conventional and (b) proposed system models of the power delay profile measurement. In Fig. 1(a), PN based periodic signals in the 2.4 GHz band are transmitted from the SG to the SA. After the received baseband IQ data in the SA are saved in its memory, the cross correlation (sliding correlation [7]) process between the known PN sequence and received IQ signals creates estimated CIRs. The power delay

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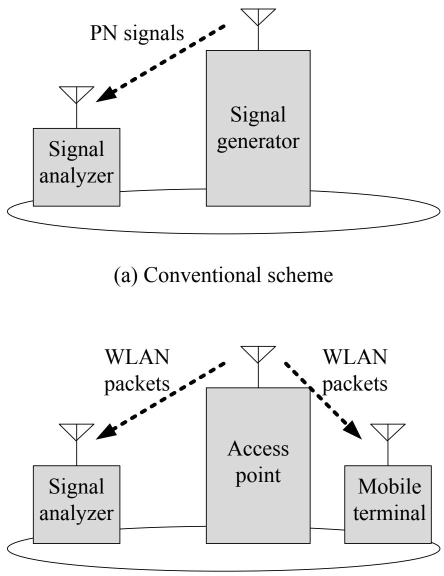


(a) Conventional scheme

(b) Proposed scheme

Fig. 1. System models.

profile between the SG and SA will be calculated by averaging the absolute square values of the CIRs.

However, as shown in Fig. 1(b), there is one AP, one MT, and one SA in the power delay profile measured environment. When the MT receives OFDM packets based on the IEEE 802.11g in the 2.4 GHz band from the AP, the SA can also receive the same packets. In our proposed scheme, the SA saves the IQ data of OFDM packets in its memory and the power delay profile from the AP to the SA is estimated using received long preamble signals.

When compared to the conventional model, the APs of the marketed products have already received certification for use in the 2.4 GHz band, thus, there is no need for us to apply to the MIC in Japan. Therefore, our proposed scheme shortens the time required to acquire the experimental results. Moreover, our proposed scheme decreases the measurement cost because SGs are generally expensive products.

Figure 2 shows a block diagram of transmitted and received signals from the AP to the SA. As shown in this figure, information bits are encoded and the coded bit sequence is fed to a baseband signal generator (BSG) in which generated baseband signals are based on the OFDM modulation. WLAN packets are transmitted from the AP after the baseband signal is quadrature-modulated. In the SA, received signals are quadrature-demodulated and this baseband IQ data is saved in the memory. After the IQ data is fed to a personal computer (PC), the power delay profile is estimated. The details of the estimation process are described in the next section.

III. Delay Profile Estimation Scheme

In our proposed scheme, we focus on the construction of the long preamble in the IEEE 802.11g WLAN packet. The long preamble is used for channel estimation and automatic frequency control (AFC) processes, and it is known between the transmitter and the receiver. Therefore, the long preamble part in the IQ data can be detected, and the power delay profile between the AP and SA can be estimated using our proposed signal processing. Details of the above concept are explained as follows.

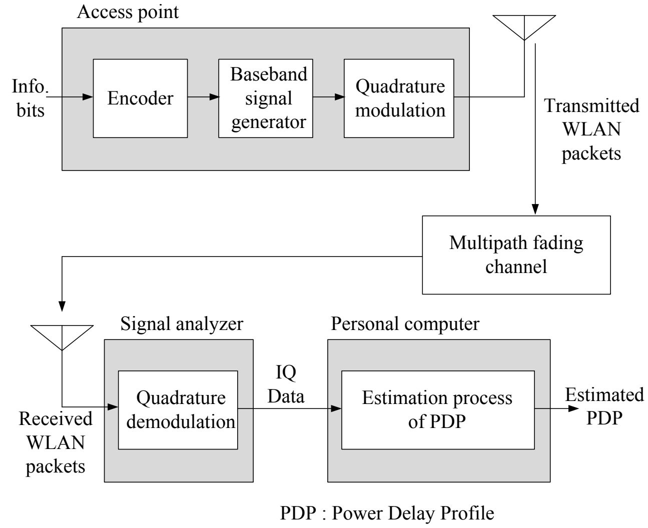


Fig. 2. Block diagram of transmitted and received signals.

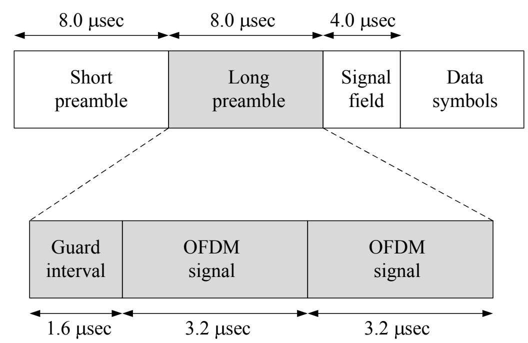


Fig. 3. Construction of OFDM packet in IEEE 802.11g.

Figure 3 shows the construction of an OFDM packet in the IEEE 802.11g. In the OFDM packet, there are short preamble, long preamble, signal field, and data symbols. The duration of a long preamble is 8.0 μsec, for which the preamble has one guard interval signal of 1.6 μsec and two OFDM signals of 3.2 μsec. For this construction of an OFDM packet, the method for the detection of long preambles in the received signal is important.

Figure 4 shows the auto correlation function of the OFDM symbol (3.2 μsec) in the long preamble. In this figure, the sampling rate is 100 Msample/s, and the value of the correlation peak is normalized to be 0 dB. As shown in this figure, the long preamble signal has a different property when compared to PN sequence based signals. The main peak is periodically occurs

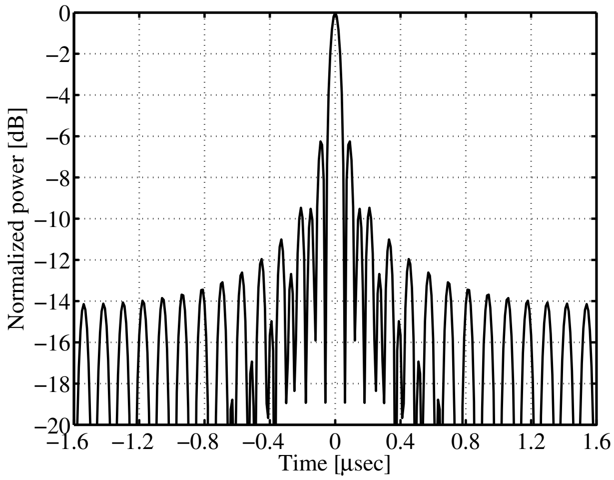


Fig. 4. Auto correlation function of the OFDM symbol (3.2 μsec) in the long preamble.

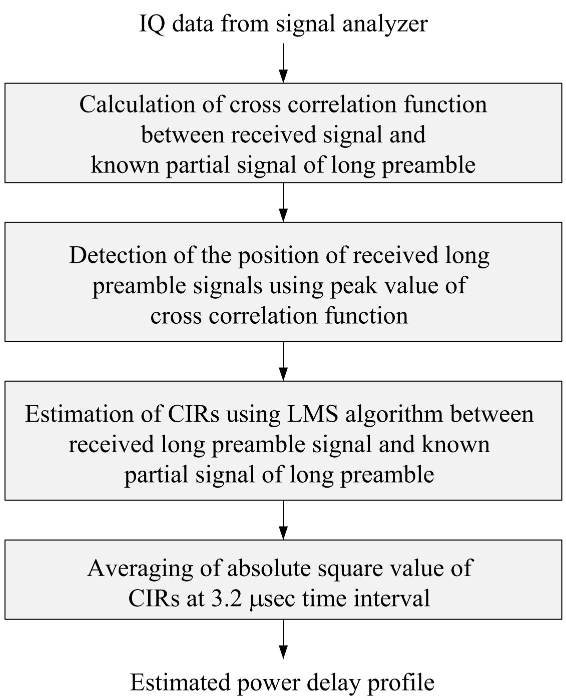


Fig. 5. Estimation process of power delay profile.

at time intervals of 3.2 μsec, and there are two subpeaks. The level of these subpeaks is about 6 dB lower than that of the main peak, thus, long preambles will be detectable by the cross correlation process between the received signal and the known long preamble signal.

Figure 5 shows the estimation process of the power delay profile in our proposed scheme. First, after the IQ data in the SA's memory are fed to the PC, a cross correlation function between the received signal and the known long preamble signal is calculated[1]. Second, the positions of received long preambles are detected using the calculation results of the cross correlation function. Third, only after some received long preamble signals are selected, the CIRs are estimated using the least mean square (LMS) algorithm [12] between the received long preamble signals and the known long preamble signal.

In the LMS algorithm, the $n+1$-th iteration of the estimated CIR vector $\hat{\boldsymbol{h}}_{n+1} \in \mathbb{C}^{M\times 1}$ is calculated by

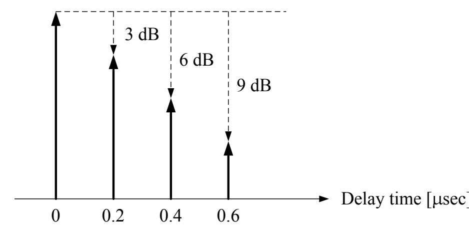
$$\hat{\boldsymbol{h}}_{n+1} = \hat{\boldsymbol{h}}_n + \mu \boldsymbol{u}_n (d_n^* - \boldsymbol{u}_n^H \hat{\boldsymbol{h}}_n), \tag{1}$$

where M is the number of samples for the duration of the CIR vector, μ is the step-size parameter, $\boldsymbol{u}_n \in \mathbb{C}^{M\times 1}$ is the n-th iteration of the tap-input vector, d_n is the n-th complex value of the received long preamble, x^* is the complex conjugate of scalar x, and $\boldsymbol{a}^H$ is the conjugate transpose of vector $\boldsymbol{a}$.

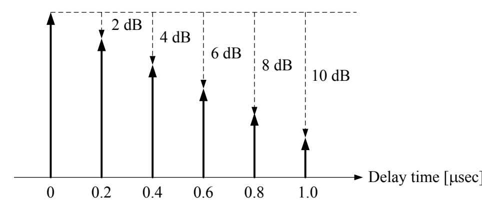
Finally, as shown in Fig. 5, the power delay profile between the AP and SA is estimated by averaging the absolute square value of the CIRs.

TABLE I
SIMULATION PARAMETERS.

Average E_s/N_0	10 dB
Sampling rate	100 Msample/s
Path model	1 path Rayleigh, 3 dB decaying 4-path Rayleigh, and 2 dB decaying 6-path Rayleigh
μ of LMS algorithm	0.0001



(a) 3 dB decaying 4-path Rayleigh model.



(b) 2 dB decaying 6-path Rayleigh model.

Fig. 6. Exponentially decaying multi-path Rayleigh model.

IV. COMPUTER SIMULATION

A. Simulation Parameters

The performances of the proposed scheme for the power delay profile estimation based on Fig. 5 are evaluated using computer simulations. Table I shows the simulation parameters. The average E_s/N_0 is 10 dB. The sampling rate is 100

[1]The transmission process for a long preamble is described in the Appendix.

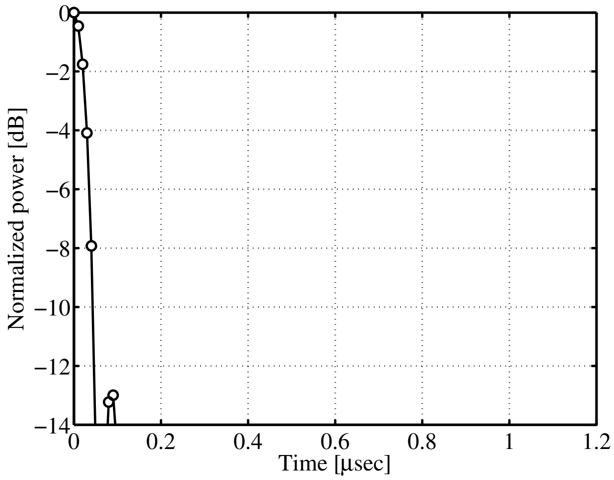


Fig. 7. Estimated power delay profile in 1-path fading channel.

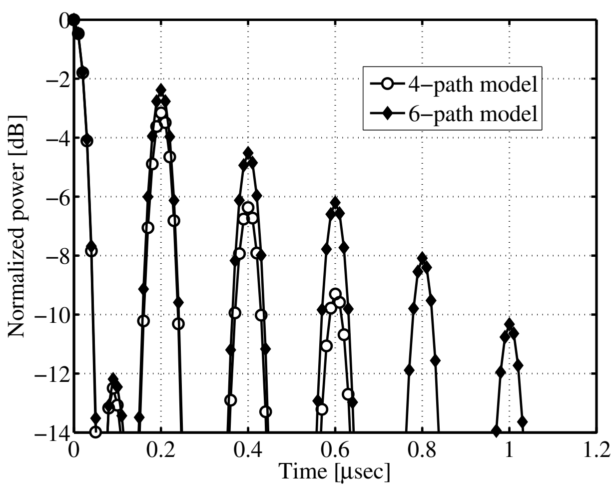


Fig. 8. Estimated power delay profiles in multi-path fading channel.

Msample/s, thus a 3.2 μsec OFDM signal has 320 samples. 1-path Rayleigh, 3 dB decaying 4-path Rayleigh, and 2 dB decaying 6-path Rayleigh are used as path models, where each path is independent of the others. Figure 6 shows the multi-path Rayleigh models, where the average delay time and delay spread of the 3 dB decaying 4-path Rayleigh model (Fig. 6(a)) are 0.147 μsec and 0.186 μsec, respectively, and those of the 2 dB decaying 6-path Rayleigh model (Fig. 6(b)) are 0.261 μsec and 0.286 μsec, respectively. In the LMS algorithm, μ is 0.0001, and M is set as 120, which means that the duration of the estimated delay profile is 1.2 μsec since the sampling rate is 100 Msample/s.

B. Simulation Results

Figure 7 shows the estimated power delay profile in the 1-path Rayleigh model, and Figure 8 shows the estimated power delay profile in the 3 dB decaying 4-path Rayleigh and 2 dB decaying 6-path Rayleigh models. In these figures, Doppler frequency f_d is 0 Hz and the number of averaging CIRs calculated by the received long preamble is 100, where we assumed that the CIR randomly changes for each preamble. As shown in Fig. 7, the difference between the 1st peak and 2nd peak values is approximately 12 dB. Some subpeaks occur because long preamble signals do not have a high auto correlation property when compared to the PN sequence. As shown in Fig. 8, there are four and six peaks with high power for 1.2 μsec, and each of the path powers decays by approximately 3 dB and 2 dB per 0.2 μsec interval, as in Fig. 6. Therefore, our proposed scheme can estimate the power delay profile when the power difference between the main and other paths is less than 12 dB.

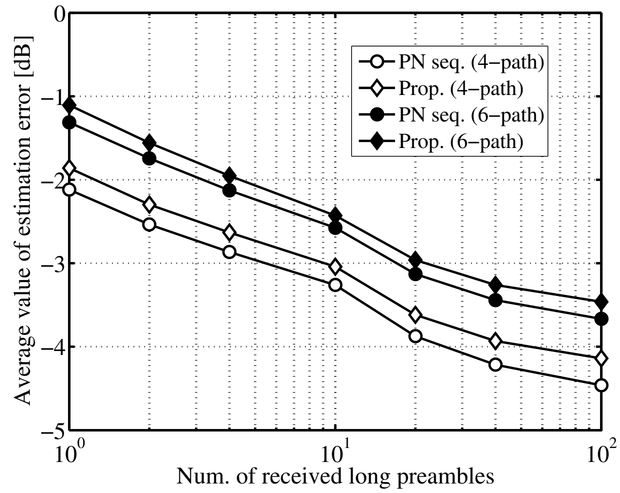


Fig. 9. Average value of estimation error in the delay profile vs. Num. of received long preambles in the 4-path and 6-path models.

Figure 9 shows the average value of the estimation error for the power delay profile for 1.2 μsec against the number of received long preambles when E_s/N_0 is 3 dB, where a 6-stage PN-sequence based measurement scheme (PN seq.) and the proposed scheme (Prop.) are compared. In this figure, we assumed that each packet transmits in a random channel that is based on the exponentially decaying multi-path Rayleigh model (Fig. 6), and the estimation error e between the ideal delay profile vector $\boldsymbol{v}_{ideal} \in \mathbb{R}^{N\times 1}$ and the estimated delay profile vector $\boldsymbol{v}_{est} \in \mathbb{R}^{N\times 1}$ is obtained by

$$e = \|\boldsymbol{v}_{ideal} - \boldsymbol{v}_{est}\|, \tag{2}$$

where $\|\boldsymbol{a}\|$ is a norm of $\boldsymbol{a}$ and N is the number of down-sampling of M. We assumed that the sampling rate and down-sampling rate are 100 and 20 Msample/s, respectively. Then M and N are 120 and 24, respectively. $\boldsymbol{v}_{ideal}$ is given by Fig. 6, and $\boldsymbol{v}_{est}$ is calculated by averaging the absolute and square values of the estimated CIRs. As shown in Fig. 9, the larger the number of preambles, the smaller will be the average value of the error. When the number of preambles is 100 and the number of paths is 4, the average value of the error of Prop. is approximately –4.1 dB, and the difference in the estimation error between the PN seq. and Prop. is approximately 0.3 dB. Moreover, when the number of preambles is 100 and the number of paths is 6, the average value of the error of Prop. is approximately –3.5 dB, and the difference in the estimation error between the PN seq. and Prop. is approximately 0.2 dB. Therefore, our proposed scheme can be expected to achieve almost the same performance as that of the PN sequence based measurement scheme for the exponentially decaying multi-path Rayleigh model.

V. CONCLUSIONS

This paper proposed the measurement scheme of power delay profiles using long preamble signals in IEEE 802.11g OFDM packets in the 2.4 GHz band in order to solve the cost problems associated with the PN sequence based measurement scheme. Simulation results show that the average error between the estimated and ideal delay profiles is small when the number of long preambles is large, and the proposed scheme achieves almost the same performance as that of a PN sequence based measurement scheme. Future studies will include conducting field experiences of the power delay profile measurement using an advanced proposed scheme.

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APPENDIX

A subcarrier vector of a long preamble [1] in the frequency domain $\boldsymbol{s}^{f}_{long} \in \mathbb{C}^{64\times 1}$ is converted to a partial signal vector of a long preamble in the time domain $\boldsymbol{s}_{long} \in \mathbb{C}^{64\times 1}$, which is given by

$$\boldsymbol{s}_{long} = (\boldsymbol{F}_{64})^{H} \boldsymbol{s}^{f}_{long}, \tag{3}$$

where $\boldsymbol{F}_{64} \in \mathbb{C}^{64\times 64}$ is a discrete Fourier transform (DFT) matrix.

A full signal vector of the long preamble in the time domain $\boldsymbol{s}_{full:long} \in \mathbb{C}^{160\times 1}$ is defined as

$$\begin{aligned}&\boldsymbol{s}_{full:long}\\ =\ &\left[\boldsymbol{s}_{long}(33), \ldots, \boldsymbol{s}_{long}(64),\ (\boldsymbol{s}_{long})^{T},\ (\boldsymbol{s}_{long})^{T}\right]^{T}, \end{aligned} \tag{4}$$

where $\boldsymbol{s}_{long}(k)$ is the k-th element of $\boldsymbol{s}_{long}$.

When the AP transmits $\boldsymbol{s}_{long}$ in the broadband channel, the SA receives a full signal vector of the long preamble in the time domain $\boldsymbol{r}_{full:long} \in \mathbb{C}^{163\times 1}$, which is expressed as

$$\boldsymbol{r}_{full:long} = \boldsymbol{H}\boldsymbol{s}_{full:long} + \boldsymbol{\nu}, \tag{5}$$

where $\boldsymbol{H} \in \mathbb{C}^{163\times 160}$ is the channel Toeplitz matrix from the AP to the SA when the number of delay paths is 3, and $\boldsymbol{\nu} \in \mathbb{C}^{163\times 1}$ is the noise vector in the time domain.

The l-th cross correlation value $\eta(l)$ $(1 \le l \le 100)$ for the long preamble signal in the sliding process is given by

$$\eta(l) = \left[\boldsymbol{r}^{*}_{full:long}(l), \ldots, \boldsymbol{r}^{*}_{full:long}(l+63)\right] \boldsymbol{s}_{long}. \tag{6}$$