Comb-Type Pilot Aided Channel Estimation for OFDM Systems

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***Abstract* — In this paper, a comb-type pilot arrangement method for OFDM channel estimation is investigated. Increasing the number of comb-type pilots, transmitted over a frequency selective radio channel, can decrease the data throughput while increasing the accuracy of the channel estimation. Using the LMS channel estimation and linear interpolation, we investigate the effects of number of pilots, as well as effects of channel Doppler frequency on the BER. Simulation results show that the BER improves significantly by increasing the number of pilots in fixed 4-QAM and 8-QAM modulations, as well as in adaptive loading. Moreover, the number of transmitted bits in adaptive loading is 1.8 times that of the fixed modulation of 8-QAM.**

***Index Terms* — OFDM, Channel Estimation, Pilot arrangement, LMS, Comb-Type,**

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) has been paid more attention in wireless communication systems since it has the capability of both high data rate transmission and robustness to multi-path delay. For this reason, it has been used in different wireless local area network (WLAN) standards such as IEEE 802.11a and HIPERLAN/2 [1]. Since the radio channel is frequency selective and time varying for mobile communication systems, accurate channel estimation is necessary before performing the demodulation of the OFDM signals [2].

Most channel estimation methods for OFDM systems have been developed under the assumption of a slow fading channel, where the channel transfer function is assumed to be stationary at least in some consecutive OFDM symbols (a data block). But, in practice the channel transfer function of a wideband radio channel may have significant variation even in a single OFDM data block. Therefore, it is preferable to estimate channel parameters in each OFDM data block [3].

The channel estimation can be performed by either periodically inserting pilot tones into all sub-carriers (Fig. 1) or by inserting pilot tones in a number of sub-carriers over the transmission time (Fig. 2). The first method is called block-type pilot channel estimation, in which the period of pilot insertion must be much smaller than the coherence time of the channel. In this case, channel varies slowly enough so that the channel estimation will have a good accuracy. So, if channel varies fast compared with the period of the pilot insertion, then the channel estimation may not work properly. This block-type channel estimation can be based on Least Square (LS) [4] or Minimum Mean Square Error (MMSE) [5]. The second method is called comb-type pilot channel estimation as the number of pilots used for channel estimation is usually much smaller than the number of sub-carriers. This method can be used in systems having significant channel variation over a short period of time (about one or two symbol periods). In this method, channel estimation can be based on LS, MMSE, or Least Mean Square (LMS). Since channel estimation is done only for a limited number of sub-carriers, interpolation must be used to estimate channel response over the whole channel bandwidth.

II. SYSTEM MODEL

The OFDM system model used in this work is shown in Fig. 3. In this model, first the binary information is grouped and mapped according to the modulations in the *signal mapper*. Then, using a serial to parallel converter, the signal is put on N parallel paths. After that, a given number of pilot signals (N_p), which are uniformly distributed among all N sub-carriers, are inserted into the N-point data sequence. After inserting N_p pilots into specific sub-carriers, IDFT is used to transform the N-point data sequence $\{X(k)\}$ into time domain signal $\{x(n)\}$. Following IDFT, guard time is inserted to prevent inter-symbol-interference (ISI). This guard time is chosen to be larger than the maximum time delay spread of the channel. To avoid inter-carrier interference (ICI), the guard time must include the cyclically extended part of OFDM symbol. The parallel to serial converter puts all the N-paths signals into a serial form signal. The channel is considered to have multiple paths along with additive white Gaussian noise (AWGN). As it can be seen in Fig. 3, all blocks of the receiver, except channel estimation block, do the inverse operations of the blocks used in the transmitter. More detail about this system model is given in [2].

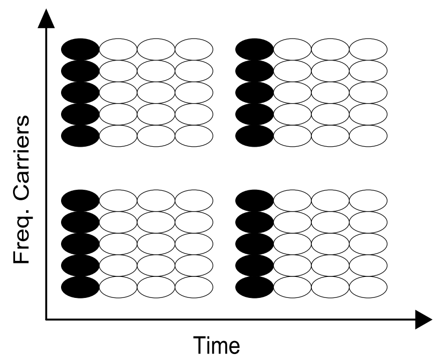

Fig. 1. Block-Type pilot arrangement

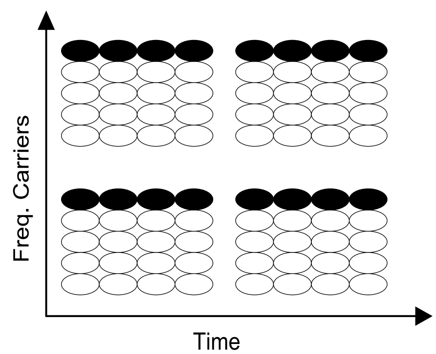

Fig. 2. Comb-Type pilot arrangement

III. CHANEL ESTIMATION AND INTERPOLATION

For channel estimation, N_p pilot signals are uniformly inserted into *{X(k)}* according to equation $X(k) = X(mL+l)$ so that $X(k) = x_p(m)$ for *l*=0 and *X(k)*=information data for *l*=1,2,…,*L*, where $L = N/N_p$ and $x_p(m)$ is the m^{th} pilot signal. If the channel frequency response at sub-carrier *k*=0, 1,…, N_p is denoted by $H_e(k)$, then the channel estimation, at sub-carrier k is given by

$$H_e(k) = \frac{Y_p(k)}{X_p(k)} \qquad (1)$$

where $Y_p(k)$ and $X_p(k)$ are the output and input at the k^{th} pilot sub-carrier, respectively.

To reduce disadvantages of the channel estimation due to ICI and noise, we propose LMS algorithm. For interpolation and channel prediction, different researchers use linear interpolation [6, 7], which is accurate enough for this purpose. For this reason, we use linear interpolation for channel prediction using the estimated values by the LMS algorithm.

IV. SIMULATION

In our simulation we consider a 4-tapped channel with additive white Gaussian noise (AWGN). The channel is assumed to be frequency selective fading. The attenuation in each path is valued by a Rayleigh random variable. For the phase of each tap, a uniform distribution over $[0, 2\pi]$ is considered. Also, we assume that the channel remains unchanged during each symbol interval, but it may change from one symbol to another.

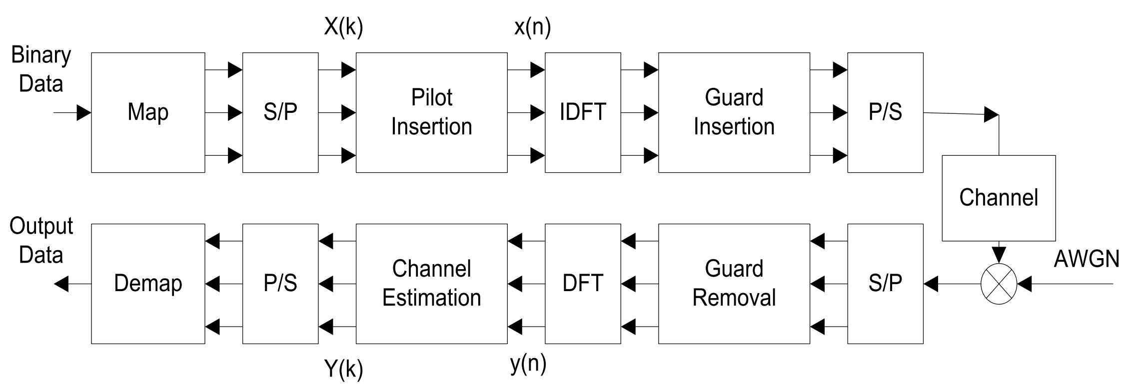

Fig. 3. OFDM pilot aided channel estimation system

Since a number of correlated channels is desired, the random phase is held constant during one simulation iteration, and a number of correlated Rayleigh random variables is generated for taps' magnitudes. The autocorrelation of each tap is characterized by a given Doppler frequency. One efficient method for generating correlated Rayleigh random variables is given in [8]. This method is briefly shown in Fig. 4. The LMS algorithm is used to estimate the channel impulse response from the pilots.

One of the advantages of the OFDM system is that we can change the amount of transmitted bits in each sub-channel (frequency) considering the attenuation of that sub-channel. To increase the throughput in our system, it is preferable to transmit more bits at frequencies in which the channel has lower attenuation and assign less number of bits to sub-carriers having more attenuation. This is called adaptive loading.

The normalized Doppler frequency is defined as

$$f_d = \frac{\phi_d}{\phi_s} \tag{2}$$

where ϕ_s is sampling frequency and ϕ_d is maximum Doppler frequency and we have

$$\phi_d = \frac{v}{\lambda} \tag{3}$$

where v is the relative velocity of the transmitter with respect to the receiver and λ is the carrier wavelength.

For example, if the sampling frequency is 640 KHz and the number of sub-carriers is 32, the normalized Doppler frequency $f_d = 0.01$ results in the maximum Doppler frequency of

$$\phi_d = \frac{1}{2} \times 0.01 \times \frac{640\text{KHz}}{32} = 100\text{Hz} \tag{3}$$

In our simulation we consider 2 pilots and the total number of sub-carriers N is assumed to be 32. Fig. 5 shows that this method works well for low Doppler frequencies ($f_d < 0.01$), but for high Doppler frequencies ($f_d > 0.01$) the bit error rate (BER) increases. We can also see that for low Doppler frequencies, the increase of BER is proportional to the Doppler frequency. The slope of BER curve has larger values for normalized Doppler frequencies having values of less than 0.01. This means that BER variation is more sensitive to the variation of the Doppler frequencies having small values. For higher normalized Doppler frequencies, this slope decreases significantly and for $f_d > 0.05$ we almost have a flat line. So, for $f_d > 0.01$ the channel estimation is not precise enough to provide a small BER.

We can see in Fig. 5 that the BER for adaptive loading has larger values compared with those of other modulations. This larger BER is the cost of transmitting more bits by adaptive loading. For the values used in this simulation we can transmit about 1.8 times the number of bits transmitted in 8-QAM.

Fig. 6 shows effect of increasing the number of pilots on the BER. It can be seen that by increasing the number of pilots, the BER decreases, but the price we would pay is the reduction in the number of transmitted data bits due to occupying more bandwidth by the pilots.

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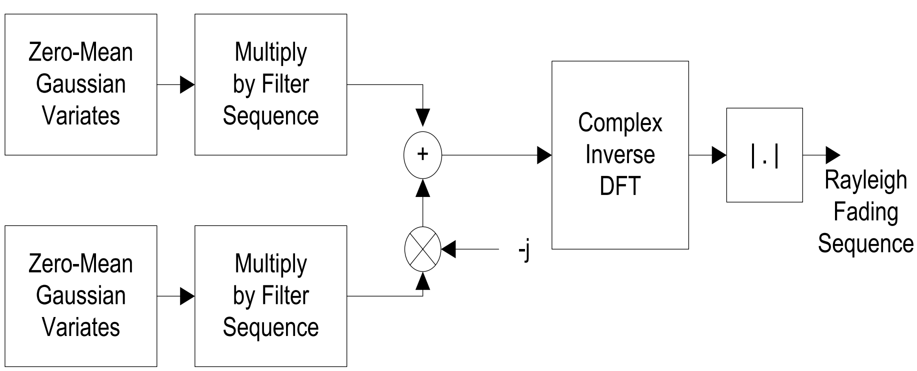

Fig. 4. The procedure of generating correlated Rayleigh random variables

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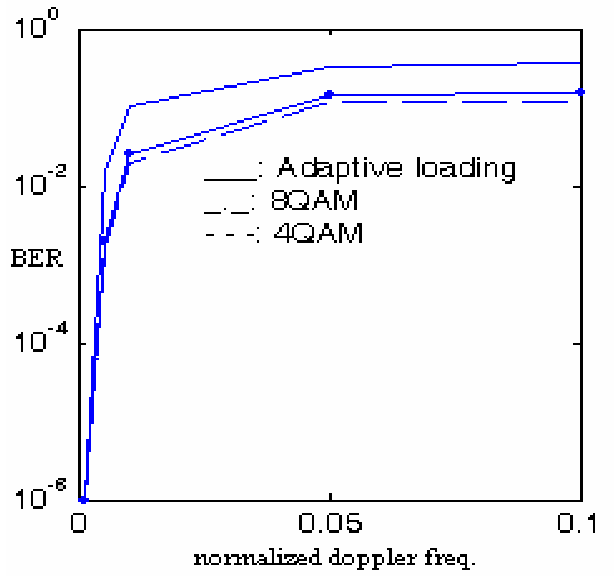

Fig. 5. BER vs. Doppler frequency

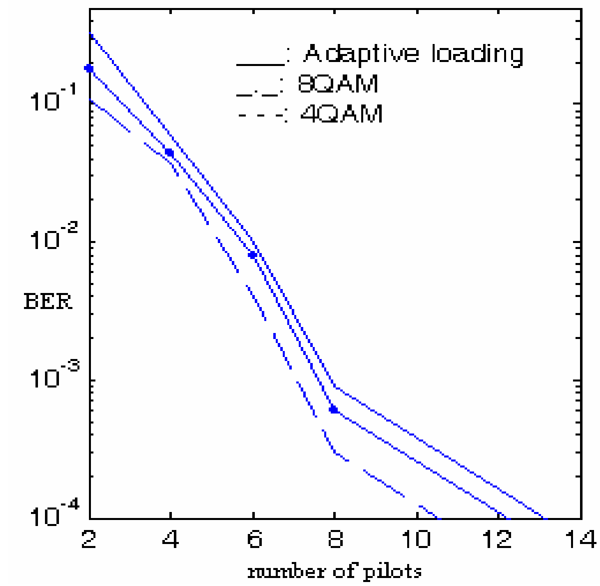

Fig. 6. BER vs. number of pilots

V. CONCLUSION

In this paper, a method based on comb-type pilot aided channel estimation was investigated. We used the LMS algorithm and linear interpolation for channel estimation (from the pilots) and prediction, respectively. The simulation results show that this method works well for Doppler frequencies having small values. However, by increasing the value of Doppler frequency, the quality of the channel estimation decreases, which results in the degradation of the BER. Moreover this method has better performance for low level data modulations, and by using higher level modulations, the BER increases.

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