Channel Estimation for OFDM Systems Based on Adaptive Radial Basis Function Networks

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***Abstract*— In this paper, we investigate new radial basis function (RBF) networks for channel estimation for pilot symbol aided orthogonal frequency division multiplexing (OFDM) systems. One-dimensional RBF networks and RBF network interpolation channel estimators are proposed. The latter can reduce the redundancy and guarantee a high transmission rate. Computer simulation demonstrates that our proposed channel estimators exhibit an improved performance compared to the conventional linear channel estimation methods in fast fading channels. They have robust performance when the normalized fading rate ranges from 0.001 to 0.2.**

I. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) has received considerable interest in wireless research recently. It has been used in wireless LAN standards such as high performance radio local area network (HIPERLAN) and IEEE802.11a. For wideband mobile communication systems, the radio channel is frequency selective and time variant. Therefore, channel estimation constitutes an essential feature of high-performance receivers.

Pilot-symbol-aided channel estimation has become popular for OFDM systems [1]. Channel estimation techniques using different pilot types have been analyzed in [2]. Pilots can be arranged as block-type and comb-type. The block-type pilots are suitable for a slow fading channel. Some OFDM symbols consisting of pilot subcarriers entirely are transmitted periodically. Channel interpolation in frequency domain is thus not required. Channel estimation is based on Least Square (LS) or Minimum Mean-Square (MMSE) [1], [3]. In comb-type pilots, several pilot subcarriers are evenly distributed in each OFDM symbol. The comb-type pilot channel estimation consists of channel estimation at pilot subcarriers and channel interpolation in frequency domain. The approach provides a better resistance to a fast fading channel. Meanwhile two dimensional channel estimation by Wiener filtering is proposed in [4].

The radial basis function network is one of the most used neural network models and is useful for approximating continuous functions. They have been used for channel equalization [5]. RBF equalizers with MMSE have shown better performance than the ones with LS. RBF networks can also be used for channel estimation, considering the anti-noise property of the RBF networks. In [6], one-dimensional and two-dimensional RBF networks have been developed for the estimation of frequency selective fading channel for OFDM systems. The two channel estimation techniques are based on block-type pilot arrangement. In this paper, we develop a one-dimensional RBF channel estimators for comb-type pilots. Pilot symbols are used to train the networks adaptively. The RBF networks act as non-linear channel estimators. We also introduce a new pilot symbol arrangement, which reduces the redundancy and allows a high transmission rate. Furthermore, we develop a channel estimation algorithm for this pilot arrangement, which is based on RBF network parameter interpolation. The parameters of the RBF networks of two OFDM symbols with pilots are interpolated linearly between the two symbols. Simulation results over fast fading channels show that they have significant improvement over previous channel estimation methods.

The paper is organized as follows. Section II describes OFDM system and pilot channel estimation. Section III develops two RBF channel estimators. The simulation environment and results are given in Section IV. Section V presents the conclusion.

II. System Description

Fig. 1 shows a typical block diagram of an OFDM system with pilot symbols. The binary source data are grouped and mapped into multi-amplitude and multi-phase signals. In this paper, we use quadrature phase-shift keying (QPSK).

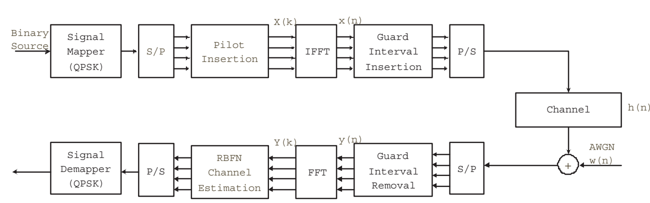

Fig. 1. OFDM system with pilot-symbol-aided channel estimation

After the pilot insertion, the complex data are modulated by inverse discrete Fourier transform (IDFT) on N parallel subcarriers. The resulting time-domain samples are

$$\begin{aligned} x(n) =& \text{IDFT}\{X(k)\}, \quad n = 0, 1, 2, \cdots, N-1 \\ =& \sum_{k=0}^{N-1} X(k) e^{j(2\pi kn/N)}. \end{aligned} \tag{1}$$

The guard interval is inserted to prevent inter-symbol interference. The guard interval includes the cyclic prefix, and the resulting time-domain samples are:

$$x_g(n) = \begin{cases} x(N+n), & n = -N_g, -N_g+1, \cdots, -1 \\ x(n), & n = 0, 1, \cdots, N-1 \end{cases} \quad (2)$$

where N_g is the number of samples in the guard interval. The transmitted signal is sent over a frequency selective time varying fading channel. The received signal is given by

$$y_g(n) = \sum_{l=0}^{r-1} h(n;l) x_g(l) + w(n) \quad (3)$$

where $w(n)$ is an Additive White Gaussian Noise (AWGN) sample; $h(n;l)$ represents the sampled time-varying channel impulse response (which combines the transmit filter $g(t)$ with the physical channel $h_c(t;\tau)$); r is the total number of propagation paths. Each channel path is complex Gaussian and the power spectrum is determined by the Doppler frequency f_D.

At the receiver, after removing guard interval from $y_g(n)$, DFT demodulation of $y(n)$ gives

$$\begin{aligned} Y(k) = & \text{DFT}\{y(n)\}, \quad k = 0, 1, 2, \cdots, N-1 \\ = & \frac{1}{N} \sum_{n=0}^{N-1} y(n) e^{-j(2\pi kn/N)}. \end{aligned} \quad (4)$$

The pilot symbols are extracted and the channel transfer function $H(k)$ is estimated in the channel estimation block. The transmitted data symbols can be estimated using

$$\hat{X}(k) = \frac{Y(k)}{\hat{H}(k)} \quad (5)$$

where $\hat{H}(k)$ is an estimate of $H(k)$. After signal demapping, the binary information data are obtained at the receiver output.

III. CHANNEL ESTIMATION

We now present two channel estimators for the system model in Section II. These estimation techniques are based on RBF networks.

A. One-dimensional RBF network channel estimation

The one-dimensional RBF network in [6] is based on block-type pilot arrangement, which is suitable for a slow fading channel. In our case the pilot signals are arranged in comb-type (Fig.2 (a)). It can be used for a fast fading channel. The N_p pilots are uniformly inserted into $X(k)$ according to

$$X(k) = \begin{cases} p_k, & k \in I_p \\ d_k, & k \notin I_p \end{cases} \quad (6)$$

where I_p is the index set of subcarriers reserved for pilot symbols. Here we define $\tilde{H}(k)$, $k \in I_p$ as the channel response of pilot subcarriers. Then the channel estimation at pilot subcarriers based on the LS criterion is given by:

$$\tilde{H}(k) = \frac{Y(k)}{X(k)}, \quad k \in I_p. \quad (7)$$

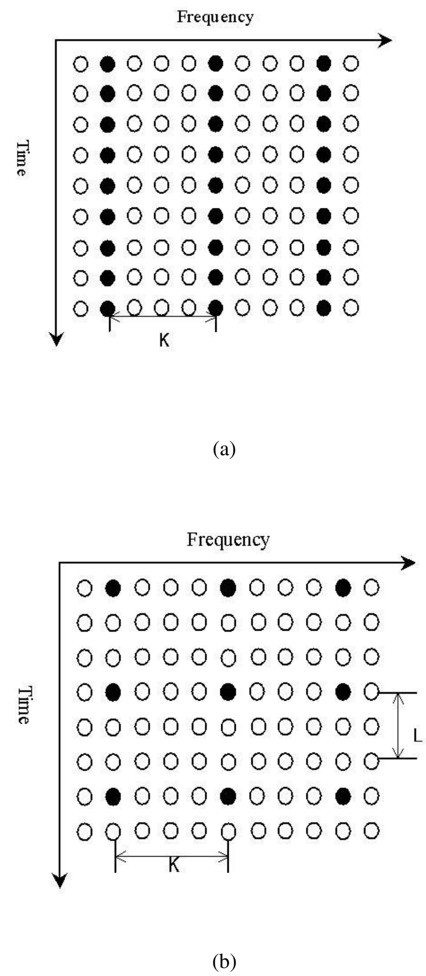

Fig. 2. Pilot arrangement

Next, an RBF network is used to represent the frequency response of the channel at all subcarriers. The channel response is given by

$$\hat{H}(n) = \sum_{k \in I_p} w(k) \phi_k(n) = \sum_{k \in I_p} w(k) \phi(\frac{|n - \mu_k|^2}{\sigma_k^2}) \quad (8)$$

where $\phi(x)$ denote the Gaussian function, $w(k)$ output layer weight, μ_k center and σ_k center spread parameter respectively. The RBF network is trained using the pilot subcarriers and the least-mean-square (LMS) algorithm. The error signal $e(k)$ is obtained using the pilot subcarriers as

$$e(k) \triangleq Y(k) - \hat{H}(k) X(k), \quad k \in I_p \quad (9)$$

The initial value of the network parameters are set: $w(k) = \tilde{H}(k) \left\{ \phi_k(k) / \sum_{i \in I_p} \phi_i(k) \right\}$, $\mu_k = k$, and $\sigma_k = 0.5N/N_p$, $k \in I_p$.

When the RBF network is trained via the LMS algorithm, the channel response at all subcarriers is given by (8).

B. RBF network parameter interpolation for channel estimation

Eq. (8) uses the fact that the channel can be represented by an RBF network. That is, the RBF parameters can be chosen so as to represent the channel response. The RBF representation (8) exploits only the channel correlation structure in the frequency domain. For better performance, it is reasonable to exploit both the time and frequency correlations. Here we use the pilot pattern shown in Fig. 2(b). The pilots are spaced in K in time.

To apply an RBF network with this pilot pattern, a parameter interpolation method is proposed. As the parameters of the RBF network can represent the channel response, they can be linearly interpolated in time domain instead of interpolating the frequency response at the pilot symbols directly. This linear interpolation is given by

$$\begin{aligned} w_i(k) &= (w_i(m+1) - w_i(m))\frac{k}{K} + w_i(m) \\ \mu_i(k) &= (\mu_i(m+1) - \mu_i(m))\frac{k}{K} + \mu_i(m) \\ \sigma_i(k) &= (\sigma_i(m+1) - \sigma_i(m))\frac{k}{K} + \sigma_i(m) \end{aligned} \qquad (10)$$

where $mK < k < (m+1)K$. That is what we call parameter interpolation. A RBF network can be constructed at each frame to represent the channel response. We reduce the redundancy using interpolation and get a flexible tradeoff between computational complexity and the symbol error rate (SER) performance. The training of RBF networks at the pilot frames is the same as the training algorithm in the RBF estimator (8).

IV. SIMULATION

A. Simulation Parameters

The simulation parameters used in the OFDM system are shown in Table 1. The guard interval is assumed larger than the maximum delay spread of the channel. Simulations are carried out for different SNR and different Doppler spreads.

TABLE I

SIMULATION PARAMETERS

Parameters	Specifications
Number of Carriers (N)	1024
Pilot Ratio	1/8
Guard Interval	256
Guard Type	Cyclic Extension
Bandwidth	10M
Signal Constellation	QPSK

B. Channel Model

In this paper, a six-ray multipath fading channel in the ATTC and the Grande Alliance DTV Laboratory's ensemble A model [7] is considered. The parameters are as follows: the relative delays are 0, 0.2, 1.9, 3.9, 8.2 and 15(μs); the average powers are 0, 20, 20, 10, 14 and 18(dB). The power spectrum of the fading processes follows the classical Jakes' model.

C. Simulation Results

We compare several channel estimation methods: LS estimate of pilot with linear interpolation, LS estimate of pilot with linear interpolation through a low pass filter, LS estimate of spline interpolation, LS estimate of cubic interpolation, LS estimate of sinc interpolation in this section.

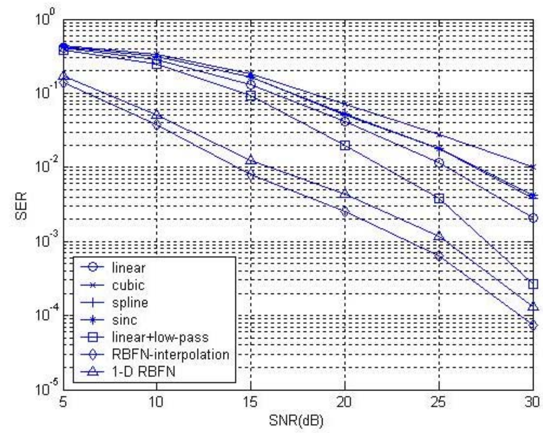

Fig. 3. SER versus SNR with Doppler frequency 53 Hz

Fig. 3 gives the SER performance of channel estimation algorithms for a time-variant frequency-selective fading channel with a Doppler frequency of 53Hz and OFDM parameters given in Table 1. The RBF network (8) has the best performance among all the methods and a gain of 5dB over other methods. Simulation results show that the SER rapidly declines for SNR greater than 30dB with the RBF estimators without priori channel information.

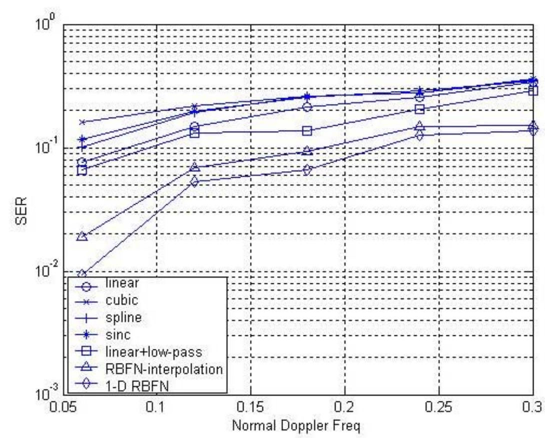

Fig. 4. SER versus Normal Doppler frequency with SNR 15dB

Fig. 4 shows the SER performance as a function of the normalized Doppler $f_D T$, with fixed 15dB. The RBF network has a robust performance when the fading rate ranges from 0.06 to 0.2, and it is better than other methods. The RBF network achieves the best performance in fast fading channels. In summary, we find that the RBF network and the RBF parameter interpolation proposed in this paper are especially effective in fast fading channels. Other interpolation methods are not as effective compared as our proposed estimators. The RBF networks developed in [6] based on block-type pilot arrangement may not work at high fading rates due to the estimates of the channels at pilot positions being corrupted by interchannel interference. The proposed RBF channel estimators are based on comb-type pilot arrangement. Hence, they perform well in relatively fast fading channels, without knowing the channel statistics.

V. CONCLUSION

We have developed new RBF channel estimators for OFDM over a time-variant frequency-selective fading channel. Our proposed estimators are essentially nonlinear interpolators of the pilot subcarriers. Compared with the existing OFDM channel estimators using linear filtering, our proposed methods offer robustness to different Doppler rates, and perform better in relatively fast fading channels without knowledge of channel statistics.

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