Kamal Thakur et al. International Journal of Recent Research Aspects ISSN: 2349-7688, Vol. 4, Issue 3, Sept 2017, pp. 71-74

Arrangement of Pilot Tones in Wireless OFDM Systems

Kamal Thakur, Tanu Arora

Department of ECE, Gurgaon Institute of Technology and Management, Gurgaon

***Abstract*— In this paper, we analyze different pilot patterns in terms of resulting bit error rate, and propose a new scheme of transmitting pilot symbols in wireless OFDM system. Rearrangement of the pilot pattern enables a reduction in the number of needed pilot symbols which in turns reduces the transmission overhead still retaining the same performance. The question is where and how often to transmit pilot symbols, so that the spacing between the pilot symbols shall be small enough to enable reliable channel estimates but large enough not to increase the overhead too much.**

Keywords*—*OFDM, Channel Estimation

I. OFDM SYSTEM MODEL

Modulation The basic baseband-equivalent OFDM system is shown in Figure 1. Each OFDM symbol consists of a packet of N data points that are carried on N frequency tones respectively. IFFT block is used at the transmitter to transform the data sequence $X(k)$ of length N into time domain signal $\{x(n)\}$ with the following equation:

$$x(n) = IDFT\{X(k)\} \quad n = 0,1,2,\ldots.N-1$$
$$= \sum_{k=0}^{N-1} X(k) e^{j\frac{2\pi kn}{N}} \quad (1)$$

where N is the FFT length. Following IFFT block, cyclic prefix, which is chosen to be greater than the expected delay spread of the channel, is inserted to prevent ISI [1]. This cyclic prefix includes the cyclically extended part of OFDM symbol in order to eliminate intercarrier interference (ICI) [2]. As pointed out in [3], the cyclic extension makes the linear convolution of the channel looks like circular convolution inherent to the discrete Fourier domain, as long as guard time duration is longer than the delay spread of the multipath channel.

The resultant OFDM symbol is given as follows:

$$x_f(n) = \begin{cases} x(N+n), & n = -GI, -GI+1, \ldots., -1 \\ x(n), & n = 0,1,2,\ldots., N-1 \end{cases}$$
(2)

where GI is the length of the guard interval. The transmitted signal $x_f(n)$ pass through the frequency selective time varying fading channel with additive white gaussian noise. The received signal is given by:

$$y_f(n) = x_f(n) \otimes h(n) + w(n)$$
(3)

Where $w(n)$ is Additive White Gaussian Noise (AWGN) and $h(n)$ is the channel impulse response. Channel is assumed to be slowly fading, so it is considered to be constant during one OFDM symbol. Under these conditions we can describe our system as a set of parallel Gaussian channels, shown in Figure 2, with correlated attenuations $h(n)$. At the receiver, cyclic prefix is removed:

$$y(n) = \begin{cases} y_f(n), & for\ n = -GI \le n \le N-1 \\ y_f(n+GI),, & n = 0,1,2,\ldots., N-1 \end{cases}$$
(4)

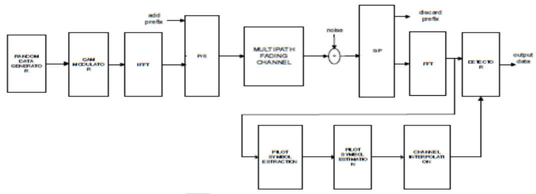

Fig 1: OFDM System Used in simulations

DAB standard. The drawbacks are about a 3 dB noise enhancement, and inability to use efficient multiamplitude constellations. An interesting alternative of DPSK is differential amplitude phase shift keying, where a spectral efficiency greater than DPSK is achieved by using a differential coding of amplitude as well. Obviously, this requires a non-uniform amplitude distribution. However, in wired systems, where channel is not changing with time, coherent modulation is an obvious choice. But, in wireless systems, the efficiency of coherent modulation makes it an ideal choice when the bit error rate is high, such as in DVB [4]

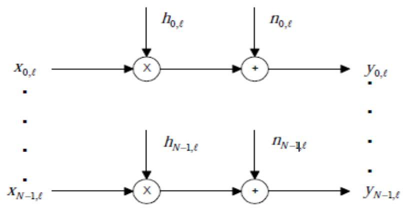

Fig 2: OFDM system, described as a set of parallel Gaussian Channels with correlated attenuations

Then $y(n)$ is sent to FFT block for the following operation:

$$Y(k) = DFT\{y(n)\}$$
$$= \frac{1}{N} \sum_{k=0}^{N-1} y(n) e^{-j\frac{2\pi kn}{N}}$$
(5)

Assuming there is no ISI, in it was shown that the relation of the resulting $Y(k)$ to $H(k)$, $I(k)$ that is ICI because of Doppler frequency and $W(k)$, with the following relation [5]:

$$Y(k) = X(k)H(k) + I(k) + W(k) \quad k = 0,1,2,\ldots,N-1 \quad (6)$$

Following FFT block pilot signals are extracted and the estimated channel $H_e(k)$ at pilot sub-channels is obtained. Then the transmitted data is estimated by:

$$X_e(k) = \frac{Y(k)}{H_e(k)} \qquad k = 0,1,2,\dots,N-1$$

(7)

A. Channel Model Used in Simulations

We are using a fading multipath channel model [8], consisting of M paths

$$g(\tau) = \sum_{k=0}^{N-1} \alpha_k \delta(t - \tau_k T_s) \qquad (8)$$

where α_k are Rayleigh distributed channel taps whose fading is based on Jake's model [6] with an exponential power delay profile $\theta(\tau_k)$, defined as

$$\theta(\tau_k) = Ce^{-\frac{\tau}{\tau_{rms}}} \qquad (9)$$

where $\tau_{rms}$is the RMS-value of power delay profile. In this paper, we have used $M = 2$paths, in which the first fading path always has a zero-delay $\tau_0 = 0$, and other fading path has delay that is always less than the length of guard interval GI

The channel estimation is based on pilots transmitted at certain positions in the time frequency grid of the OFDM system. The channel attenuations are estimated by means of interpolation between these pilots, where we assume that the channel estimator can use all transmitted pilots. This is the case in, e.g. broadcasting or in the downlink of a multiuser system. Channel attenuations in neighboring time frequency grid points are highly correlated, a feature that can be used to channel estimation.

Our scenario consists of a wireless 16-QAM OFDM system, designed for an outdoor environment that is capable of carrying digital video. The system operates at 500 kHz bandwidth and is divided into 64 tones with a total symbol period of 136$\boldsymbol{\mu s}$ of which 8$\boldsymbol{\mu s}$ is the cyclic prefix. Our OFDM symbol thus consists of 68 samples ($N + GI = 68$), four of which are contained in the cyclic prefix($GI = 4$).

The uncoded data rate of the system is1.9$MBPS$. We assume that $\tau_{rms} = 1$ sample for the channel considered.

B. Problem Formulation

The transmitter uses certain tones, so called pilot tones, in some particular symbols to transmit known data. The channel impulse response can be estimated using LS or LMMSE criterion, given knowledge of transmitted and received signals. The questions that arise are:

1. How many pilot tones are needed per symbol for estimation?

2. What pattern of pilot tones are better than others? Which tones should be used as pilot tones, and what is the impact of pilot tone selection on the quality of estimate?

3. How does a scheme that uses some tones as pilot tones in each symbol (comb) can compare with a scheme that uses all tones as pilot tones (block) in some symbols? And how block and comb arrangements can be compared with the proposed arrangement of pilots?

II. Number of Pilot Tones

One of the important question is about number of pilot tones per symbol needed for channel estimation.

Theorem: In the absence of noise, any GI of the N available tones can be used for training to recover the channel h exactly.

Proof: Let $\{k_1, k_2, \dots . k_{GI}$ be the set of GI tones used for transmitting training data. The channel gains of these tones can be found exactly as $\boldsymbol{H}_{k_i}$=$\boldsymbol{R}_{k_i}$. Collect these gains in a vector $\boldsymbol{H}^p = (k_1, k_2, \dots, k_{GI})^T$. Then we can write

$$\boldsymbol{H}^p = \begin{bmatrix} 1 & W_N^{k_1} & \dots & W_N^{k_1(GI-)} \\ 1 & W_N^{k_2} & \dots & W_N^{k_2(GI-)} \\ \dots & \dots & \dots & \dots \\ 1 & W_N^{k_{GI}} & \dots & W_N^{k_{GI}(GI-)} \end{bmatrix} \qquad (10)$$

where $W_N^k = e^{-j2\pi k/N}$

Since the matrix is a Vandermonde matrix with all parameters GI distinct, therefore it is non-singular [8], and hence h can be found exactly by inverting it. Also, with less than GI pilot tones, we have an under-determined system of linear equations, which results in a non-unique solution h.

III. Proposed Pattern of Pilot Tones

Channel estimation can be performed by either inserting pilot symbols into all subcarriers of OFDM symbols with a specific period (block arrangement) or inserting pilot tones into each OFDM symbol (comb arrangement) [9]. Block pilot patterns are effective in slow varying channels, and underlying assumption is, channel transfer function changes very slowly. However, comb type arrangement works well in fast varying channels, therefore, comb patterns can be used easily for tracking fast channels. In comb patterns, every OFDM symbol have some known data, i.e., pilots, in contrast to block patterns, where some specific OFDM symbols have pilots.

To minimize the bit error rate, it is desirable to spread the pilot symbols in both time and frequency, in contrast to block and comb, in which pilot symbols are transmitted in frequency and time, respectively, but not too far apart in case of fast fading. Here, we propose that instead of sending all pilots in one OFDM symbol or sending pilots in all OFDM symbols, better way is to spread the pilots in time and frequency, as shown in Figure 3. Simulation result shows that it works well especially in slow varying channels.

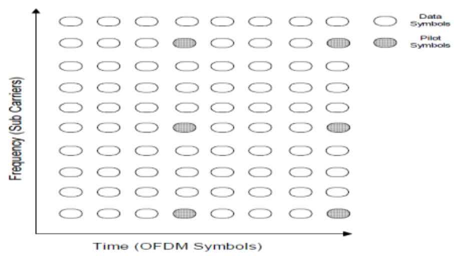

Fig 3: Proposed pilot Arrangement

IV. Simulation Results and Discussions

For all simulations, we assume that:

-Cyclic Extension of OFDM symbols are used as guard interval.

-The channel impulse response is shorter than the cyclic prefix to avoid ISI.

-Transmitter and Receiver are perfectly time synchronized.

-Channel is assumed to remain unchanged during one OFDM symbol, to avoid ICI.

All simulation parameters are shown in table 1.

Parameter	***Specifications***
Number of Subcarriers	64
IFFT and FFT Size	64
Length of Guard Interval	4 samples
Guard Type	Cyclic Extension
Modulation Type	16-QAM
Bandwidth	500kHz
Pilot Ratio	1/8
Channel Taps 2	2
Channel Taps PDF	Exponential
Channel Model	Rayleigh Fading

Table 1: Simulation Parameters

As mentioned earlier, we assume perfect synchronization since the aim is to observe channel estimation performance. Similarly, we consider pilot ratio of 1/8, which is quite sufficient, and here our basic purpose is to compare different arrangements. For comparison purposes, same number of pilots are use in all schemes. Simulations are carried out for different signal to noise ratios and for different Doppler frequencies. For block-type pilot channel estimation, we assume that each block consists of a fixed number of OFDM symbols, which is 8 in our case. Pilots are sent at all subcarriers of the first symbol of each block and channel estimation is performed by using LS and LMMSE estimation. Channel estimated at the beginning of the block is used for all of the following symbols of the block. LMMSE estimation performs better than LS estimation, and according to [7], it gives improvement of 10 – 15 dB in SNR. Simulation results are shown in Figure 4.

It is clear from Figure 4, for nominal value of BER for block-type pilot signal estimation, LMMSE estimation promises improvement of around 10 - 12 dB over LS estimation.

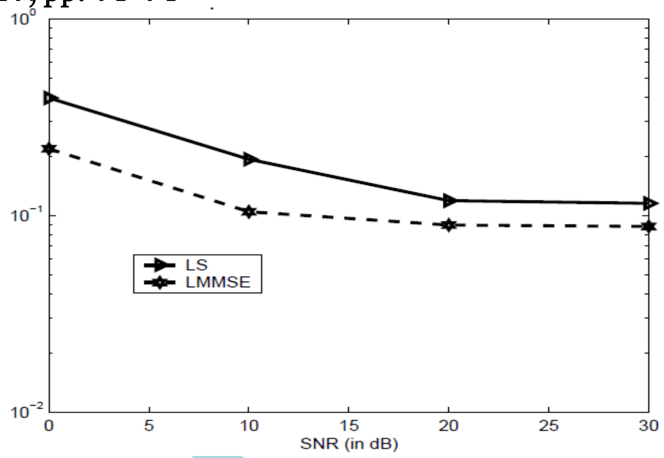

Fig 4: Comparison of LS and LMMSE Estimation in block-type pilot Signal Estimation

In comb-type pilot signal estimation, channel is estimated at pilot frequencies by using LS estimation. After having estimates of channel at pilot frequencies, channel attenuations and phases at data locations can be obtained by using channel interpolation techniques, already discussed in Chapter 4. Channel is estimated at data symbols, by means of an interpolation filter, that uses the following interpolation techniques:

1. Linear Interpolation
2. Spline Interpolation
3. Cubic Interpolation
4. Low Pass Interpolation

These result are expected since the low pass interpolation used in simulations does the interpolation such that the mean square error between the interpolated values and there ideal values is minimized. From Figures 5, 6 and 7 it is clear that comb arrangement can track variations of fast varying channels. It is also consistent with the logical reasoning, because in comb arrangement pilots are transmitted in every OFDM symbol, and hence it allows tracking of fast fading channels.

At lower values of Doppler frequencies, performance of the proposed scheme is better than any other pilot transmitting scheme, as shown in Figure 5. So it is recommended that in slow varying environments, it is much better to spread pilots symbols in time and frequency, instead of sending them along time or frequency separately. In slow varying channels, the proposed scheme works well for all values of SNR as shown in Figure 5. However, with the increase of Doppler frequency, proposed scheme works well only at higher values of SNR, as shown in Figure 6. For lower values of SNR, performance of lowpass-comb arrangement is better than equidistance arrangement. For highly

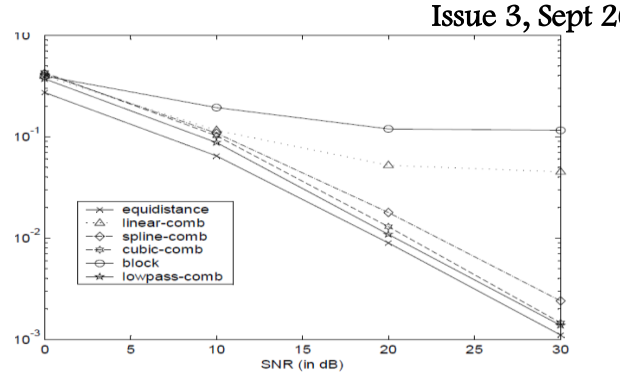

Fig 5: Comparison of channel estimation algorithms, for different pilot arrangements (Doppler freq. 10 Hz)

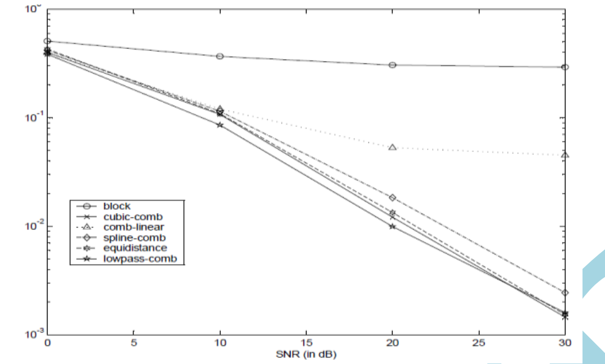

Fig 6: Comparison of channel estimation algorithms, for different pilot arrangements (Doppler freq. 70 Hz)

varying channels, e.g. at Doppler frequency of 240 Hz, the performance of lowpass comb is better for all values of SNR, as shown in Figure 7. From the above discussion, it is clear that

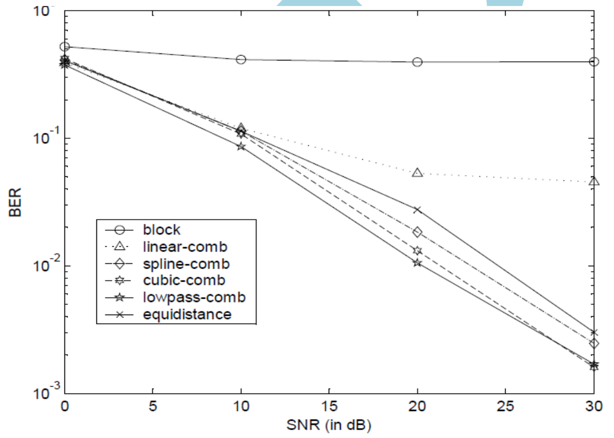

Fig 7: Comparison of channel estimation algorithms, for different pilot arrangements (Doppler freq. 240 Hz)

proposed arrangement of pilot symbols is an excellent choice for lower values of Doppler frequencies.

REFERENCES

[1] Eric Lawry, The suitability of OFDM as a modulation technique for wireless telecommunications, with a CDMA comparison. PhD thesis, James Cook University, October 1997. J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68-73.

[2] I. A. Peled and A. Ruiz, “Frequency Domain Data Transmission using Reduced Computational Complexity Algorithms,” Procedings of International Conference on Acoustics, vol. 3, pp. 964–967, April 1980.

[3] H. Sari, G. Karam, and I. Jeanclaude, “Transmission Techniques for Digital Terrestrial TV Broadcasting,” IEEE Communications Magazine,, pp. 100–109, February 1995

[4] D. video broadcasting systems, “Digital Broadcasting Systems for Television, sound and data services,” European Telecommunications Standards Institute, April 1996.

[5] MEng-Han Hieh and Che-Ho Wei, “Channel Estimation for OFDM Systems based on COMB-Type Pilot arrangement in frequency selective fading channels,” IEEE Trans. on Commun., 2000.

[6] W. Jakes, Microwave Mobile Communications. Wiley-Interscience USA, 1974.

[7] Louis L. Scharf, Statistical Signal Processing. Addison-wesley Publishing Company, 1991.

[8] R. A. Horn and C. R., Matrix Analysis. Cambridge University Press, 1990.

[9] Sinem Coleri, Mustafa Ergen, Anuj Puri and Ahmad Bahai, “Channel Estimation Techniques based on Pilot Arrangement in OFDM systems,” IEEE Transactions on Broadcasting, September 2005.