Equalization for Burst OFDM Systems in Multipath Fading Channels

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Abstract: In this paper, we analyze the channel estimation method by using Reference symbols for burst OFDM transmission systems. We set some parameters (the number of Reference symbols, the pilot spacing in Reference symbols, the update constant of equalizer coefficients) to evaluate their performance in the fixed multipath fading channel as like indoor environment.

1. Introduction

OFDM(Orthogonal Frequency Division Multiplexing) is one of the multi-carrier modulation techniques that transmit data with several carriers. Because of long symbol duration and presence of the guard interval, OFDM system is immune to multipath channel, robust to impulse noise and requires relatively simple equalizer structure [1]. OFDM technique is being applied extensively to high data-rate digital transmission, such as digital audio/video broadcasting and wireless LANs [1]-[7]. Recently various methods which OFDM is applied to burst transmission are actively suggested [3]-[7]. For a packet type of high data-rate burst transmission, a rapid synchronization and channel estimation is essential.

In this paper, we will analyze the equalization method for burst OFDM systems by using Reference symbols, which are placed at the head of the transmitted packet.

2. OFDM System model

2.1 Baseband OFDM system model

OFDM modulator and demodulator with IFFT(Inverse Fast Fourier Transform) and FFT respectively are depicted in Figure 1. Samples of OFDM signal generated by IFFT can be represented as [8]

$$x_n(m) = IFFT\{X_k(m)\} = \sum_{k=-N/2}^{N/2-1} X_k(m) e^{j2\pi kn/N}, \quad n = -G, -G+1, \ldots, 0, 1, \ldots, N \tag{1}$$

where $X_k(m)$ is subsymbol(e.g., from M-QAM constellation) for k[th] subcarrier of m[th] OFDM symbol and n is sample index of the OFDM symbol. The size of IFFT is denoted by N, which is also the total number of subcarriers as well as the number of samples in the useful data interval and G is the number of samples in the guard interval. When samples $x_n(m)$ are passed through a channel, $h_n(m)$, with additive noise, $w_n(m)$, the received samples, $z_n(m)$, can be expressed as

$$z_n(m) = x_n(m) \otimes h_n(m) + w_n(m) \tag{2}$$

where $\otimes$ means convolution operator.

After removing the guard interval, the receiver demodulates received samples by using FFT defined by

$$Z_k(m) = FFT\{z_n(m)\} = \frac{1}{N}\sum_{n=0}^{N-1} z_n(m) e^{-j2\pi kn/N}, \quad k = -N/2, \ldots 0, \ldots, N/2-1 \tag{3}$$

Eq.(2) can be expressed in frequency domain as

$$Z_k(m) = X_k(m) H_k(m) + W_k(m) \tag{4}$$

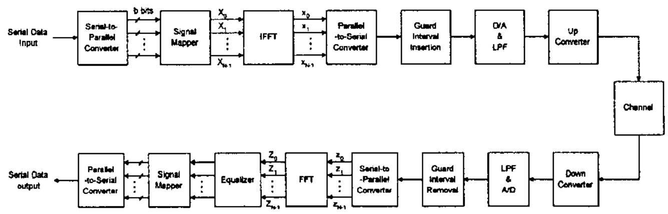


Figure 1. Block diagram of OFDM system

2.2 General frame structure

The general frame structure for burst transmission depicted in Figure 2 consists of Reference symbols and Data symbols. The first some Reference symbols are used for signal detection, AGC(automatic gain control), timing synchronization and frequency synchronization, which the number of symbols are defined 1 to 2 for the various specifications [3]-[7]. The other Reference symbols are used for channel estimation, which the number of symbols is defined 1 to 2. Therefore the number of total Reference symbols becomes 2 to 4 [4],[6],[7]. Data symbols include the transmitted data. Each Reference symbols and Data symbols consists of the guard interval and the useful data interval and Data symbols have data-subcarriers and pilot subcarriers. In this paper, we focus on the channel estimation by using Reference symbols.

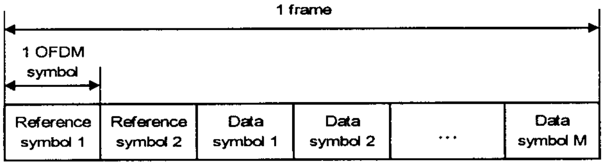


Figure 2. General frame structure

2.3 Channel model

Figure 3 shows the channel model used in this paper, which the length of the delay spread is 7 samples. The length of guard interval, G, and useful data interval, N are 16 and 64 samples respectively. The length of the channel delay spread is shorter than that of guard interval.

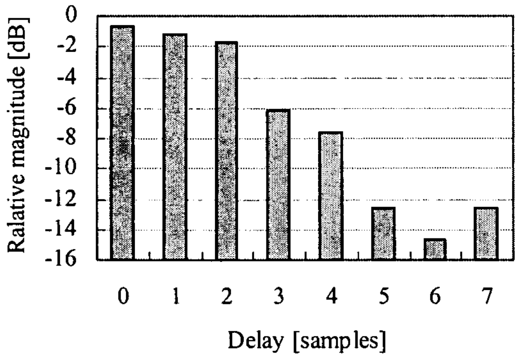


Figure 3. Channel delay and attenuation

3. Channel estimation for burst transmission

3.1 Channel estimation scheme

The equalizers are initialized after receiver carries out synchronization by using a known Reference symbol, $X_k(m)$, and by calculating the initial value for equalizer coefficients from

$$\hat{C}_k(m) = \frac{1}{\hat{H}_k(m)} \approx \frac{X_k(m)}{Z_k(m)} \tag{5}$$

where $\hat{C}_k(m)$ is the channel characteristic at kth subcarrier of mth OFDM symbol.

For burst transmission system it is necessary to minimize the time for estimation of channel characteristic and the zero-forcing method is rather than LMS(Least Mean Square) method for acquisition of channel characteristic in Reference symbols [8].

3.2 The number of Reference symbol for channel estimation

We consider the number of Reference symbols for channel estimation of 1 to 4. In [7] 2 symbols are used and in [4] and [6] 1 symbol is used for channel estimation. When the number of Reference symbols is larger than 2, final channel characteristic, $\hat{C}_k(m)$, is obtained by averaging the channel characteristic estimated at each Reference symbol.

$$\hat{C}_k(L) = \frac{1}{L}\sum_{m=1}^{L} \frac{X_k(m)}{Z_k(m)} \tag{6}$$

where L is the number of Reference symbols.

Figure 4 shows MSE(Mean Squared Error) of the final channel characteristics for the number of symbols. Increasing from 1 to 2, the gain of about 1.5dB is obtained and increasing from 2 to 3, the gain is about 0.5dB and when the number is larger than 3, the gain is not remarkable. 2 symbols are optimum number. The case of using 3 Reference symbols offers excellent performance but is not good for efficiency because increasing the number of Reference symbols means decreasing the bandwidth efficiency.

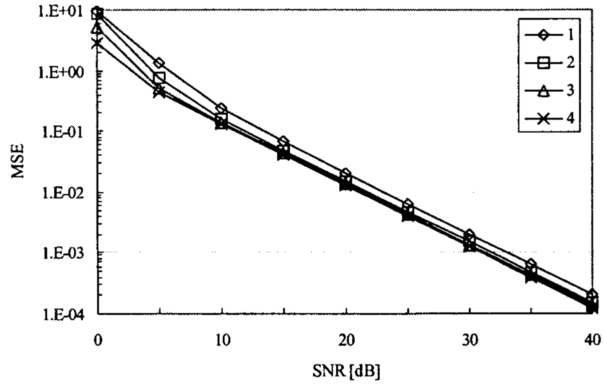


Figure 4. MSE vs. SNR for the number of Reference symbols

3.3 The pilot spacing in Reference symbols

It may be used all subcarriers or some for pilot in Reference symbol for channel estimation [9]. In the latter case, the frequency spacing between the adjacent pilots may be considered as 2 to 4 subcarrier spacing and the increasing rate of each pilot magnitude is as given by Eq. (7)

$$G_{pilot} = \sqrt{\frac{N_u}{N_p}} \tag{7}$$

where N_u and N_p are the number of the subcarriers used in the system and the number of the subcarriers for pilot respectively. The magnitude of the transmitted pilot becomes G_{pilot} times as large as that of the pilot of Reference symbol which all subcarriers are used so that the total power of Reference symbol is independent on the number of the pilots. And in decreasing the number of pilots, that means the pilot spacing is increased, the gain of SNR for each pilot increases but the interpolation is needed to estimate the channel characteristics at subcarriers between pilots [9]. Table 1 shows the value of G_{pilot} for the pilot spacing. We select N and N_u as 64 and 52 respectively, which are defined at wireless LAN standard [7].

In the linear interpolation, two consecutive pilot are used to determine the channel characteristic of subcarriers that are located in between the pilots.

Table 1. G_{pilot} for the various pilot spacing

pilot spacing	G_{pilot}
1	1.
2	$\sqrt{52/26} \cong 1.414$
3	$\sqrt{52/18} \cong 1.700$
4	$\sqrt{52/14} \cong 1.927$

$$\hat{C}_{k+a}(m) = \hat{C}_k(m) + \frac{\hat{C}_{k+b}(m) - \hat{C}_k(m)}{b-a}, \quad 0 < a < b \tag{8}$$

where $k+a$ is the subcarrier index for estimation and b is the pilot spacing.

Figure 5 shows MSE of the channel estimation for the pilot spacing of 1 to 4. Figure 5(a) is the estimation result by using 1 Reference symbol. Increasing the pilot spacing from 1 to 2 and from 2 to 3, the gain becomes 1.5dB and 0.4dB respectively. In using 2 Reference symbols the gain becomes 1dB and 0.2dB respectively as shown in figure 5(b). The results by using 3 and 4 Reference symbols are similar to that of using 2 Reference symbols. Increasing pilot spacing, MSE of estimation is decreased because the pilot power is increased and SNR for pilot is improved. However, we can notice that due to the estimation error of the linear interpolation, the whole gain is smaller than the increase rate of pilot power, G^2_{pilot}. In addition, if the channel spread is shorter enough than the guard interval and the propagation environment has LOS(Line-Of-Sight), the estimation performance can be improved by using some subcarrier as pilot selectively in Reference symbols. If the number of Reference symbol is larger than 2, the gain becomes smaller than 0.5dB so the optimum pilot spacing is 2 subcarrier spacing. However, the selection of pilot spacing is dependent on channel coherence bandwidth.

3.4 Update equalizer coefficients in the Data symbols

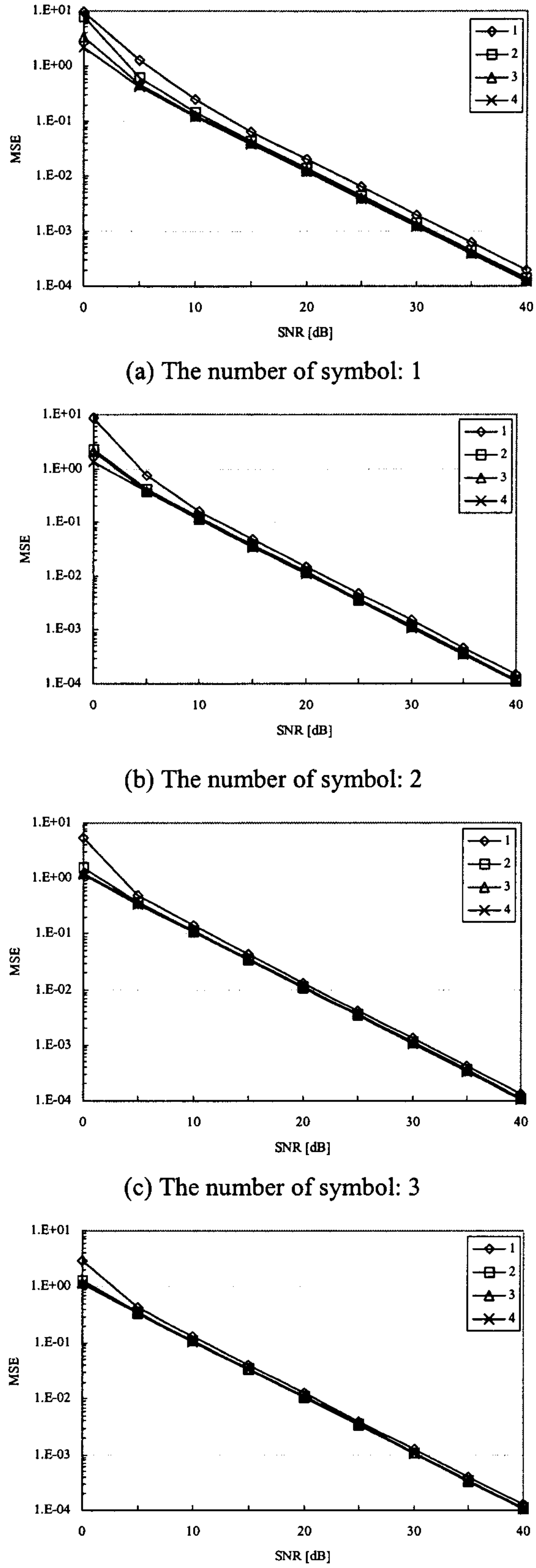
It may be considered the update the equalizer coefficients during Data symbols by using DD(Decision Direct) method. As shown in figure 6 [8], the coefficient update equation of the LMS equalization is given by

$$\hat{C}_k(m+1) = \hat{C}_k(m) + \Delta\varepsilon_k(m) Z_k^*(m) \tag{9}$$

where update constant is denoted by $\Delta(\Delta > 0)$. The error term, $\varepsilon_k(m)$, is given by

$$\varepsilon_k(m) = \Pi[\hat{X}_k(m)] - \hat{X}_k(m) \tag{10}$$

where $\hat{X}_k(m) = Z_k(m)\hat{C}_k(m)$ and denotes equalized sample and $\Pi[\cdot]$ is the decision operator according to the mapping scheme in the transmitter.



(a) The number of symbol: 1

(b) The number of symbol: 2

(c) The number of symbol: 3

(d) The number of symbol: 4

Figure 5. MSE vs. SNR for the pilot spacing

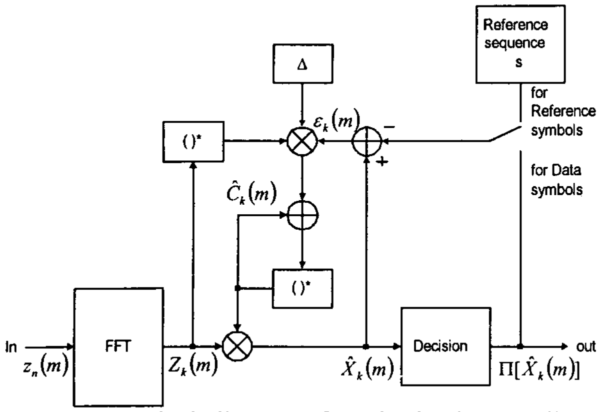


Figure 6. Block diagram of LMS adaptive equalizer

We select 0.005 as the value of the update constant, Δ, because of during Reference symbols the channel characteristics can be acquired. The number of Reference symbols and the pilot spacing are 2 and 1 respectively.

Figure 7 shows the BER(Bit Error Rate) performance after equalization. In the figure "fix" means that the equalization coefficients estimated in Reference symbols are unchanged during all Data symbols. For burst transmission under fixed multipath channel whose delay spread is shorter than the guard interval, the performance of the case with LMS adaptive equalization is similar to that of the other.

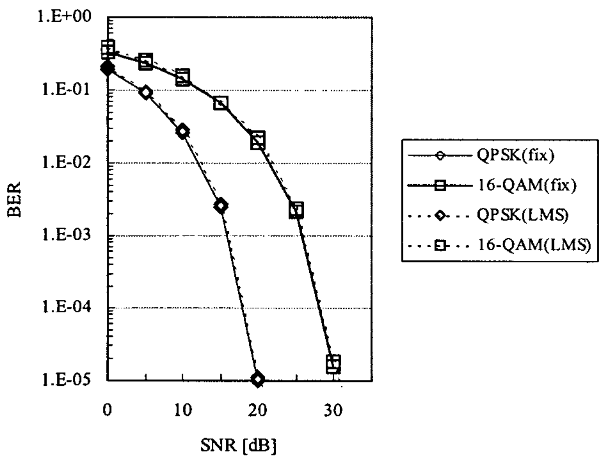


Figure 7. The BER performance

4.Conclusion

In this paper, we analyzed the channel estimation method by using Reference symbols for burst OFDM transmission systems. We set some parameters (the number of Reference symbols, the pilot spacing, update constant of equalizer coefficients) to evaluate their performance in the fixed multipath fading channel as like indoor environment. Under the channel which the spread is shorter than the guard interval, both the optimum number of Reference symbols and the pilot spacing are 2. In addition, channel estimation by using Reference symbols is enough for equalization of Data symbols.

References

[1] John A.C. Bingham, "Multicarrier Modulation for Data Transmission: An Idea Whose Time Has Come," *IEEE Commun. Mag.*, pp.5-14, May 1990.

[2] Hikmet Sari, Georges Karam, and Isabelle Jeanclaude, "Transmission Techniques for Digital Terrestrial TV Broadcasting," *IEEE Commun. Mag.*, pp.100-109, Feb. 1995.

[3] T. Keller and L. Hanzo, "Orthogonal Frequency Division Multiplexing Synchronisation Techniques for Wireless Local Area Networks," *Proc. of PIMRC'96*, pp.963-967, 1996.

[4] Timothy M. Schmidl and Donald C. Cox, "Robust Frequency and Timing Synchronization for OFDM," *IEEE Trans. on Communication*, Vol.45, No.12, pp.1613-1621, December 1997.

[5] Takeshi Onizawa, Masato Mizoguchi, Masshiro Morikura and Toshiaki Tanaka, "A Fast Synchronization Scheme of OFDM Signals for High-Rate Wireless LAN," *IEICE Trans. Communication*, Vol.E82-B, No.2, pp.455-462, February 1999.

[6] Dong Kyu Kim, Hyung Jin Choi, Je Woo Kim and Jong Hyeon Park, "OFDM Burst Transmission Scheme for Rapid Synchronization," *Proc. of ITC-CSCC'99*, pp.285-288, July 1999.

[7] IEEE "Supplement to Standard for Telecommunications and Information Exchange Between Systems-LAN/MAN Specific Requirements-Part 11: Wireless MAC and PHY Specifications: High Speed Physical Layer in the 5-GHz Band," P802.11a/D7.0, July 1999.

[8] J. Rinne and M. Renfors, "An Improved Equalizing Scheme for Orthogonal Frequency Division Systems for Time-Variant Channels," *Proc. of GLOBECOM'95*, pp.879-883, 1995.

[9] J. Rinne and M. Renfors, "Pilot Spacing in Orthogonal Frequency Division Multiplexing Systems on Practical Channel," *IEEE Trans. on Consumer Elect.*, Vol.42, No.4, pp.959-962, November 1996.