Journal of Southeast University (English Edition) Vol.19 No.2 June 2003 ISSN 1003—7985

# An enhanced iterative joint channel estimation and symbol detection algorithm for OFDM systems

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**Abstract:** For orthogonal frequency division multiplexing (OFDM) wireless communication, the system throughput and data rate are usually limited by pilots, especially in a high mobility environment. In this paper, an enhanced iterative joint channel estimation and symbol detection algorithm is proposed to enhance the system throughput and data rate. With lower pilot power, the proposed scheme increases system throughput firstly, and then the channel estimation and symbol detection proceed iteratively within one OFDM symbol to improve the BER performance. In the proposed algorithm, the original channel estimate of each OFDM symbol is based on the channel estimate of the previous OFDM symbol, thus the variation of the mobile channel is traced efficiently, so the number of pilots in the time domain can be reduced greatly. Besides reducing the system overhead, the proposed algorithm is also shown by simulation to give much better BER performance than the conventional iterative algorithm does.

**Key words:** OFDM; channel estimation; iteration; multipath fading channel

Orthogonal frequency division multiplexing (OFDM) is a choice for a variety of wireless applications since it has been shown to outperform single-carrier schemes[1,2]. For OFDM systems without co-channel interference, channel parameters estimation has been investigated to improve system performance by allowing for coherent demodulation[3].

Although the blind channel estimation techniques try to estimate the channel without any knowledge of the transmitted data, they are only effective when a large amount of date can be collected to make a reliable stochastic estimation[4]. It is clear that blind channel estimation is disadvantageous in the case of mobile wireless, for which the time-varying channel would preclude accumulation of a large amount of data. Therefore pilot-symbol-aided channel estimation is needed for this case.

A wideband radio channel is normally frequency selective and time variant. For an OFDM mobile communication system, the channel transfer function appears unequal in both frequency (i.e. at different subcarriers) and time domain; that's the reason the pilots are spread out throughout both the time and frequency domains[3,5].

Under the assumption that the first and second order statistical properties of the channel are already known, pilot-symbol-aided channel estimation by Wiener filtering brings satisfactory BER performance while inducing the hard-to-avoid mismatch problem[6]. Another disadvantage of Wiener filtering is the high computational complexity for a large number of sub-carriers.

DFT-based channel estimation, which concentrates the channel power to a few coefficients by transformation, provides an efficient tradeoff between complexity and performance[7]. For DFT-based channel estimation, better performance leads to larger system overhead. The iterative joint channel estimation and symbol detection algorithm with high data-to pilot power ratio (DPR) can provide both satisfactory BER performance and low system overhead[8]. In this paper, an enhanced iterative joint channel estimation and symbol detection algorithm is proposed to give much better performance than Ref. [8] does. The enhanced algorithm is based on the algorithm proposed in Ref. [8]; the difference is that without any extra computational complexity, the enhanced algorithm traces the time-variation of the mobile fading channel and thus gives better channel estimate and BER performance.

## 1 Channel Estimation for OFDM Systems

By multiplexing the training symbols known to the receiver into the data stream, the receiver is able to estimate the channel at any time given the observations at the pilot locations. For an OFDM system consisting of $N$ sub-carriers, the transmitted symbols including pilots and data are denoted by

**Received** 2002-06-17.

**Foundation item:** The National Hi-Tech Development Plan (2001AA123015).

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$$s(n,k)=\begin{cases}p(n,k)\\x(n,k)\end{cases}\quad n=0,1,\cdots;k=0,1,\cdots,N-1 \tag{1}$$

where $p(n,k)$ and $x(n,k)$ are the pilot symbol and the data symbol, respectively, at the $n$-th OFDM block and the $k$-th sub-carrier. Accordingly, the transmitted symbols can also be denoted in vector notations by

$$s(n)=\begin{cases}p(n)\\x(n)\end{cases}\quad n=0,1,\cdots \tag{2}$$

For the convenience of analysis, we give the same assumptions as Ref.[8] does.

- The cyclic prefix is not shorter than the maximum delay of the multipath channel;
- There is no timing error or frequency offset in the OFDM system;
- The wireless channel does not change within a whole OFDM block but varies for different OFDM blocks.

With the assumptions above, the received signal after DFT, $r(n)$, is formulated in frequency domain by

$$r(n)=s(n)h(n)+w(n) \tag{3}$$

where $h(n)$ and $w(n)$ are the frequency response of the multipath fading channel and the sample of the DFT-performed additive white Gaussian noise, respectively. Based on the received symbols at pilot locations, the least square (LS) estimated channel attenuation in the frequency domain is

$$\hat{h}_{\mathrm{p}}(n)=h_{\mathrm{p}}(n)+\frac{w(n)}{p(n)} \tag{4}$$

Once the noise-corrupted channel attenuations located at pilots are known, the channel attenuation at every point in the pilots-data grid can be obtained by interpolation, and then coherent detection can be carried out.

Fig.1 shows the principle of DFT-based channel estimation[9]. $L$ denotes the normalized maximum time delay of the channel and $M$ is the number of pilots for each OFDM symbol ($L<M\leqslant N$). By the inverse discrete Fourier transformation (IDFT), the estimated channel parameters in the frequency domain are transformed to the time domain to obtain the channel impulse response. Since the constraint $L<M$ is generally met, $M-L-1$ terms from the output of the IDFT are nothing but noise. Those noise-only terms were discarded and the channel impulse responses with $L+1$ taps were transformed back to give the DFT-based channel estimation in the frequency domain. In this paper, we set $M=N$ to suppress the noise to the greatest extent.

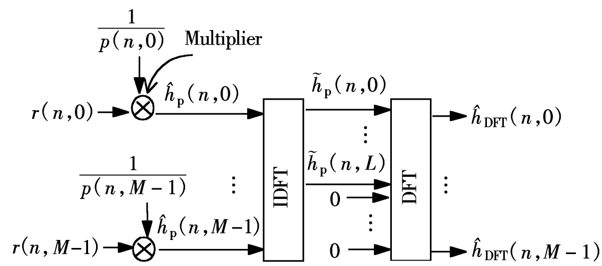


**Fig.1** DFT-based channel estimation

## 2 Enhanced Iterative Joint Channel Estimation and Symbol Detection Algorithm

By the DFT-based channel estimate, the channel parameters at the pilot positions are estimated and the subsequent channel parameters according to the data symbols are usually estimated by time-domain interpolation.

According to the LS criterion, the joint optimal solution of $s(n)$ and $h(n)$ can be obtained by

$$\{\hat{s}(n),\hat{h}(n)\}=\arg\{\min\|r(n)-\hat{s}(n)\hat{h}(n)\|_{\mathrm{F}}\} \tag{5}$$

where $\|\cdot\|_{\mathrm{F}}$ is the Frobenius norm.

In Ref.[8], for the purpose of decreasing the computational complexity, the channel estimate according to the pilot symbol is used as the initial channel estimation for the subsequent data symbols till the next pilot symbol comes. In the enhanced algorithm, it is not the pilot symbol, but the estimated channel estimate according to the last data symbol that is used as the initial channel estimate of the current data symbol. Fig.2 shows the block diagram of the enhanced iterative joint channel estimation and symbol detection algorithm applied to the $n$-th received OFDM symbol. The dashed lines in Fig.2 mean that the initial channel estimate $h_{\mathrm{DFT}}(n-1)$ is used to give the initial detection and they won't be used in the subsequent iterative steps. In the convergence judgment modulo, instead of being taken as the detection result, $\hat{d}(n)$ is encoded and modulated again to estimate the channel attenuation, and then the symbol detection. The iteration goes on till the decoded result is invariant compared with the result of the last iteration.

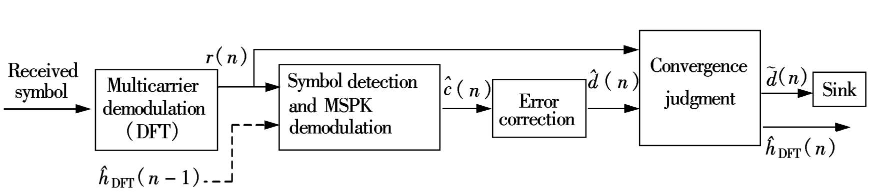


**Fig.2** Block diagram of the iterative joint channel estimation and symbol detection algorithm

In the enhanced algorithm, the estimated channel parameters of the last OFDM symbol are taken as the initial channel estimate of the current OFDM block. Since compared with the channel parameters at the pilot positions, those at the last OFDM symbols are relatively static, it is more exact to give an acceptable initial channel estimation; the system performance will also be better. This point is also demonstrated in the computer simulation results.

The enhanced iterative joint channel estimation and symbol detection is summarized as follows:

1) For the received OFDM symbol $r(0)$ at the pilot symbol position, the channel estimate $\hat{h}_{\mathrm{DFT}}(0)$ is obtained by the DFT-based estimation.

2) For the next received OFDM data symbol, $\hat{h}_{\mathrm{DFT}}(0)$ is used to give the initial symbol detection $\hat{x}(1)$, and then $\hat{x}(1)$ is demodulated and error-corrected and we get $\hat{d}(1)$. Then $\hat{d}(1)$ is coded and modulated again to obtain $\hat{y}(1)$, which is used to give the iterative channel estimation, and then symbol detection. The iteration won't terminate until the error-corrected symbol $\hat{d}(1)$ remains invariable. When the iteration ceases, $\hat{d}(1)$ is sent to the sink and $\hat{h}_{\mathrm{DFT}}(1)$ is sent to the detector of the next symbol.

3) For the $n$-th OFDM data symbols, use $\hat{h}_{\mathrm{DFT}}(n-1)$ to give the initial symbol detection of the current symbol; the iterative algorithm is about the same as 2). This step is repeated until the next pilot symbol comes at which time it goes back to 1).

## 3 Simulation Results

In the computer simulation, the QPSK modulated symbols are transmitted through 64 subcarriers. A six-path WSSUS (wide-sense stationary uncorrelated scattering) channel model with a 200 Hz maximum Doppler shift and 8 μs maximum delay spread is adopted as the time variant multipath channel. A 1/2 rate convolutional code is used to improve the performance of the algorithm. The bandwidth used is 2 MHz, and the transmitted OFDM block duration is 40 μs of which 8 μs consists of cyclic prefix.

We compare the performance of the conventional algorithm and the enhanced algorithm with DPR = 0, 10 and 20 dB, respectively. For each DPR, three cases of pilot-data grids are adopted to make the performance comparison. For case 1, the pilot symbols are positioned 5 symbols apart, i.e. one pilot symbol is followed by 4 data symbols; for case 2, the pilot symbols are positioned 10 symbols apart and for case 3, the pilot symbols are positioned 20 symbols apart. The conventional iterative algorithm is applied to these three cases. In the enhanced case, for which the pilot symbols are positioned 20 symbols apart, the enhanced algorithm is applied.

Fig.3 shows the BER and MSE of the channel estimation when DPR is 0 dB. According to Fig.3(a), the BER performance of the enhanced algorithm is better than that of case 2 and case 3, of which the system overhead (pilots) is equal or one time more than that of the system adopting the enhanced algorithm. The BER performance of the enhanced algorithm is about 2 dB worse than that of case 1, of which the system overhead is four times more than that of the system adopting the enhanced algorithm. From Fig. 3(b), the MSE of the enhanced algorithm is much better than that of case 2 and case 3, and a little worse than that of case 1 at the high SNR region. Thus we conclude that for systems with equal data-to pilot power ratios, the enhanced algorithm can give better performance under the condition of equal system overhead.

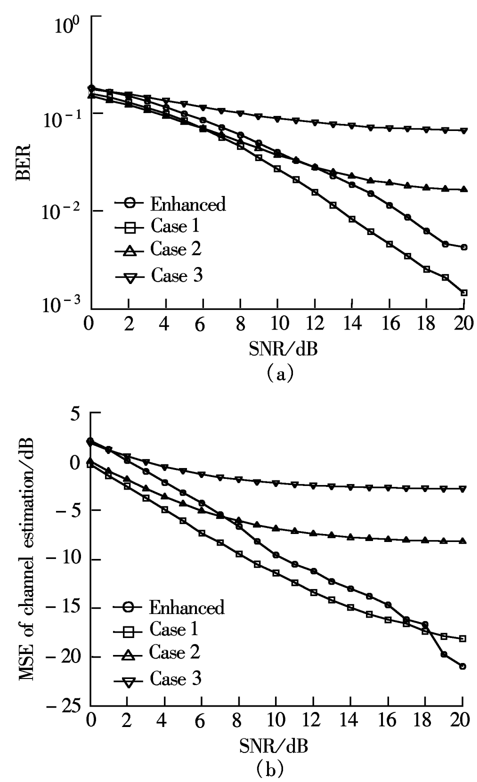


**Fig.3** Performance comparison of conventional and enhanced iterative joint channel estimation and symbol detection with DPR = 0 dB. (a) BER; (b) MSE

Fig.4 illustrates the BER and MSE performance when the DPR is 10 dB, i.e. the power of the pilot symbol is 1/10 that of the data symbol. The SNR vs. BER figure yields the same results as the system with DPR = 0 dB does. From the SNR vs. MSE figure, it is worth noticing that the mean square error of the system adopting the enhanced algorithm is much closer to that of the system using the conventional iterative algorithm, which means that with the decrease of the power of the pilots, the enhanced algorithm gives a more exact channel estimate.

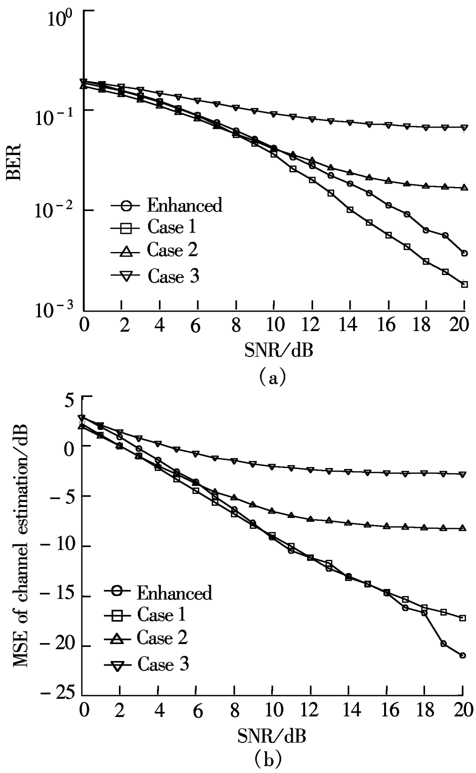


**Fig.4** Performance comparison of conventional and enhanced iterative joint channel estimation and symbol detection with DPR = 10 dB. (a) BER; (b) MSE

The point noticed above is more clearly demonstrated in Fig.5, where DPR is 20 dB. In this figure, the system adopting enhanced algorithm gives the best BER performance: about 2 dB better than the system adopting the conventional iterative algorithm with the pilot density four times higher and much better than the system with the same pilot density. In Fig. 5(b), it is also shown that the enhanced algorithm outperforms the conventional iterative algorithm.

The performance comparison of BER and MSE of the systems adopting enhanced iterative joint channel estimation and symbol detection algorithm is shown in Fig.6. Four DPR values are involved in making the comparison. It is worth noticing that the BER performances are about equal for the systems with DPR = 0 dB and DPR = 10 dB, and less than 2 dB better than the performance with DPR = 20 dB. The same results are shown in the SNR vs. MSE figure.

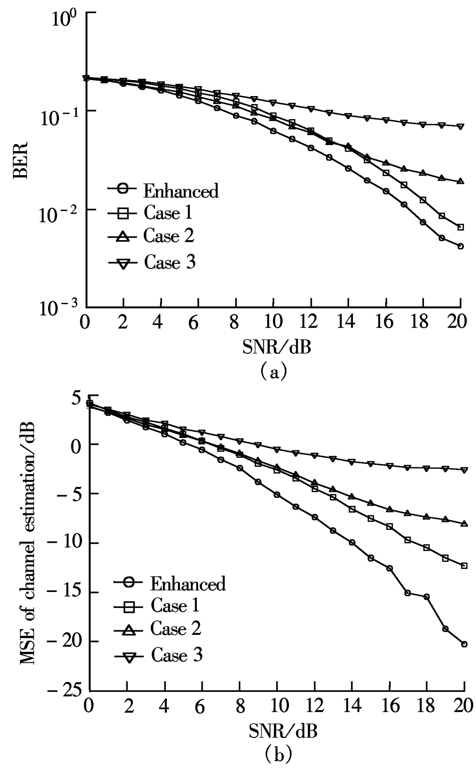


**Fig.5** Performance comparison of conventional and enhanced iterative joint channel estimation and symbol detection with DPR = 20 dB. (a) BER; (b) MSE

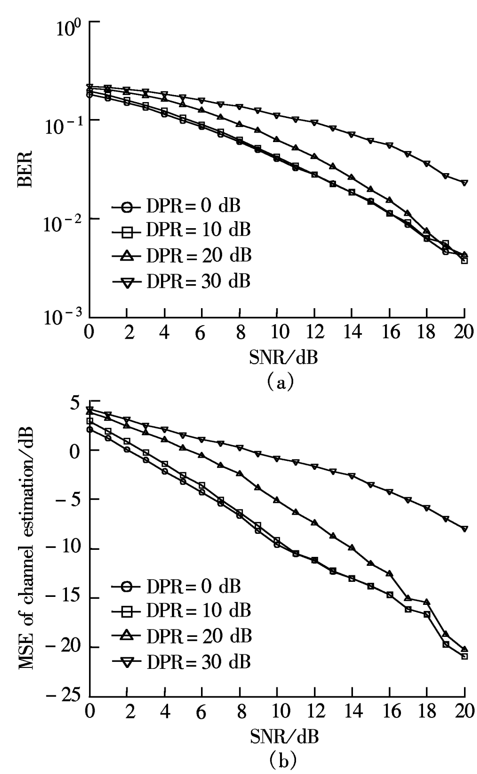


**Fig.6** Performance of enhanced iterative joint channel estimation and symbol detection for different DPRs. (a) BER; (b) MSE

## 4 Conclusion

An enhanced iterative joint channel estimation and symbol detection algorithm is proposed. With the enhanced algorithm, system overhead is about two to four times less than in the system using a conventional iterative algorithm. Another merit of the enhanced algorithm is its insensitivity to DPR variation. Generally the proposed algorithm can trace the variation of the channel and thus save more system overhead than the conventional iterative algorithm does.

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# OFDM 系统改进的迭代联合信道估计与符号检测算法

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**摘　要**　在正交频分复用(OFDM)无线通信系统中,系统的吞吐量和数据速率受到导频因素的制约,这种情况在高速移动环境下尤为明显.本文提出了一种改进的迭代联合信道估计与符号检测算法,以提高系统的吞吐量和数据速率.首先降低导频功率来提高系统的吞吐量,然后在一个 OFDM 符号内,通过迭代进行的信道估计与符号检测来提高系统的误码率.每个 OFDM 符号的初始信道估计值取自上一个 OFDM 符号的信道估计,从而该算法能有效地跟踪衰落信道的变化,因此导频的数目可以大大降低.仿真结果显示,与传统的迭代算法相比,本文提出的算法能提供更好的误码性能.

**关键词**　OFDM; 信道估计; 迭代; 多径衰落信道

**中图分类号**　TN911.5