（様式６号）「課程博士用」

学 位 論 文 の 要 旨

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学位論文題目： Study on Channel Estimation and Equalization Methods for OFDM based Next Generation Wireless Communication Systems under Higher Mobile Environments
（和訳：高速移動通信環境下における次世代 OFDM 通信システム用伝送路推定法と伝送路等化法に関する研究）

Recently, the demands for wireless multimedia communication services are drastically increasing from the fact that it can be used at anytime, anywhere and for any multimedia services by end users. To realize wireless multimedia communication services, it is strongly required to achieve higher transmission data rate with keeping higher signal quality under the limited frequency bandwidth and lower carrier to noise power ratio (C/N). However, the signal quality would be degraded relatively in wireless communications due to the occurrence of multipath fading distortion which is usually experienced in the received signal. To overcome this problem, orthogonal frequency division multiplexing (OFDM) has been proposed as one of efficient transmission techniques for wireless communications systems because of its efficient usage of frequency bandwidth and robustness to multipath fading distortion. The salient features of OFDM technique are to divide wide-band data information into a group of narrowband subcarriers and adding a cyclic prefix (CP) at the start of every data symbol which enables an employment of simple one-tap frequency domain equalization with keeping the orthogonality among narrowband OFDM subcarriers even in multipath fading channels. From these advantages, OFDM has been already adopted as the standard transmission technique in advanced wireless communications systems such as the 4^{th} generation mobile phone (LTE: Long Term Evolution), digital video broadcasting (DVB), wireless local area networks (WLANs) and worldwide interoperability for microwave access networks (WiMAX).

When assuming lower time-varying fading channels, the channel impulse responses (CIRs) can be considered as a constant during one OFDM symbol period. Accordingly, the channel frequency responses (CFRs) which are converted from the CIRs at any sampling points during one OFDM symbol period are also constant. From this fact, the received OFDM signal can be equalized precisely at the receiver by using simple one-tap frequency domain equalization. However in higher time-varying fading channels, the CIRs are changing during one symbol period and the corresponding CFRs are also changing during one OFDM symbol. From this fact, the signal quality would be degraded relatively in higher time-varying fading channels accompanying with the Doppler frequency shift in which the original property of orthogonality among OFDM subcarriers is no more satisfied due to the occurrence of inter-carrier interference (ICI). To solve the ICI problem in higher time-varying fading channels, various channel estimation and data equalization methods for CP-OFDM signal were proposed up to today.

In conventional CP-OFDM systems, the CIR is usually estimated by using scattered pilot subcarriers which are inserted into data subcarriers periodically both in the frequency and time domains. However, the CIR estimation accuracy would be degraded due to the occurrence of ICI in the received pilot subcarriers. To solve this problem, time domain training sequence (TS) inserted TS-OFDM was proposed in which the TS signal is employed in the estimation of CIR as well as the role of CP. The employment of TS signal can achieve higher estimation accuracy than that for using pilot subcarriers in higher time-varying fading channels from the reason that the period of TS is much shorter than the symbol period which could be assumed that the CIR is constant during the period of TS signal. However, the TS signal would cause the undesirable leakage of power spectrum density (PSD) at the outside of allocated OFDM bandwidth due to the repetition of same data pattern of TS signal in the time domain which leads the serious adjacent channel interference problem to other systems.

From the above backgrounds, this thesis firstly proposes a channel estimation method by using a new design of TS signal. The features of proposed method are to employ the random data patterns of TS signal added to each data symbol over one frame and to employ a triangular window function as the waveform shaping both for reducing the leakage of PSD with keeping higher CIR estimation accuracy. In addition, this thesis conducts theoretical examinations for the effect of CIR estimation method of using the TS signal when the detected symbol timing at the receiver has an offset from the ideal symbol timing.

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As for the ICI problem in higher time-varying fading channels, various frequency domain equalization (FDE) methods for CP-OFDM signal were proposed up to today including a minimum mean square error-frequency domain equalization (MMSE-FDE) and successive interference cancellation (SIC) equalization methods. These methods employed the direct inverse matrix calculation for the channel frequency response (CFR) matrix to mitigate the ICI. However, the computation complexity for the inverse matrix calculation required at every symbol is relatively higher and unsuitable in the implementation of practical receiver. To reduce the complexity, a low-complexity MMSE-FDE method for CP-OFDM signal was proposed in which the full elements of CFR matrix are approximated by a banded matrix so as to enable the employment of the fast algorithm in the calculation of inverse matrix. However, the bit error rate (BER) performance would be degraded in higher time-varying fading channels due to the lower CIR estimation accuracy by using the scattered pilot subcarriers and the approximation for full elements of CFR matrix by the banded matrix. To solve the above problems, a low-complexity overlap and add (OLA) with MMSE-FDE (OLA-MMSE-FDE) and fast suboptimum with MMSE-FDE (FAST-MMSE-FDE) methods for TS-OFDM signals were proposed. In these methods, the CIR is assumed by changing linearly during one symbol period so as to employ the low complexity Maclaurin's expansion approximation technique in the calculation of inverse matrix. Although these methods can achieve lower complexity, the BER performance would be degraded in higher time-varying fading channels due to the assumption of linear changing of CIR and the approximation of first order Maclaurin's expansion. In the development of next generation wireless communication systems, it is strongly required to realize an efficient equalization method which can achieve higher transmission data rate with keeping higher signal quality even in higher time-varying fading channels. The realization of efficient equalization methods in higher time-varying fading channels is still challenging research topic and many researchers in worldwide has been investigating to solve this problem.

From above backgrounds, this thesis firstly proposes a new MMSE-FDE method for TS-OFDM signal in conjunction with the proposed CIR estimation method in higher mobile Rayleigh fading channels. The salient features of proposed method are to enable the acquisition of frequency diversity gain by using an enhanced CIR matrix and enable the reduction of complexity by using a fast algorithm for inverse matrix calculation. Although the proposed MMSE-FDE method can achieve better BER performance than the conventional MMSE-FDE methods with keeping lower complexity, the improvement of BER performance is insufficient especially under higher mobile environments. To solve this problem, this thesis secondly proposes a time domain equalization (TDE) method of using the enhanced CIR matrix in the time domain instead of using the CFR matrix for the MMSE-FDE method. The feature of proposed TDE method is to employ the partial differentiation for the received signal in solving the maximum likelihood (ML) equation in which the CIR matrix becomes a symmetric banded matrix. This feature enables to employ the fast algorithm for inverse matrix calculation without any approximation which can achieve the same BER performance with much lower computation complexity as that for the direct inverse matrix calculation. These are completely different features from the conventional MMSE-FDE methods. The proposed TDE method can achieve much better BER performance with keeping lower complexity when employing in the wireless cellular phone systems under higher mobile Rayleigh fading environments.

To reduce further complexity, this thesis also proposes an iterative based TDE method for the TS inserted discrete Fourier transform spreading-OFDM (TS-DFTS-OFDM) signal in conjunction with the proposed CIR estimation method under higher mobile Rician environments. The salient features of proposed iterative based TDE method are to employ the enhanced CIR transfer matrix in the mitigation of ICI and to employ the preconditioned conjugate gradient squared (PCGS) algorithm as the iterative solution in the calculation of inverse matrix. The proposed iterative based TDE method can achieve better BER performance with keeping much lower computation complexity when employing in the inteligent transportation systems (ITS) under higher mobile Rician fading environments.

This thesis conducts numerous computer simulations to demonstrate the effectiveness of all proposed methods in higher time-varying fading channels. From the simulation results, it is confirmed that all methods including the CIR estimation method and equalization methods proposed in this thesis could be considered as the practical solutions in the development of OFDM based next generation wireless communication systems.