새로운 반복 LMS 기반의 결정 궤환 등화기의 설계

論 文
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Design of Novel Iterative LMS-based Decision Feedback Equalizer

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Abstract - This paper proposes a novel iterative LMS-based decision feedback equalizer for short burst transmission with relatively short training sequence. In the proposed equalizer, the longer concatenated training sequence can provide the more sufficient channel information and the reused original training sequence can provide the correct decision feedback information. In addition, the overall adaptive processing is performed using the low complexity LMS algorithm. The study shows the performance of the proposed method is enhanced with the number of iterations and, furthermore, better than that of the conventional LMS-based DFEs with the training sequence of longer or equal length. Computational complexity is increased linearly with the number of iterations.

Key Words : decision feedback equalizer, block iterative LMS, multi-training LMS

1. Introduction

In the mobile wireless packet data system, the short-burst transmissions reduce end-to-end transmission delay, and limit the time variation of wireless channels over a burst [1] and training overhead is a critical factor for such short-burst formats. When the adaptive decision feedback equalizer (DFE) is applied to short-burst wireless communication system to reject inter-symbol interference, a fast converging adaptive algorithm for the short training sequence is essential. A DFE using the RLS (recursive least square)-type algorithms converges fast but RLS-type algorithms require high computational complexity and consumes a large amount of the computational power.

Despite its low complexity, adaptive DFE using the LMS filtering has not been successful to short-burst wireless transmissions, because of its slow convergence. However, a block iterative normalized LMS (BINLMS) algorithm, which uses a block-iterative adjustment of the DFE tap coefficients, has been introduced as an effective adaptive algorithm [2-3] that can provide the desired converging performance with a competitive computational complexity in the short-burst transmissions. Originally, BINLMS algorithm was applied to only training sequence. Recently, the BINLMS (called 'multiple-training LMS (MLMS)' in [3]) algorithm was extended to the tracking mode to explore the decision information fully. This extended MLMS (EMLMS) algorithm has been applied to the mobile wireless communications system, especially IS-136 receiver [3]. However, it has been shown that there is only a slight improvement in the performance by block-iterative processing in the tracking mode.

In the EMLMS algorithm, the block iterative adaptation has been operated separately on the training and data sequence. This cannot achieve the desired performance in the short-burst transmission system using the relatively short training sequence. In the proposed method, the original training sequence and the decisioned data sequence of the equalizer output are concatenated and re-used as a concatenated training sequence for the adaptation of the DFE tap coefficients at next iteration. This has several advantages as follows: 1)the longer concatenated training sequence can provide the more sufficient channel information; 2) the reused original training sequence can provide the correct decision feedback information; 3) the overall adaptive processing is performed using the low complexity LMS algorithm. Throughout the computer simulations, it is shown that the performance of the proposed method is better than that of the conventional LMS-based DFEs.

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2. Conventional LMS-based DFEs

The DFE scheme using BINLMS algorithm uses the iterative adjustment of the DFE tap coefficients only in the training mode [2]. The received training sequence is trained repeatedly by the LMS algorithm. The initials of the DFE tap coefficients at current iteration are set to the last updated DFE tap coefficients at previous iteration. The iteration is stopped at the first instance of the estimation degradation of the average squared error. Note that the maximum number of the iteration is K_{train} which is enforced so that the MLMS algorithm does not exceed the maximum allowable processing load. The last updated DFE tap coefficients at last iteration in the training mode are used as the initials of the DFE tap coefficients in the tracking mode. The DFE using the extended multiple-training LMS (EMLMS) algorithm uses the extension of the MLMS algorithm to the tracking mode to explore the decision information fully [3]. After the received training sequence is trained repeatedly using the BINLMS algorithm described above, the received data sequence is tracked repeatedly until a pre-assigned iteration number of K_{track} is reached. However, from the simulation results, it has been shown that the iteration in the tracking mode did not produce a further advantage if the tracking period was shortened.

3. Description of proposed method

In the proposed iterative LMS-based DFE scheme, the original training sequence and the decisioned data of the equalizer output at (k-1)th iteration are concatenated and reused as a training sequence for adjusting the DFE tap coefficients at k-th iteration. The iteration is continued until a pre-assigned number of K_{con} is reached. At k-th iteration, the n-th DFE output can be written as

$$\hat{a}^k(n) = \sum_{i=0}^{N_f-1} g_f^k(n,i)x(n-i) + \sum_{j=1}^{N_b} g_b^k(n,j)b^k(n-j),$$
$$\text{for } n=0,1,\cdots,N_s-1 \text{ and } k=1,2,\cdots,M \quad (1)$$

where $g_f^k(n,i)$ and $g_b^k(n,j)$ represent the i-th feedforward filter (FFF) tap coefficient and the j-th feedback filter (FBF) tap coefficient, respectively. N_f and N_b are the length of the FFF filter and the FBF filter, respectively. N_s denotes the slot length. A slot consists of the N_t original training sequence and the N_m information sequence. $x(n)$ is the power-normalized signal of the received signal and $b^k(n)$ is the input signal to the FBF filter. $b^k(n)$ is

$$b^k(n) = \begin{cases} d(n) & \text{for } 0 \le n \le N_t - 1 \\ \text{dec}[\hat{a}^{k-1}(n)] & \text{for } N_t \le n \le N_s - 1 \end{cases} \quad (2)$$

where $d(n)$ is the original training symbol, $\hat{a}^{k-1}(n)$ is the DFE output symbol at (k-1)th iteration, and dec[.] denotes a decision operation. Note that $\hat{a}^0$ is the initial DFE output symbol acquired using the BINLMS algorithm with $K_{train} = 10$ and $K_{trac} = 1$.

The DFE tap coefficients are updated using the adaptive power-normalized LMS algorithm as

$$g_f^k(n+1,i) = g_f^k(n,i) + \mu_f e^k(n)x^*(n-i), \text{ for } i=0,1,\cdots,N_f-1 \quad (3)$$

$$g_b^k(n+1,j) = g_b^k(n,j) + \mu_b e^k(n)b^{k*}(n-j), \text{ for } j=1,2,\cdots,N_b \quad (4)$$

where μ_f is the FFF step size and μ_b is the FBF step size. $x(n-i)$ is the power normalized output element of the received signal $r(n)$ and given by

$$x(n-i) = \frac{r(n-i)}{\sqrt{\varepsilon + P(n,i)}} \quad (5)$$

where $P(n,i)$ is the instantaneous power estimate of $r(n-i)$ and ε is a small constant that eliminate overflow when the value of $P(n,i)$ are very small. For computing the values of $P(n,i)$, the exponential weighted method was used as follows

$$P(n,i) = \beta P(n-1,i) + (1-\beta)|r(n-i)|^2 \quad (6)$$

where β is the forgetting factor between 0 and 1.

The error signal $e^k(n)$ of the n'th DFE output at k'th iteration is calculated by

$$e^k(n) = \hat{a}^k(n) - b^k(n) \quad (7)$$

Note that the initial DFE tap coefficients at next iteration are the same as the last updated coefficients at previous iteration, i.e.,

$$g_f^k(1,i) = g_f^{k-1}(N_s,i), \text{ for } i=0,1,\cdots,N_f-1 \quad (8)$$

$$g_b^k(1,j) = g_b^{k-1}(N_s,j), \text{ for } j=1,2,\cdots,N_b \quad (9)$$

Because overall process is based on the low complexity LMS algorithm, the computational complexity of the proposed iterative adaptive DFE increases linearly with the number of iterations.

4. Simulation results

To test the performance of a new iterative LMS-based adaptive DFE, a 4-path Rayleigh fading channel with the z-transform of

$H(z) = 0.575 + 0.362z^{-1} + 0.057z^{-2} + 0.006z^{-3}$ was considered. Total channel impulse response includes $h(t)$ and non-ideal pulse shaping filter $p(t)$ using the square root raised cosine filter with the roll-off factor of 0.3 and a support [-3T, 3T). A QPSK signal is transmitted. A simulated burst length was set to be 160 (for the purpose of simulation). The training sequence length was set to be 16 (10% overhead) or 32 (20% overhead). The carrier frequency and the channel bandwidth was assumed to be 5 GHz and 1 MHz, respectively. The symbol interval T is 1μs. One slot burst occupies 160μs time duration (this is a short burst). The Doppler frequency was 200 Hz, which corresponded to the vehicle speed of about 43 km/h. The FFF length was set to be 7 and the FBF length was set to be 4. The equalizer delay was set to be 4. The FFF step size was 0.05 and the FBF step size was 0.005.

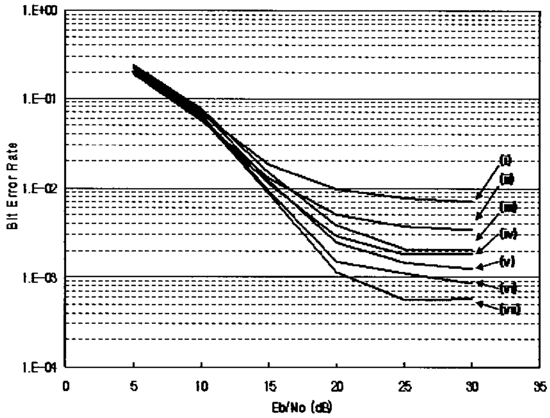

Fig. 1 Comparison of BER performance for various LMS-based DFE schemes ((i) original NLMS-based DFE; (ii) EMLMS-based DFE; (iii) and (iv) BINLMS-based DFE; (v) Proposed method, $K_{con}=1$; (vi) Proposed method, $K_{con}=5$; (vii) Proposed method, $K_{con}=10$)

Fig. 1 shows the comparison of BER performance for the various LMS-based DFE schemes as a function of the SNR (E_b/N_0). The iteration parameters were set to be $K_{train}=1$, $K_{track}=1$ for the NLMS-based DFE, $K_{train}=10$, $K_{track}=1$ for the BINLMS-based DFE, $K_{train}=10$, $K_{track}=10$ for the EMLMS-based DFE, and $K_{train}=10$, $K_{track}=1$, $K_{con}=1\ or\ 5\ or\ 10$ for the proposed DFE. The index (iv) only uses the 20% overhead while the other indices use the 10% overhead. From simulation results, it is shown that the performance of the proposed method can be improved with the iteration number, K_{con}, and better than that of the conventional LMS-based DFE schemes with the training sequence of longer (20% overhead) or equal length (10% overhead).

In the short-burst transmission system, the proposed method is an effective scheme for achieving the better performance with the relatively short training sequence and so improving the frame efficiency.

5. Conclusions

The novel iterative LMS-based adaptive DFE scheme is proposed and applicable to the short-burst wireless communications system. The original training sequence and the decisioned data sequence of the equalizer output are concatenated and re-used as a extended training sequence for the adaptation of the DFE taps at next iteration. The following advantages can be achieved. The longer concatenated training sequence can provide the more sufficient channel information and the reused original training sequence can provide the correct decision feedback information. In addition, the overall adaptive processing is performed using the low complexity LMS algorithm and so the computational complexity increases linearly with the iteration number. Computer simulation result shows that the performance of the proposed scheme is superior to that of the existing LMS-based DFE schemes with the training sequence of longer or equal length. In the short-burst transmission, the proposed method can achieve the better performance with the relatively short training sequence and so is more effective scheme in terms of frame efficiency.

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