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Analysis and Algorithm Improvements of MUD Receiver in UWB System

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Abstract: Based on the research of the technology of MUD, we probe into the MUD scheme based on adaptive MMSE in UWB system. Furthermore, based on MUD, the adaptive receiver can improve the algorithm structure and computational complexity at the price of sending training sequence. In this paper, an adaptive receiver algorithm based on training sequences of variable length is proposed. Compared to the adaptive algorithm of fixed length, this novel algorithm is able to improve the transmission capacity effectively with the least training consumption from the premise of little cost, low power consumption, simplicity and practicality and certain error code.

Key words: UWB, rake receiver, MMSE, MUD

INTRODUCTION

The UWB (Ultra-wideband) system differs greatly from the traditional communication system in such aspects as signal spectrum and the channel characteristics, thus practical UWB receiver design has become a key issue in the UWB system research. Initial UWB systems usually employ link schemes based on Rake receiver whose characteristic is to achieve diversity reception with Rake receiver and needs channel estimation (Benedetto and Giancola, 2004). In addition, to reduce IPI (Inter-path Interference) and the influence of synchronization error, Rake receiver needs high sampling frequency for received signals to over-sampling (A. Rajeswaran *et al*., 2003). Therefore, due to the not very ideal receiver performance or high processing overhead, Rake receiver is limited in the actual application. For this problem, people applied MUD (Multi User Detection) technology suitable for multipath reception to UWB and gave full consideration to the correlation between users' signals(Li and Rusch, 2002). We research MUD scheme of DS-UWB (Direct Sequence Ultra-wideband) system in detail and adopt adaptive MUD scheme. The purpose is to find the method of effective concentrations of multipath energy through analysis of the received signal and eliminate inter-symbol interference.

MODEL DESCRIPTION OF ADAPTIVE DS-UWB MULTI-USERDETECTIONRECEIVERSIMULATION SYSTEM

This study focuses on the signal of K (K = 1~15) users through indoor multipath channel in a UWB system, in which each user uses the way of BPSK (Binary Phase Shift Keying) direct sequence spread spectrum modulation, this study tries to detect all k users data bits. Overall diagram is shown in the Fig. 1 as follows.

The binary data bit-stream sent by the k user exports after the BPSK modulation of signal waveform. The expression of transmission signals generated by the k user is as followed:

$$x_k(t)=\sum_{i=1}^{M} b_k(i)s_k(t) \tag{1}$$

In which, the signal waveform contains N=15 pulse transmission (Mielczarek *et al*., 2003).

Assume that the k user's signal x_k (t) receives the signal after the multipath channel h_k (t) transmission and the received signal is:

$$y_k(t) = x_k(t)*h_k(t) \tag{2}$$

The synthetic signal at the receiver input is as followed:

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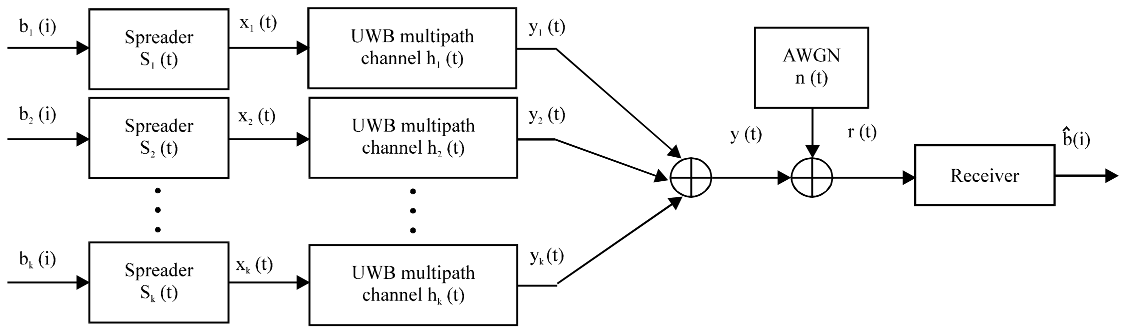

Fig. 1: UWB system model

$$r(t)=\sum_{k=1}^{K} y_k(t)+n(t) \tag{3}$$

n (t) is AWGN (Additive White Gaussian Noise) in which the mean is zero.

During each data bits, the output of adaptive filter will make a bit of judgment and return the error, adjust the weight coefficient of filters according to the error. Per frame data sent by users all have a training sequence and this training sequence is used to adapt to the channel. Usually we fix the length of 500 bits as the training sequence (Jin *et al*., 2010). The weight coefficient of adaptive will use the RLS (Recursive least mean square) adaptive filter or LMS (Least Mean Square) algorithm to adjust; after training hard decisions will be made, RLS or LMS algorithm can be made to update weight coefficient of filters through estimation value when the hard decisions are made (Ye *et al*., 2004).

IMPROVEMENT OF THE ADAPTIVE FILTER WEIGHT COEFFICIENT ADJUSTMENT ALGORITHM

Because there is a fixed length (500 bits) of the known training bits in front of data frames sent by each user, so there is one problem in this training mode: In the process of practical communication, channel condition and changeable situation is unknown for the receiver. So the length of training sequence cannot be determined in advance. If the length of training sequence is too short, the tap coefficient may make the error performance become deteriorate in the transmission stage when it has not yet to reach a stable state of convergence; If the length of training sequence is too long, even if the tap coefficient of convergence achieves a steady state, it may make a waste of the bit overhead and then reduce the effective data throughput of the whole system.

Considering convergence and complexity, this paper presents an improved algorithm based on variable length training sequence LMS algorithm, namely NLMS (Normalized Least Mean Square) algorithm, which is that judge whether the MSE is stable convergence to a certain threshold or not between filter output and training of the bit, to link the state of the switch. In the training stage, bit training is sent at first, then from the receiver to obtain the received signal discrete sampling value of the observation window, calculate the filter MSE between the output and bit training, at the same time to update filter coefficient MMSE criterion. If the MSE is below a certain threshold over a period of observation time, it is considered into the stable convergence condition, link-state is then switched to the transmission phase, otherwise go on training; in the transmitting stage, except for the hard decision of data, use the verdict as a reference at the same time, watch MSE between this and the next output of filter and continue to update the filter coefficient.

Algorithm performance analysis: Based on the above,a frame signal can be obtained through the signal after the multipath fading channel:

$$\begin{aligned} y(t) &= x(t)*h_k(t) \\ &= X^{(k)}\sum_{l=0}^{L-1}\sum_{m=0}^{M-1}\alpha_{m,l}^{(k)}\,x(t-T_l^{(k)}-\tau_{m,l}^{(k)}) \end{aligned} \tag{4}$$

At the receiver side, the input signal can be expressed as:

$$r(t) = y(t)+n(t) \tag{5}$$

After the sampling channel fading signal and receiver input signals can be represented as, respectively:

$$\tilde{y}(j)=y(jT_s),\ \tilde{r}(j)=r(jT_s) \tag{6}$$

According to the MMSE criterion, the optimization problem of filter tap coefficients can be described as:

$$\min j(w) = \min E\left\{\left|d(n) - w^H(n)u(n)\right|^2\right\} \tag{7}$$

in which, d (n) is the reference quantity, w (n) is the adaptive filter receiver tap coefficient vector, u (n) is the observation window of the observation vector of received signal.

Using the recursive method, the traditional LMS algorithm is used to approximate optimal solution about type (7). On the premise of not significantly increasing the complexity of algorithm, in order to improve the convergence performance of the LMS algorithm, a simple and practical idea is to use variable convergence factor, this paper adopts the power normalization to achieve the convergence of variable factors. Firstly we transform the optimization problem in type (7) into the constraint optimization problem in which the squared norm of a tap coefficient increment is minimized:

$$\begin{cases} \min\limits_{w(n+1)} \left\|\delta w(n+1)\right\|^2 = \min\limits_{w(n+1)} \left\|w(n+1) - w(n)\right\|^2 \\ w^H(n+1)u(n) = d(n) \end{cases} \tag{8}$$

Lagrange multiplier method was applied to solve Eq. 8, λ is laser multiplier (plural), at the time the objective function is:

$$\begin{aligned} J(w) &= \left\|\delta w(n+1)\right\|^2 \\ &\quad + \mathrm{Re}\left\{\lambda^*[d(n) - w^H(n+1)u(n)]\right\} \\ &= \left\|w(n+1) - w(n)\right\|^2 \\ &\quad + \mathrm{Re}\left\{\lambda^*[d(n) - w^H(n+1)u(n)]\right\} \end{aligned} \tag{9}$$

Using 9 partial derivatives of w* (n+1), available:

$$\frac{\partial J(w)}{\partial w^*(n+1)} == 2[w(n+1) - w(n)] - \lambda^* u(n) \tag{10}$$

In order to get the optimal solution in the w (n+1), type (10) is zero, get it:

$$w(n+1) = w(n) + \frac{1}{2}\lambda^* u(n) \tag{11}$$

Take type 11 into 8, the Lagrange multiplier is:

$$\lambda = \frac{2e(n)}{u^H(n)u(n)} \tag{12}$$

Again take type 12 back to 11, we can conclude that the improved form of LMS algorithm is:

$$w(n+1) = w(n) + \frac{e^*(n)}{u^H(n)u(n)} u(n) \tag{13a}$$

Because:

$$\frac{u(n)}{u^H(n)u(n)}$$

is the vector quantity in which norm is 1, so the type (13a) is called a Normalized LMS algorithm, referred to as NLMS algorithm. In practice, in order to improve the numerical stability, type (13a) can be slightly modified to:

$$w(n+1) == w(n) + \mu(n)e^*(n)u(n) \tag{13b}$$

We can prove strictly that no matter whether linear correlation between the observation vector input, NLMS algorithm in each update tap coefficient of the instantaneous MSE is minimum and it is a good simple estimates for MSE. Therefore, can expect NLMS algorithm has faster convergence speed than the LMS algorithm.
For stable convergence of adaptive receiver, it is not difficult to get the BER performance of the single user to the theoretical value:

$$P_{su} = Q\left(\sqrt{\frac{w_0^H E_S}{\sigma^2 \left|w_0\right|^2}}\right) \tag{14}$$

in which, w_0 is the optimal solutions tap coefficient of MMSE, E_S is the receiver input signal vector. For the above three kinds of adaptive filtering algorithm, although their convergence paths may vary, as long as their ultimate tap coefficients of convergence to a considerable accuracy, they can output error proper performance of a single user.

Above comprehensive analysis, in quite MSE accuracy, LMS and NLMS algorithm computational complexity is low than RLS algorithm; And NLMS and RLS algorithm convergence speed is faster than LMS algorithm. Therefore, considering from two aspects of the training cost and computational complexity, in three kinds of adaptive algorithm, the NLMS algorithm is best suited for adaptive receiver scheme.

Algorithm simulation and analysis results: In order to verify the previous theoretical analysis, this study use Matlab simulation tools to realize the adaptive receiver module based on variable length of training sequence and

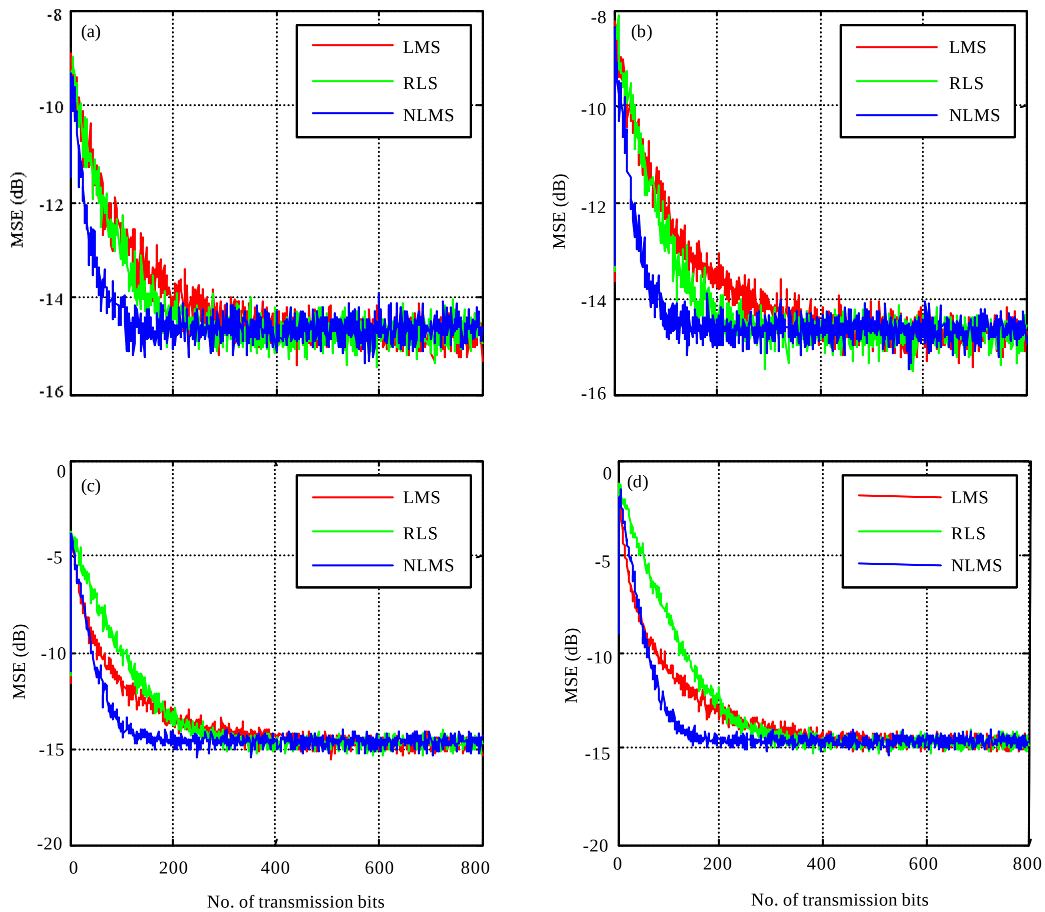

Fig. 2: Comparison of convergence properties of three kinds ofadaptive

embed it in DS-UWB systems for single user link simulation. Respectively by RLS, LMS and NLMS algorithm to implement the MUD.

Figure 2a-d are given the information that when SNR is fixed in the 10dB, the adaptive receiver's convergence characteristic curve in the channel model of CM1¡«CM4. It can be seen that, in the four channel models, we can obtain the convergence characteristic curve similar to all three adaptive receivers: compared to others, NLMS converges are very fast, about 100~150 training bits after convergence can reach steady state; and the stable state of RLS in the 200~300 training bits can be reached; the slowest is LMS, it needs 250¡«400 training bit to reach a stable state. Three MSE converge to a stable value basic. Therefore, the convergence of the NLMS characteristics is the best receiver scheme, namely for variable length scheme based on training sequence is presented in this paper, the steady NLMS training is minimal (minimum overhead than LMS and RLS save more than 30%). And from the analysis of the previous performance, compared with LMS, the computational complexity of NLMS did not significantly increase.

Figure 3 shows that, under the channel models CM1~CM4, we use three adaptive algorithm receiver based on variable length of training sequence to study the output bit error rate after the convergence stability. In the case of MSE convergence to a level, three kinds of adaptive receiver output bit error rate are in substantial agreement, the result is fit the analysis result in 14, the receiver output bit error rate is only related to the precision when the MSE have a stable convergence. Therefore, under the premise of without destroy the error performance, NLMS with minimum steady-state training expenses, can exchange for in (without channel estimation) algorithm structure (low sampling rate) and the calculation complexity of improvement.

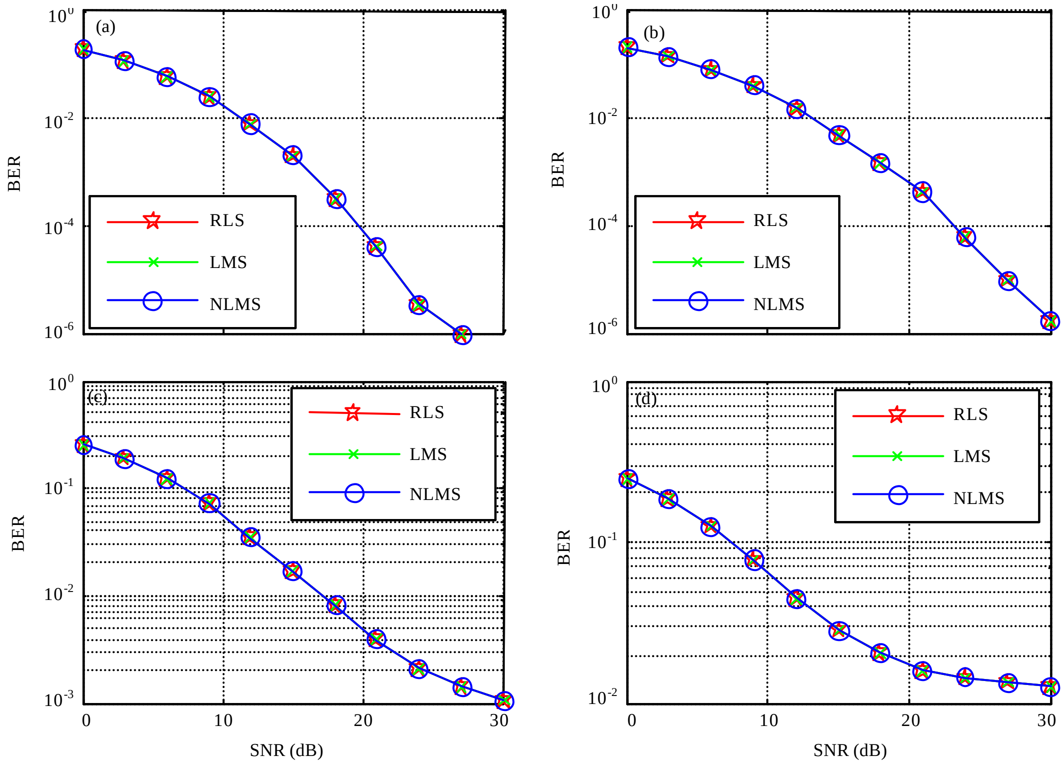

Fig. 3: BER of three algorithms after convergence and stability

CONCLUSION

Through exploring the technique of Multiuser Detection (MUD), this paper mainly probes into the adaptive plan for MUD based on MMSE in DS-UWB system. Aiming at MMSE adaptive MUD receiver, this paper puts forward a kind of adaptive receiver scheme based on length-variable training sequence, where the adaptive NLMS algorithm is adopted. The simulation results show that even the slowest convergent LMS, also can achieve stable convergence after training at 400 bits (saving 20% of the training cost). And the NLMS which has the best comprehensive properties can save 80% of training costs. Therefore,the algorithm is able to improve 11the transmission capacity effectively with the least training consumption from the premise of little cost, low power consumption, simplicity and practicality and certain error code.

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