The performance analysis of B-WLL system using pre-equalization techniques with fast adaptive algorithms under the Ka-Band channel

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***Abstract**:* In this paper, we propose the pre-equalization technique for the uplink burst transmission under the *intersymbol interference (ISI)* channel and the rain attenuation channel existed in the *Ka-Band* (20~30GHz) of the B-WLL system. We compare the *mean-square-error (MSE)* convergence properties of *standard least-mean-square (SLMS)* and *discrete cosine transform (DCT)*-based *transform-domain least-mean-square (TRLMS)* algorithms, analyze the BER performance of pre-equalization and post-equalization using *TRLMS* and SLMS algorithms. Pre-equalization, which is a technique to enhance the BER performance by avoiding the noise enhancement of receiver, needs the post-equalization as an initial step to extract the tap coefficients of pre-equalizer in the transmitter. The simulation results show that *TRLMS* as a post-equalization algorithm provides much faster *MSE* convergence rate and lower steady-state *MSE* properties than *SLMS* does under the ISI and rain attenuation channel. From the above *MSE* results, it is preferable to use the *TRLMS* as an adaptive filter algorithm of pre-equalizer system rather than the *SLMS* to obtain better BER performance.

Key-Words: ISI, SLMS, MSE, TRLMS, DCT, Equalization, Ka-Band

1 Introduction

The B-WLL system requires line of sight (LOS) to provide high quality of service (QOS) and various services between base station (BS) and mobile station (MS). But the signals transmitted through the wireless communication channel are faded by intersymbol interference (ISI) according to the frequency selective fading channel and the rain attenuation channel. Therefore, adaptive algorithms are necessary to compensate for fading effects in the receiver. The simplest and the most extensively utilized algorithm for adaptive filtering is the Widrow-Hoff LMS algorithm. The merit of it comes from its low computational complexity, however the demerit of it is slow convergence rate. Unfortunately, its convergence rate is highly dependent on the conditioning of the autocorrelation matrix of its inputs. Convergence rate is inversely proportional to the eigenvalue spread of the input signals. Therefore, it is really necessary to reduce the correlations of the input signals to have small eigenvalue spread. Transform-domain LMS (TRLMS) algorithm is the class of algorithms that utilize an unitary block transform to diagonalize the input correlation matrix. Discrete-cosine transform (DCT) TRLMS algorithm is utilized as a unitary block transform. TRLMS algorithm using this block transform obtains fast MSE convergence rate than SLMS algorithm by reducing the eigenvalue spread of input signals. Above mentioned, various adaptive filter algorithms are generally utilized as post-equalization technique in the receiver, however this post-equalization method has shortcoming that induces the additive thermal noise enhancement. As a method of resolving this shortcoming, this paper proposes pre-equalization technique. This is very effective technique to transmit burst data in the uplink. Pre-equalization technique is performed as follows. First, post-equalization technique must be preceded to obtain optimal tap coefficients that compensate for fading channel information in the receiver. Secondly, these tap coefficients are transmitted to the transmitter through the MAC frame. Thirdly, pre-equalization is performed by using of these tap coefficients. When the first step is performed, it is really necessary to use optimal adaptive filter algorithm that can obtain much faster MSE convergence properties and lower steady-state MSE because this optimal algorithm can enhance BER performance of the system. The post-equalization must keep its periodic pattern and estimate tap coefficients that properly compensate for fading channel in the pre-equalizer.

The statistical channel model of B-WLL system that is usually performed in the LOS communication is similar to the Ka band fixed orbit satellite channel model. This channel model can be easily influenced by the rain attenuation channel that be expressed as Gaussian function with different parameters. The channel condition of B-WLL system is good because B-WLL system requires the LOS component to provide high quality service. But distortions occur to signals that pass through the multipath channel and the rain attenuation channel.

Computer simulations were performed to compare the MSE convergence performance of SLMS and TRLMS adaptive filter algorithms, to analyze the BER performance of post-equalization and pre-equalization techniques using two adaptive filter algorithms under the ISI and the rain attenuation channels. Simulation results show that the TRLMS algorithm provides much faster and lower MSE convergence properties than SLMS algorithm regardless of channel conditions. These also show the improved BER performance by using of the pre-equalization technique. In Section 2,3,4, LMS adaptive algorithm, Rain Attenuation channel and Pre-equalization are reviewed. In Section 5, performance comparison is performed. Conclusions are drawn in Section 6.

2 LMS adaptive algorithm

2.1 SLMS (Standard LMS)

SLMS tap coefficient update algorithm, which is defined as

$$\mathbf{c}_k(n+1) = \mathbf{c}_k(n) + \mu \cdot e(n) \cdot \mathbf{X}^*(n) \tag{1}$$

where μ is step-size parameter, $e(n)$ is error signal, and $\mathbf{X}(n)$ is input signal.

2.2 DCT based TRLMS

The class of algorithms that utilize a unitary block transform to diagonalize the input correlation matrix are known as TRLMS algorithm. And the practical solution is to use the unitary block trasform-like discrete cosine transform(DCT). DCT-based unitary block transform ($\mathbf{T}_n(N \times N)$) is defined as [4].

$$\mathbf{T}_n(i, j) = \sqrt{\frac{2}{n}} K_i \cos\left(\frac{i(j+\frac{1}{2})\pi}{n}\right) \tag{2}$$

with $K_i = 1/\sqrt{2}$ for $i = 0$ and 1 otherwise

$$s_k(i) = \sum_{j=0}^{N-1} \mathbf{T}_n(i,j) u_{k-j} \qquad for \quad i = 0,\cdots,N-1. \tag{3}$$

transformed signals $s_k(i)$ are the output signals of DCT transform for input signal u_k.

TRLMS adaptive algorithm processes the input to diagonalize its correlation matrix and the usese it in the Newton-LMS type adaptive algorithm as [6].

$$\mathbf{h}(n+1) = \mathbf{h}(n) + 2\tilde{\mu}\hat{\mathbf{R}}_s^{-1}(n)\mathbf{s}(n)e(n) \tag{4}$$

where $\mathbf{h}(n) = [h_0(n), h_1(n), \cdots, h_{N-1}(n)]^T$ is the weight vector, $\tilde{\mu}$ is step-size parameter. $\mathbf{s}(n) = \mathbf{Tu}(n)$. $\mathbf{T}$ defines a fixed unitary block transform $y(n) = \mathbf{s}^{\mathbf{T}}(n)\mathbf{h}(n)$ is adaptive filter output signal, $e(n) = d(n) - y(n)$ indicates error signal. $\hat{\mathbf{R}}_s(n)$ is a diagonal matrix having as diagonal elements the power estimates of the elements of the transformed vector $\mathbf{s}(n)$.

3 Rain Attenuation Channel

The statistical channel model of B-WLL system which is usually performed in the LOS communication is similar to the Ka band fixed orbit satellite channel model. this channel model can be easily influenced by the weather conditions and be expressed as gaussian functions with different parameters. Probability density function(PDF) of the received signal is as.

$$f(s) = \frac{1}{\sigma_s\sqrt{2\pi}} \exp\left[-\frac{(s-\mu_s)^2}{2\sigma_s^2}\right] \tag{5}$$

where μ_s is signal envelope average, σ_s^2 is variance.

4 Pre-Equalization

As an initial step, Post-equalization must be proceeded before performing the pre-equalization. After tap coefficients are estimated according to the channel types by using of the post-equalization, these coefficients are transmitted to the transmitter through the MAC frame. To be transmitted signals are compensated by transmitted coefficients in advance. Therefore convergence rate of the post-equalization performed in an initial step must be fast by using optimum algorithms for the high speed burst transmission. Post-equalization must keep its periodic pattern and estimate tap coefficients which properly compensate for time varing channel distortions. Fig.1 shows the structure of the pre-equalizer using 10 taps. $[w_1, w_2, \cdots, w_9, w_{10}]$ indicate tap coefficients of pre-equalizer transmitted through the MAC frame.

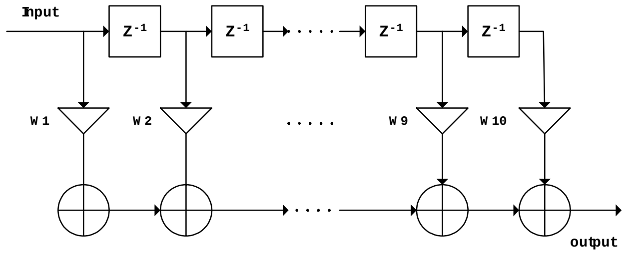


Fig.1 the structure of the pre-equalizer using 10 taps

5 Performance Comparison

The channel condition of B-WLL system is good because B-WLL system requires the LOS component to provide high quality service. But signals distortions occur according to signals that pass through the multipath channel and the rain attenuation weather condition. In our simulations, we used the ISI channel suggested in the IEEE 802.16 and did rain attenuation channels exiting in the Ka band. Z-transform of the ISI channel impulse response is as.

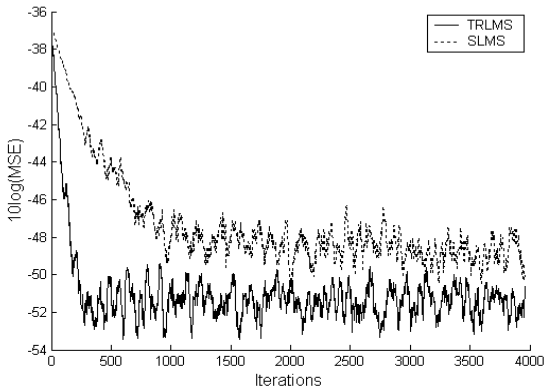
$$C(Z) = 0.999 + 0.0447\, z^{-1} \tag{6}$$

3 kinds of rain attenuation channel models used in our simulation are as [7].

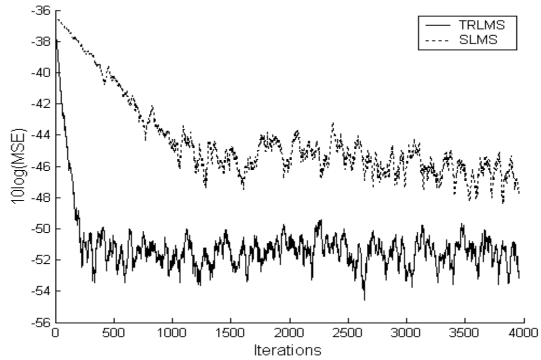
Weather condition	Envelope parameters	
	Mean	Variance
Rain	0.662	0.02
Thunder Shower(TS)	0.436	0.01386
ILR(Intermittent Light Rain)	0.483	0.00003

Table 1. Envelope parameters in terms of weather condition

Computer simulations were carried out to evaluate the performance of pre-equalization and post-equalization, to compare with their BER performance under the rain attenuation channels. We used two adaptive filter algorithms(SLMS, DCT-based TRLMS).



(a) Rain channel



(b)TS channel

Fig.2 Leaning curves of SLMS and TRLMS under the rain attenuation channels

Fig. 2(a) shows the learning curves of SLMS and TRLMS under the rain channels, and Fig. 2(b) shows the learning curves of the SLM and TRLMS under the TS channels. The step-sizes for SLMS and TRLMS are all equal to 0.01. The number of taps is all equal to 10. As seen, the TRLMS algorithms provide much faster convergence than SLMS algorithms under the rain attenuation channels. Therefore TRLMS algorithms are required to maximize the performance of systems using pre-equalization techniques because of much faster convergence rate regardless of channel conditions

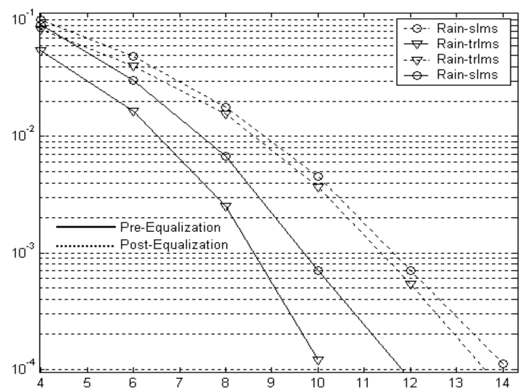


Fig.3 The BER performance of algorithms under the rain channel

Fig. 3 shows that BER performance of post-equalizer and pre-equalizer systems using the SLMS and TRLMS algorithms. Simulations show improvements of 3 dB for BER(10^{-3}) when pre-equalizations and post-equalizations are compared under the rain and ISI channels. TRLMS algorithms have the gain of 1 dB for BER(10^{-3}) for pre-equalizations.

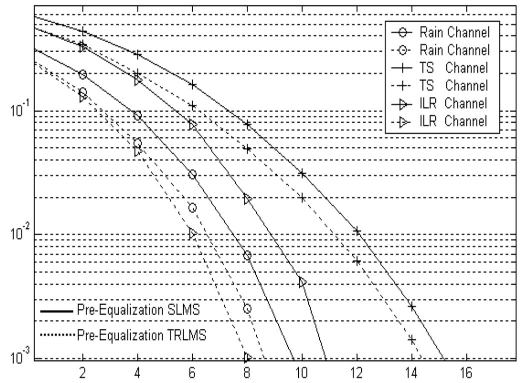


Fig.4 The BER performance comparison of pre-equalization under the rain attenuation channels

Fig.4 shows the BER results of pre-equalizer using the SLMS and TRLMS under the Rain and Ts channels. Both rain attenuation channels, the BER performance of pre-equalizer using TRLMS algorithms has the gain of 1 dB for BER(10^{-3}) for pre-equalizations.

6 Conclusion

In this paper, we proposed the pre-equalization as techniques for the uplink burst transmission in the B-WLL system, compared the BER performance of post-equalization and pre-equalization using SLMS and TRLMS algorithms and compared the MSE convergence performance of two algorithms under the ISI channel and the rain attenuation channels. As knew from the simulation results, it is required to choose the TRLMS algorithms having the fast convergence properties. It makes much better BER performance than other algorithms. Knowledge obtained from this paper is that it is necessary to choose the optimal adaptive filter algorithms having fast MSE convergence rate and low MSE steady-state values from the post-equalizer in the pre-equalizer systems regardless of channel conditions.

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