Pre-Equalization Techniques for Mitigating Rain Attenuation Channels in a Broadband Fixed Wireless Uplink System

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ABSTRACT

In this paper, the performance of pre-equalization technique which can be applicable for the B-WLL uplink is evaluated and compared to post-equalization technique under three kinds of rain attenuation channels such as rain, intermittent light rain and thundershower. The BER performance comparisons of two algorithms (LMS and RLS) are investigated in the context of channel models and the length of training sequence. From the simulation results, it is shown that the post-equalization outperforms only at quite good channel conditions such as AWGN, while the pre-equalization can guarantee better BER performance at every channel conditions, especially performance gain increases as the severity of channel increases. It is concluded that the pre-equalizer using LMS algorithm is preferable at delay-tolerant situation where the complexity of algorithm is not a strict factor, while one using RLS is suitable for fast burst transmission with a relatively short training sequence.

***Keywords**: Pre-equalization, B-WLL, LMDS, Rain Attenuation, IEEE 802.16, LMS, RLS*

1. INTRODUCTION

The broadband wireless local loop (B-WLL) system is millimeter wave broadband wireless access systems whose base station (BS) and subscribers' positions are fixed. Usually individual subscribers have a fixed antenna mounted on a building that provides unobstructed line of sight (LOS) to the BS, such that the channel environment of B-WLL systems is not hostile to users. For this reason, such systems are less vulnerable to Doppler effect than conventional mobile communication systems with high mobility. On top of this advantage, the B-WLL system, e.g. local multipoint distribution service (LMDS), can exploit wide frequency bands such as 27.5 ~31.225 GHz, which provide the wide channel bandwidth and the possibility of implementing small-size transceivers [1][2]. However, it was well known that wireless communication link using millimeter wave suffered severe rain attenuation. The presence of raindrops can severely degrade the reliability and the performance of communication link in B-WLL frequency band (i.e. Ka-band). In this paper, the performance of pre-equalizer technique for the B-WLL system under rain attenuation channel environments is evaluated and discussed along with two proponent convergence algorithms such as LMS and RLS.

This paper is organized as follows: In Section 2, channel propagation model based on IEEE 802.16 standard and rain attenuation channel model which is studied in a fixed satellite communication are discussed. In Section 3, we describe pre-equalization technique, procedure, requirement, cons and pros of pre-equalization technique. We analyze and compare

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Manuscript received Dec.15, 2006 ; accepted Dec. 29, 2006

This research work is supported by the Research Grant (2006.7~2007.6) from Mokpo National University, Korea.

performance of pre-equalizer and post-equalizer by computer simulation results in Section 4. Finally, concluding remarks are given in Section 5.

2. CHANNEL MODEL AND RAIN ATTENUATION MODEL

2.1 Channel propagation and ISI model

Among three kinds of IEEE 802.16 standard propagation channel model as proposed in [3], a typical deployment scenario with weak multi-path components (type 2 in [3]) is considered in this paper. Since the channel model must be modified as symbol rate changes, symbol rate is assumed 10240 Ksymbol/sec.

Table 1. propagation model in 10240 Ksymbol/sec

Propagation model	Tap number	Tap delay(ns)	Tap amplitude
type 0	0	0	1.0000
type 1	0	0	0.9990
	1	97.66	0.0447
type 2	0	0	0.9017
	1	97.66	0.4323

It is a clear fact that the necessity of equalizer gets reduced in type 0 and type 1 channel, thus mainly type 2 as a channel propagation model of following simulation process is studied in this paper.

2.2 Rain attenuation model

Ka band channel models studied in [4][5] are taken into account in this paper without loss of generality, since these channel models are built up based on a Ka-band frequency with a LOS and furthermore, characteristics of these can be applied to B-WLL channel model. In this model, envelope of received signal is represented by Gaussian distributed probability density function. This Gaussian distributed model can be given as proposed in [4] as following

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

Three rain attenuation models such as rain, intermittent light rain and thundershower are considered. The mean and variance of signal envelope for each rain attenuation model is given as Table II.

Table 2. Parameters of Rain Attenuation Model

	Envelope Parameter	
	Mean	***Variance***
Rain	0.662	0.02
Intermittent light rain	0.483	0.00003
Thundershower	0.346	0.01386

3. PRE-EQUALIZATION TECHNIQUES FOR THE B-FWA SYSTEM

In order to support higher data rate services, the signal characteristics are severely distorted by either an inter-symbol-interference (ISI) or additive thermal noise. These degradation factors limit the use of conventional equalizer technique (herein after we call it post-equalizer) due to the fact that this kind of equalizer can reduce the ISI effect, but it enhances the thermal noise on the contrary, i.e. noise enhancement effect since noise component can be boost up during the equalizing process. Thus, in an effort to tackle this problem, the pre-equalizing technique is taken into account in this paper, since this can utilize the channel characteristics before sending a signal to channels. By doing such a procedure, the pre-equalizer can utilize almost perfect channel coefficients and thus, eliminate noise enhancement effect [5]. Moreover, the pre-equalizer techniques are quite suitable for burst transmission mode since tap coefficients can be frequently updated on a burst basis.

3.1 Noise enhancement of general equalizer

The Fig. 1 is the general structure of an equalizer, which is called here the post-equalizer.

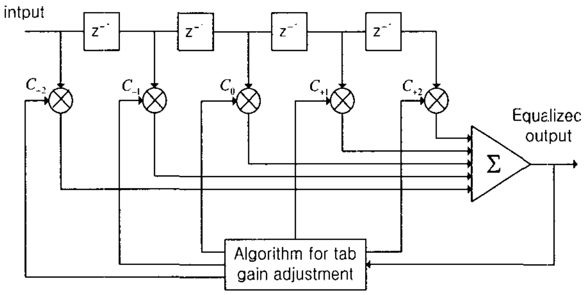


Fig. 1. The structure of a general equalizer

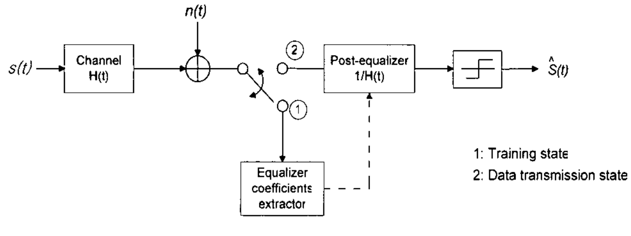
This equalizer adds up delayed version of received signal multiplied by suitable coefficient to restore desired signal.
Using the equalizer technique, ISI distorting the signal can be almost perfectly eliminated. However, during the equalization process, additive noise is also multiplied and added up. As a result, the additive noise is enhanced by the equalizer [7]. As received signal is consist of transmitted signal and additive white Gaussian noise, $r(t)=s(t)+n(t)$. The output of equalizer can be written as follows.

$$\begin{aligned} d(t) &= \sum_{i=-N}^{N} c_i r(t-i) \\ &= \sum_{i=-N}^{N} c_i\{s(t-i)+n(t-i)\} \\ &= \sum_{i=-N}^{N} c_i s(t-i)+\sum_{i=-N}^{N} c_i n(t-i) \end{aligned} \tag{2}$$

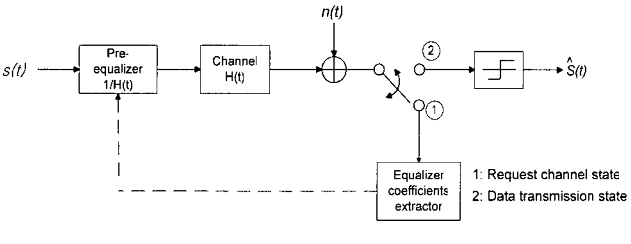
Where c_i is the channel coefficient (tap gain) of the equalizer and 2N+1 is the total number of taps. The first term is the restored signal containing data, and the second term is the noise component enhanced by the equalizer. From this equation, it is clearly inferred that the degree of noise enhancement is mainly influenced by the coefficient of the equalizer. In equalizing procedure, this weighted noise enhancement term becomes dominant, and consequently, this makes the signal-to-noise ratio (SNR) decreased, which cause the degradation of the system performance.

3.2 Pre-equalization technique

Definition of the pre-equalization is that the transmitter performs equalization before the signal is transmitted. It means that the pre-equalizer distorts the signal to make it more reliable by eliminating ISI when the signal reaches the receiver. The knowledge of the channel state information is necessary in order to pre-equalizing the signal.



a) Post-equalizer



b) Pre-equalizer

Fig. 2. The simplified structure of post-equalizer and pre-equalizer

If the pre-equalizer apply an unsuitable equalizer tap coefficients, ISI component of received signal still remains or unintentional distortion interferes decision of the receiver. In both cases performance of whole system rapidly degrades. Fig. 2 is a simplified structure of post-equalizer and pre-equalizer.

The basic procedure of the pre-equalizer is as followings:

- When the subscriber demands a channel (i.e. connection request), BS extracts a post-equalizer tap coefficients based on the received signal (training sequence) that subscriber transmits.
- Once finding tap coefficients, BS transmits them to the corresponding subscriber by inserting them into a downlink burst frame (i.e. feedback channel).
- Subscriber arranges tap coefficients of pre-equalizer based on the informed tap coefficients, and then pre-equalized signal is transmitted to uplink.
- Finally, BS periodically updates equalizer tap coefficients through a feedback channel.

The pre-equalizer technique has advantage of power saving since it can reduce the noise enhancement and thus, increase SNR compared to post-equalization technique. As describe before, the pre-equalization technique is performed at the transmitter not at the receiver, such that the pre-equalizer could not induce noise enhancement. As a result pre-equalizer achieves the same signal to noise ratio with less transmit power than that of post-equalizer. Another advantage of pre-equalizer is no delay process. The post-equalizer is triggered after receiving the training sequence. The time spent in adjusting tap coefficients of equalizer (i.e. training mode) is unavoidable, which means that the receiver cannot process data promptly. On the contrary, the pre-equalizer can process data immediately. In the equalizer coefficients extraction stage, the pre-equalizer must obtain the coefficients that guarantee sufficient low mean square error (MSE). That means acquisition of suitable coefficients. If the length of training sequence is restricted, we should choose proper algorithm. In general learning rate depends on the characteristic of algorithm. LMS algorithm is simple and capable of achieving satisfactory performance. However, it has slow learning rate. On the contrary, RLS algorithm has fast learning rate and low MSE, while it has large computational complexity [8].

4. SIMULATION RESULTS

Ka band channel models studied in [4] are taken into account in this paper without loss of generality, because these channel models are built up based on a Ka-band frequency with a LOS and furthermore, characteristics of these can be applied to B-WLL channel model. The ISI and multi-path model assumed in this simulation is type 2 as shown in Table I. Following Gaussian distributed model as proposed in [4], three kinds of rain attenuation models such as rain, intermittent light rain and thundershower are considered. The mean of signal envelope for each rain attenuation model is 0.662 (relatively stationary), 0.483 (medium stationary), and 0.436 (the worst case) in the order of rain, intermittent light rain and thundershower, respectively.

In this paper we evaluate performance of pre-equalizer using an adaptive equalization algorithm (i.e. LMS and RLS) for three different kinds of rain attenuation environments. Main parameters for adaptive algorithms are step size, forgetting factor, and the length of training sequence. We assume that the step size of LMS is 0.01 and forgetting factor of RLS is fixed to 0.999. The BER performances of pre-equalizer are compared to those of post-equalizer in the context of a variety of channel models. Our main interest is how much the pre-equalizer technique can improve the BER performance even under the severe channel environment and what's the impact of length of training sequence and selection of adaptive algorithm on BER performance.

Fig. 3 shows the BER performances for the post-equalizer and the pre-equalizer using LMS algorithm as a function of various training sequence lengths and rain attenuation models for a given signal-to-noise ratio (SNR) and four different channel scenarios, i.e. AWGN, rain, intermittent light rain, and thundershower. It is noticed that the BER performances of LMS pre-equalizer (preLMS) outperforms post-equalizer (postLMS) if enough training sequence length is guaranteed (i.e. at 250 symbols). In particular, the performance by adopting a pre-equalizer at thundershowers gains considerably compared to that of post-equalizer in a thundershower case for 10dB of SNR with 1000 training symbols. Whereas, the performance of a post-equalizer shows the BER floor irrespective of a large training sequence length. This observation presents the design parameter to optimize the system performance. We can find the similar tendency in simulation results using RLS algorithm as LMS algorithm as shown in Fig. 4. However, for a 15dB of SNR, the BER performance by post-equalizer RLS algorithm attains considerable gain compared to pre-equalizer RLS algorithm.

The BER comparison of post-equalizer and pre-equalizer is shown in Fig. 5 as a function of two adaptive algorithms (LSM and RLS), rain attenuation models and SNR values for a fixed respective training sequence length of 500 symbols and 50 symbols. We note that the required length of training sequence for a RLS algorithm guaranteeing a certain level of BER performance is small than that of LMS algorithm. This result is not surprising because LMS algorithm needs longer training sequence than RLS algorithm. In this figure it is clearly observed that even though the post-equalizer is preferable for an AWGN situation, the pre-equalizer outperforms for every rain attenuation cases. Most important result is that if sufficient training sequence and SNR given, much better BER performance can be achieved at the most severe rain condition, i.e. thundershower, by virtue of its efficient utilization of pre-knowledge of channel characteristics. The much severe the channel condition occurs, the more gain of pre-equalization. In Fig. 6, finally, BER comparison of two algorithms using pre-equalization as a function of various training sequence lengths and rain attenuation models indicates that RLS algorithm (preRLS) can provide considerably better performance than LMS algorithm (preLMS) with shorter length of training sequence (under 500 symbols for 10dB of SNR) for the all cases of rain attenuation models. However, we can observe that with 1000 symbols for 10dB of SNR, preLMS can attain the similar BER performance. From this result, it is inferred that with only sufficient length of training sequence the pre-equalization using LMS can achieve similar BER performance to one using RLS.

To summarize briefly, the post-equalization technique is feasible for relatively good channel conditions, while the pre-equalization is preferable for much severe channel conditions. The pre-equalizer using RLS algorithm is most preferable if the large computational complexity is not a stringent factor. Otherwise, pre-equalization using LMS algorithm with sufficient training sequence is preferable for rain attenuation channel environments.

5. CONCLUSION

In this paper, the performance of pre-equalization technique which can be applicable for the B-WLL uplink is evaluated and compared to post-equalization under three kinds of rain attenuation channels such as rain, intermittent light rain and thundershower. At such a millimeter wave communication as B-WLL system using Ka-band frequency, the wireless link is very susceptible to rain dropping channels which can cause severe performance degradation. Thus, the comparison of two algorithms (LMS and RLS) is investigated in the context of channel models and the length of training sequence. From the simulation results, it is shown that the post-equalization outperforms only at quite good channel conditions such as AWGN, while the pre-equalization can guarantee better BER performance at every channel conditions, especially performance gain increases as the severity of channel increases. It is concluded that the pre-equalizer using LMS algorithm is preferable at delay-tolerant situation where the complexity of algorithm is not a strict factor, while one using RLS is suitable for fast burst transmission with a relatively short training sequence.

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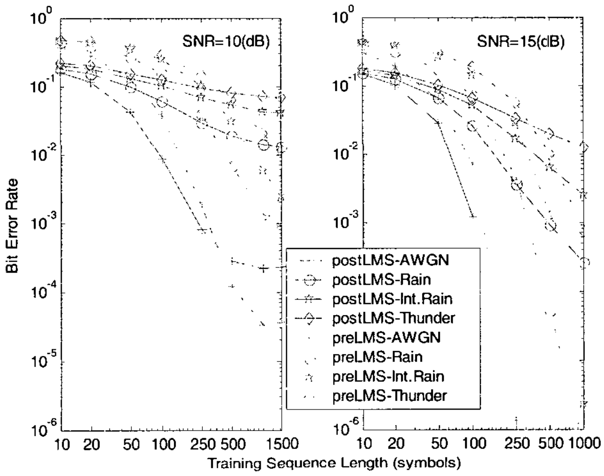


Fig. 3. BER of post-equalizer and pre-equalizer using LMS algorithm as a function of various training sequence lengths and rain attenuation models for a given SNR.

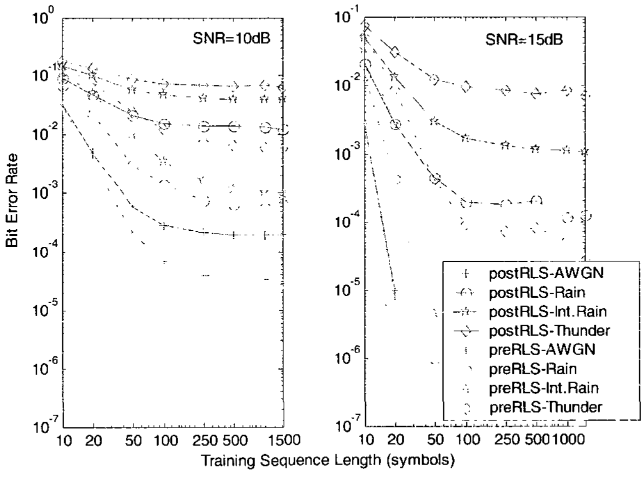


Fig. 4. BER comparison of post-equalizer and pre-equalizer using RLS algorithm as a function of various training sequence lengths and rain attenuation models for a given SNR.

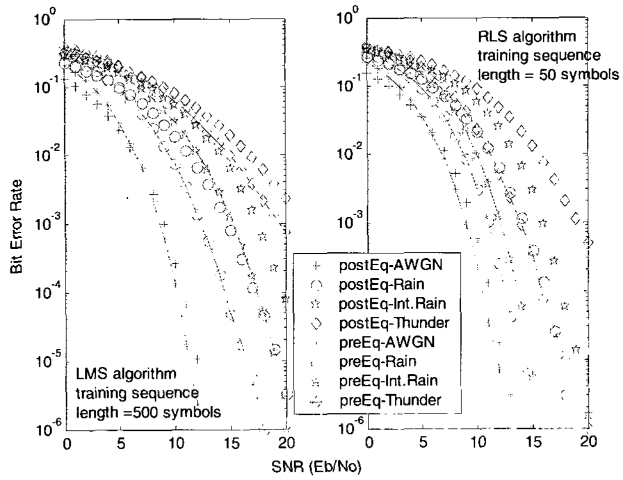


Fig. 5 BER comparioson of post-equalizer and pre-equalizer as a function of adaptive algorithms and rain attenuation models and SNR for a fixed training sequence length.

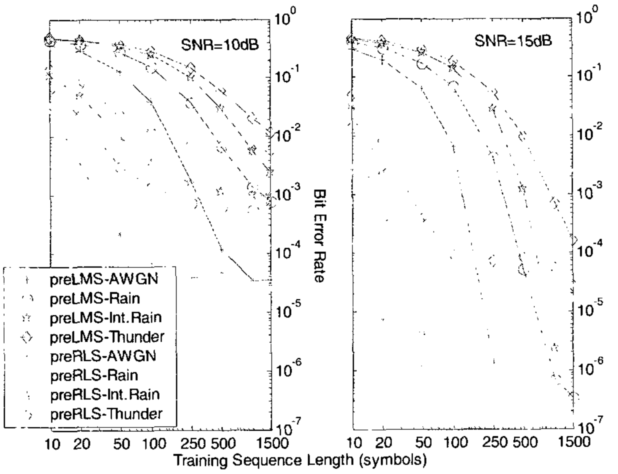
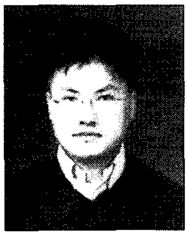


Fig. 6. BER comparison of the pre-equalizer using different algorithms as a function of various training sequence lengths and rain attenuation models for a given SNR.



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