نوزدهمین کنفرانس اپتیک و فوتونیک ایران و پنجمین کنفرانس مهندسی فوتونیک ایران

۳ تا ۵ بهمن ماه ۱۳۹۱- دانشگاه سیستان و بلوچستان

عملکرد ترازگرهای عصبی برای سیستم‌های بیسیم نوری درون ساختمانی تحت مدولاسیون‌های روشن-خاموش و مکان پالس در کانال‌های پخشی

فریده جاویدی و حسین خوشبین

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چکیده – در این مقاله ترازگر عصبی جدیدی با پیچیدگی محاسبات کمتر و عملکرد مطلوب‌تر برای سیستم‌های بیسیم نوری درون‌ساختمانی با مدولاسیون‌های مکان پالس و روشن-خاموش معرفی شده است. ترازگر عصبی پیشنهادی عملکرد سیستم‌های مکان پالس در کانال‌های پخشی را به طور چشمگیری بهبود داده است؛ چراکه سیستم‌های مکان پالس تراز نشده در کانال‌های پخشی رفتار غیر قابل قبولی دارند. عملکرد سیستم مکان پالس با ترازگر عصبی پیشنهادی در حدود 10 dB نسبت به نمونه مشابه روشن-خاموش در کانال‌های بیسیم نوری پخشی بهبود یافته است. نتایج شبیه‌سازی نیز بهبود عملکرد سیستم‌های مخابراتی بیسیم نوری درون‌ساختمانی را با ترازگر عصبی پیشنهادی نشان می‌دهد.

کلید واژه- ترازگری وفقی، سیستم‌های بیسیم نوری درون ساختمانی، شبکه‌های عصبی مصنوعی.

کد PACS – ۰۶۰/۰۰۶۰

Performance of On-Off Keying and Pulse Position Modulation for Diffused Indoor Optical Wireless Channels Employing Neural Equalizers

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Abstract- This paper presents an artificial neural network (ANN) based equalizer for indoor optical wireless communication systems. Although pulse position modulation (PPM) scheme is power efficient compared with on-off keying (OOK) modulation in line-of-sight links, its performance is unacceptable in diffused channels. So, a novel ANN equalizer has been proposed for OOK and PPM based indoor optical wireless systems in diffused channels. The new ANN equalizer not only outperforms other adaptive equalizations, but also has fewer computational complexities compared with recent ANN equalizers. Furthermore, the proposed ANN equalizer makes the PPM scheme appropriate for diffused links, since the simulation results indicates that there is about 10 dB performance improvement in neurally equalized PPM system compared to similar case in OOK scheme.

Keywords: Adaptive equalization, artificial neural networks, indoor optical wireless systems.

PACS No: 060.0060

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1 Introduction

The ever increasing bandwidth requirement per user and bandwidth congestion in the radio frequency (RF) systems has led to search for a complementary system in certain applications. The availability of license free huge bandwidth in the infrared range (IR) can be effectively utilized for indoor and outdoor optical wireless communications. Free Space Optical (FSO) which is an outdoor optical wireless communication has been developed commercially and has experienced a rapid industrial growth of applications [1]. Indoor optical wireless communication is a future proofed solution for wireless communication since providing huge bandwidth and mobility for users as well as immune links of high rate transferring data. In large environments where each user requires huge bandwidth such as waiting rooms; optical wireless communication could be the most appropriate solution [2]. Furthermore, in such locations with electromagnetic interference such as subway stations and hospitals; the optical wireless communication is preferred to the RF one.

There are two basic link topologies in indoor optical wireless communications; Line-of-Sight (LOS) and diffused links. The LOS link is not only more bandwidth efficient in compare with diffused link; but also because of no multipath and low level of dissipation is more power efficient. Although communication via a narrow beam LOS links offers high data rates in excess of 1 Gbps [3], it suffers from lack of mobility and blocking. A degree of mobility could be provided by increasing the coverage area using wide beam of lights in LOS links or employing cellular concepts, but at the cost of decreasing of the power efficiency [4]. The diffused link depends on the reflection of the optical beam of light from different opaque surfaces such as walls and ceilings. The existence of multipath between transceivers reduces the probability of blocking as well as offering considerable degree of mobility but at the cost of high path loss and reduced power level at the receiver. Therefore, the main problem of diffused link which is the result of multipath is Inter-Symbol Interference (ISI) [2]. As the channel become more dispersive, the higher penalty of ISI should be paid. Another cause of signal degradation in the optical wireless systems is ambient light interference (ALI). As to different techniques for ALI removing [3], [5], ALI is not considered in this study. Photodetector shot noise is the major noise in indoor optical wireless systems which is well modeled as a high intensity shot noise process and is considered approximately as AWGN noise due to ambient light noise.

There are several techniques such as utilizing particular transceivers [6], applying optical impulse response modulation [7], and different equalization techniques which have been employed to mitigate ISI in diffused channels. The maximum likelihood sequence detection (MLSD) technique has been illustrated to give optimum results in dispersive environments, however its complexity coupled with the delay associated with the processing time, prohibit its use in many applications [8]. Hence suboptimum equalizers have been developed to combat ISI. Ref. [9] has introduced channel equalization as a classification problem and since of its nonlinearity recommended the nonlinear structure of artificial neural network (ANN) as a solution. Different architecture of ANN has been discussed in [9] as an equalizer and have been reported that their performance is much better than conventional equalization techniques. Performance of multilayer perceptron as an equalizer in indoor optical wireless systems has been studied in [2], [3], [5], [10], [11] in order to compensate for the multipath dispersion of the diffused optical wireless channels.

In this paper, a novel feedforward back propagation neural network is adopted as an equalizer for indoor optical wireless systems to combat ISI in dispersive channels. The reminder of this paper is as follows. Optical wireless systems are described in detail in Section II. In Section III a concise comparison of optical wireless modulation methods is presented. While Section IV provides a review of adaptive equalization and ANN based equalizers for indoor optical wireless systems, the novel ANN equalizer is introduced in Section V. Finally the simulation results are discussed in Section VI and conclusion remarks are given in Section VII.

2 Optical Wireless System Model

Intensity modulation with direct detection (IM/DD) is the most common modulation technique applied for indoor optical wireless systems. In intensity modulation (IM) the instantaneous power, $x(t)$, of the optical carrier is modulated by the transmitted data. Direct detection (DD) is done via a photodetector receiver which produces an output current, $y(t)$, in concern with the received instantaneous power and photodetector responsivity. The channel model for IM/DD is described as follows:

$$y(t) = R \cdot x(t) * h(t) + n(t) \tag{1}$$

where R is the photodetector responsivity, $*$ is continuous-time convolution, $h(t)$ is the optical channel impulse response which is normalized via (2) and $n(t)$ is the noise signal which is independent of $x(t)$ and generally modeled as additive white Gaussian noise signal.

$$\sum_{k=0}^{\infty} h(kT) = 1 \tag{2}$$

where T is the sampling time.

Optical wireless channels differ from wireless radio frequency channels since $x(t)$ represents instantaneous optical power. Hence, the transmitted signal, $x(t)$, must satisfy the non-negativity constraint (3). The other constraint of the optical wireless system which is implied in (4) is on the average transmitted optical power p_t.

$$x(t) \geq 0 \tag{3}$$

$$p_t = \lim_{T \to \infty} \frac{1}{2T} \int_{-T}^{T} x(t)dt \leq p \tag{4}$$

where p is the optical average power limit imposed by eye and skin safety constraints. Equation (4) indicates that the average optical power is given by the average signal amplitude, rather than the squared signal amplitude as in the case of RF channels.

The channel impulse response of the ceiling bounce model which is the most widely used due to its computational efficiency and an excellent matching with measured channel is described as [2], [3], [5], [10], [11]:

$$h_c(t, a) = \frac{6a^6}{(t+a)^7} u(t) \tag{5}$$

where a is calculated via (6) and $u(t)$ is a unit step function.

$$a = \frac{2H}{c} \tag{6}$$

where H is the height of the ceiling above the transceivers and c is the light velocity. The delay spread of the diffused channel is given by:

$$D_{rms} = \frac{a}{12}\sqrt{\frac{13}{11}}. \tag{7}$$

3 Modulation Methods

The optical channel constraints; (3) & (4), prohibit the direct application of the most traditional RF signaling schemes and special modulation techniques must be applied in the optical wireless systems. There are a number of different modulation methods for IM/DD. Rectangular on-off keying (OOK) which is a special case of Rect-PAM[1], is the most basic scheme. OOK is desirable for indoor optical wireless channels, but it requires high power value. To reduce power, pulse time modulation (PTM) scheme, including pulse position modulation (PPM) which is the most widely used, have been adopted. L-PPM is coded OOK in which M bits are divided into $L = 2^M$ sub-intervals termed chips. In PPM method each symbol is encoded by transmitting a single non-zero pulse in one of successive slots. In fact, the position of the pulse conveys information.

To make a fair comparison between OOK and PPM methods of modulation, the power ratio, γ_{power}, and bandwidth proportion, $\gamma_{bandwidth}$, has been defined in (8) and (9) respectively.

$$\gamma_{power} = \frac{P_{OOK}}{P_{PPM}} = \frac{L}{2} \tag{8}$$

$$\gamma_{bandwidth} = \frac{BW_{OOK}}{BW_{PPM}} = \frac{M}{L} \tag{9}$$

Eq. (8) expresses that as L become greater, the average power value is reduced significantly in L-PPM signaling in concern with OOK scheme. This means that in LOS channels L-PPM signals need less power than OOK ones for the same bit error rate (BER).

In dispersive channels because of the multipath, performance of PPM signaling in concern with OOK one is different from LOS links. Regard to transmitting signal with shorter duration pulse in PPM scheme, PPM signaling is more susceptible to multipath induced ISI in diffused links and it needs more power at the same BER in diffused channels.

Despite the fact that many bandlimited pulses outperform rectangular pulses respecting ISI over dispersive channels, regard for non-negativity constraint a large number of such pulses cannot be used in optical intensity modulated channels. In fact, the non-negativity constraint prohibits the use of many band limited pulse shapes such as sinc, root-raised-cosine and many others.

4 Adaptive Equalization and ANN Based Equalizer

The common technique to compensate for the ISI induced power penalty in dispersive channels is incorporating an equalizer at the receiver.

[1] Rectangular Pulse Amplitude Modulation

Basically, the FIR digital filter with adjustable tab coefficients which its frequency response is the inverse of the channel frequency response is used as an equalizer to minimize the effect of ISI in a dispersive channel. However, the channel impulse response might be time varying and usually is unknown in advance. Therefore, adaptive equalization is the preferred option, in which channel parameters are estimated at the receiver by transmitting a number of training sequences. Adaptation algorithms such as least mean square error (LMSE), are generally based on reducing the magnitude of the error signal which is the difference between actual and target outputs, by adjusting the filter coefficients after every iteration.

Indeed, channel equalization can be considered as a classification problem [9]. The optimal solution to this classification issue is inherently nonlinear; hence nonlinear structure of ANN can enhance the performance of the conventional channel equalizers [9]. The functional unit of ANN is a neuron, depicted in Fig. 1, with a simple functionality implied in (10).

$$y_j = f(b + \sum_{i=1}^{n} w_{ij} x_i) \qquad (10)$$

where b is the input bias, $x_1, \ldots, x_n$ are the neuron inputs, $w_{1j}, \ldots, w_{nj}$ are the weights, y_j is the neuron output and $f(.)$ is the activation function. The sigmoid function and linear function are the common activation functions used in ANN for classification such as in equalizers [9].

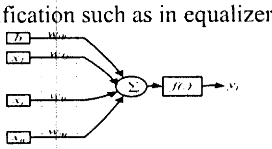


Figure 1: Neuron structure

While an ANN basically consists of input layer and output layer which have some neurons, it may have some hidden layers also. In fact, the network architecture defines the neurons arrangement in the network. In equalizing applications of ANN while the number of input neurons depends on the order of the equalizer, the output layer has only 1 neuron [9].

In [2], [10] and [11] a multilayer perceptron with 1 hidden layer of 36 neurons is applied for equalization in diffused channels. It is shown that the performance of ANN equalizer with hard decision is comparable to linear adaptive equalizer with LMS algorithm and its performance becomes better by using soft decision but at the cost of more complexity [2], [9].

5 The Proposed ANN Equalizer

According to acceptable performance of multilayer perceptron as an equalizer in indoor optical wireless systems [2] and [10], in this paper a feed-forward back propagation NN with 1 hidden layer of 26 neurons is adopted as an equalizer. The activation function which is used for both layers is log sigmoid. Following [2], [11] before applying the ANN to equalize the indoor optical wireless system, the network is trained using the scaled conjugate gradient algorithm.

Since PPM is more susceptible to ISI in dispersive channels, more delayed samples are required to equalize the system in compare to OOK one. So that the number of input neurons which depends on the number of delayed samples fed to the equalizer for OOK and PPM are 4 and 8, respectively. Due to reducing the number of neurons in the hidden layer means computational complexity reduction, the novel ANN equalizer requires about 27% fewer computational complexities in comparison to the proposed ANN equalizer in [2], [11].

6 Simulation Results

Fig. 2 shows the indoor optical wireless system model with equalizer. The input data are in the form of OOK or PPM and after intensity modulation, the signal is transmitted through diffused optical wireless channel with an impulse response of $h(t)$ which is normalized via (2) and additive white Gaussian noise $n(t)$ with zero-mean, double-sided power spectral density $N_0/2$. At the receiver after direct detection, the time delayed discrete signal $\{z_k;\ k=0, \ldots, n\}$ where n depends on the channel time dispersion, is fed to the either linear adaptive equalizer or neural equalizer. The performance of the indoor optical wireless system with 2 aforementioned types of equalizer has been studied in this paper. Following [2], [11], a linear adaptive equalizer with least mean square error (LMS) is used as benchmark for the performance comparison of the new ANN equalizer described in section V. Furthermore, different modulation techniques, OOK and PPM are applied for transmitting data.

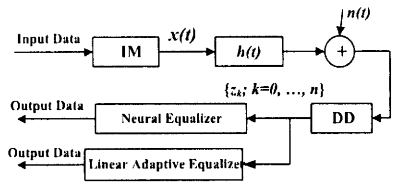


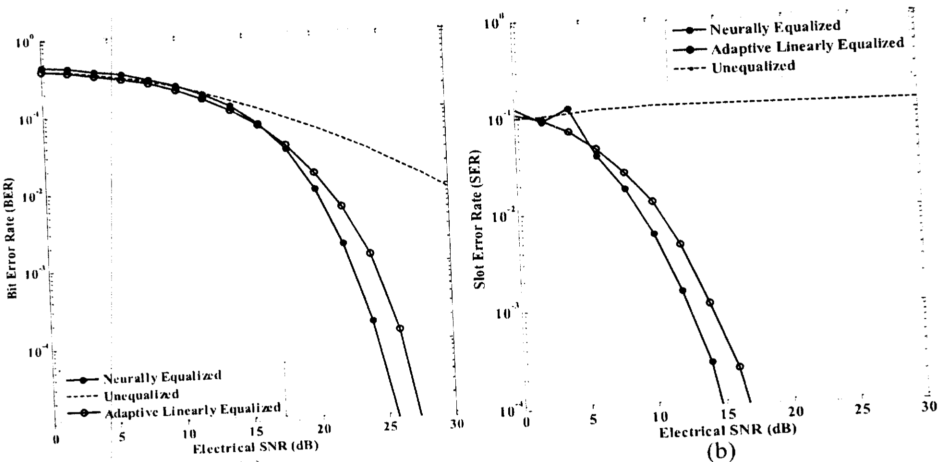
Figure 2: Indoor optical wireless system model with equalizer

Fig. 3 shows the performance of indoor optical wireless system with OOK and PPM signaling as a function of signal to noise ratio (SNR) for 150 Mbps OOK and 8-PPM schemes through a dispersive channel with D_{rms} 5 nsec. Following [2], [3], [5], [10], [11] electrical SNR is defined as:

$$SNR_{elec} = \frac{R^2 . P^2}{2R_b . N_0} \qquad (11)$$

where R is the photodetector responsivity, P is the average optical power, R_b is the bit rate and N_0 is the one sided noise spectral density.

As it is observed in fig. 3(a) which shows the BER performance of OOK optical wireless system, at the BER of 10^{-3} the unequalized OOK requires electrical SNR of about 36 dB while the BER performance of adaptive linearly equalized one improves about 12 dB. The condition becomes much better by using the new ANN equalizer. In the case of using proposed neural equalizer, there is a BER performance improvement about 14 dB in compare with unequalized system and 2 dB BER performance improvement in comparison to linearly adaptive equalized one.



(a) (b)

Figure 3: Performance of unequalized and linearly adaptive and neurally equalized indoor optical wireless system at the bit rate of 150 Mbps in diffused channel with D_{rms} 5 nsec with (a) OOK and (b) PPM scheme

In a similar way, the linear adaptive equalization with LMS algorithm and the new ANN equalization have been applied to 8-PPM system at the same bit rate and through diffuse channel with the same D_{rms}. The SER performance of unequalized 8-PPM system as noticed in fig. 3(b) is unacceptable while linear adaptive and neural equalization not only improve the SER performance but also the equalized PPM system outperform the equalized OOK one about 10 dB (refer to fig. 3). Moreover, in comparison to the performance of ANN equalizer with hard decision proposed in [2], [11], the novel ANN equalizer outperforms them while it has fewer computational complexity. In fact, the performance of the system by using novel neural equalizer is not only better than proposed ANN equalizer with hard decision in [2], [11], but also is comparable to the performance of proposed ANN equalizer with soft decoding in [2]. Meanwhile in this paper hard decision making has been done after equalization of the novel ANN equalizer which has fewer computational complexities in compare to soft decoding. The performance of the novel ANN equalizer with hard decision making is comparable to ANN equalizer with soft decoding proposed in [2].

7 Conclusion

A comparative study of common modulation performance, OOK and 8-PPM schemes in dispersive channels is presented. A new ANN equalizer has been proposed for OOK and 8-PPM based indoor optical wireless systems which has fewer computational complexities. Simulation results illustrated that the proposed ANN equalizer not only outperforms linear adaptive equalizer, but also despite its fewer computational complexities in contrast to recent ANN equalizers, it has better performance. Another achievement which is worthy to note, is the better performance of neurally equalized 8-PPM system compared to neurally equalized OOK one which makes it more convenient to diffused links of indoor optical wireless communication.

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