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# Performance of DWT-ANN Based Signal Detector/Equalizer for DPIM in Practical Indoor Optical Wireless Links

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***Abstract*— Artificial neural network (ANN) finds its application in communication engineering in a diverse areas such as channel equalization, channel modelling, error control code because of its capability of nonlinear processing, adaptability, and parallel processing. On the other hand, the wavelet transform (WT) with both the time and the frequency resolution provides the exact representation of signal in both domains. Applying these modern tools to signal processing in channel equalization and digital signal detection provide an enhanced performance compared to the traditional tools. In this paper, the slot error rate (SER) performance of digital pulse interval modulation (DPIM) in diffuse indoor optical wireless links employing equalization using discrete WT (DWT) and ANN is reported. The simulation results show that a performance gain of ~ 8 dB is achieved by utilizing the new approach compared to the traditional approach based on the finite impulse response (FIR) digital filters.**

## I. INTRODUCTION

The increasing popularity of files and video sharing and the possibility of digital radio and TV broadcast over the internet have already put a huge bandwidth demand on the personal communication systems. On the other hand, the fourth generation communications promise to support multiple applications and a higher bandwidth per user (more than 100 Mbps) for both indoor and outdoor applications [1]. This will place an enormous challenge on already congested microwave and radio frequency (RF) spectrum with limited capacities. However, the solution to the bandwidth congestion and the 'last mile access' bottleneck, would be to employ optical communications. Though optical wireless (OW) communication is not a new technology, the recent profuse demand in bandwidth makes it a real contender for the primary medium in personal communication for the future applications. In fact, combination of fibre optics, indoor and outdoor OW links can readily overcome the problem of last mile access for a foreseeable future. In fact, the largest installed short-range wireless communication links are optical rather than RF [2]. In outdoor applications we are seeing a growing range of OW system covering rages up to 5-6 km at a reasonable cost. In indoor environment, we have also seen growth in research activities and availability of device for certain application such HDTV, high-speed down load station, to name a few [3, 4]. However, mobility and cost are important issues compared with the RF links.

The basic system model for in-house OW communication was first developed by Gfeller and Bapst in 1979 [5] but the extensive study of channel capacity, channel modelling as well as modulation techniques were done mostly in late nineties [6-10]. A number of modulation techniques with certain distinctive features have been proposed. On-off keying (OOK), the most basic, requires a high average optical power, whereas pulse position modulation (PPM) offers power efficiency but at the cost of a higher bandwidth requirement and it is also more susceptible to the multipath induced intersymbol interference (ISI) in non-line-of-site (non-LOS) links as well as requiring both the slot and symbol synchronization. Differential PPM (DPPM) [11] and digital pulse interval modulation (DPIM) [12] with built-in symbol synchronization provide improved throughputs and efficient utilization of the available bandwidth. DPPM and DPIM symbols with guard slots also offer a degree of immunity to the ISI. In a highly dispersive channel, the unequalized error performances of PPM, DPPM and DPIM are rather inferior compared with the OOK. A number of equalization techniques have been investigated for these modulation schemes [4, 7, 11, 12]. Though the maximum likelihood sequence detector (MLSD) is the optimum solution, it is not suitable for variable symbol length modulation schemes of DPPM and DPIM for practical reasons [12]. Hence sub-optimum solutions like decision feedback equalizer would be the preferred option [11, 12]. But equalization based on the finite impulse response (FIR) filter suffers from severe performance degradation in time varying and non-linear channels [13].

However, defining equalization as a pattern classification problem have open the possibility of utilizing ANN [14, 15]. Furthermore, combining ANN with the WT for signal processing in dispersive environment have shown promising results [16]. In [17] it has been reported that ANN with adaptability and nonlinear processing capability is a perfect tool for signal detection for non-Gaussian, nonlinear and time-varying channel. In [14, 16] the concept has been taken further by employing the continuous WT (CWT) for the feature extraction and ANN for the pattern classification at the receiver. The ANN is an adaptive system with learning capabilities. The learning process can further be enhanced (i.e. faster convergence) by removing the noise from the training signal and reducing the number of input (if possible). It is possible to reduce the WT coefficients (hence reduce learning time for ANN) by DWT.

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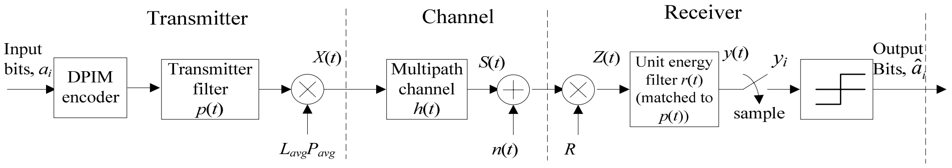


Figure 1. Block diagram of the unequalized DPIM system

Moreover denoising is possible with DWT, thus offering more flexibility. In this paper a hybrid DWT-ANN is adopted for signal detection and channel equalization for diffuse indoor OW link employing DPIM scheme.

The paper is organised as follows: the channel model for non-LOS indoor optical system is outline in Section 2 with brief introduction to DPIM and error probability of DPIM in diffuse environment. The proposed DWT-ANN based equalizer is described in Section 3 and the error performance of the proposed system is reported in the Section 4 with comparison to the linear equalizer. Finally, the conclusion is given in Section 5.

## II. DPIM, INDOOR OW CHANNEL MODEL AND UNEQUALIZED PERFORMANCE

DPIM is an anisochronous modulation technique, in which each block of $M$ (=$\log_2 L$) data bits is mapped to one of $L$ possible symbols of different length. Every symbol begins with a pulse, followed by a series of empty slots, the number of which is dependent on the decimal value of the block of data bits being encoded. In order to avoid symbols in which the time between adjacent pulses is zero, an additional guard band of one or more slots may be added to each symbol immediately following the pulse. Detailed information about DPIM can be found in [12]. In this work, our main focus is on the DPIM with no guard slot. Hence, unless stated otherwise, DPIM in the paper refers to the case with no guard slots.

Assuming independent and identically-distributed (*iid*) random data, the average symbol length is $\bar{L} = 0.5(L+1)$ and slot duration, $T_s$ in terms bit duration $T_b$ is defined as: $T_s = T_b M(\bar{L})^{-1}$ [12].

For the ideal channel without multipath distortion and additive white Gaussian noise, the slot error probability $P_{se}$ for a matched filter based receiver with a threshold level set mid way between the low and high levels can be approximated as [18]:

$$P_{se} = Q\left(\sqrt{\frac{1}{2}\bar{L}M}\ \frac{RP_{avg}}{\sqrt{\eta R_b}}\right) ; \qquad (1)$$

where $R$ is the photodetector responsivity, $\eta$ is the noise spectral density and $P_{avg}$ is the average transmitted optical signal power and $R_b$ is the bit rate.

However, in a multipath channel, which is completely characterised by its impulse response $h(t)$, the $P_{se}$ is calculated by summing the error probabilities in all possible sequences [12].

The RMS delay spread $D_{rms}$ is a parameter which is commonly used to quantify the time dispersive properties of multipath channels. Carruthers and Kahn [6] have developed the ceiling bounce model to represent the channel with an impulse response $h(t)$ given by:

$$h(t) = \frac{6(0.1D_{rms})^6}{(t+0.1D_{rms})^7}u(t) ; \qquad (2)$$

where $u(t)$ is the unit step function.

The power penalties associated with the dispersive channel may be separated into two factors: optical path loss and multipath dispersion [4]. In this paper, the consideration is limited to the power penalty due to multipath propagation only. Consequently, the channel impulse response is normalised by making area under the impulse response curve to 1.

A block diagram of the unequalized DPIM system under consideration is shown in Fig. 1. The discrete-time impulse response of the cascaded system is given as [19]:

$$c_k = p(t) \otimes h(t) \otimes r(t)|_{t=k\tau} ; \qquad (3)$$

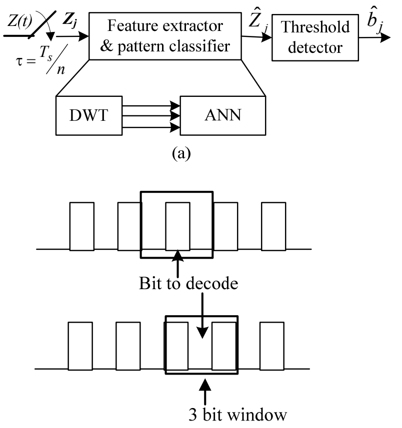
where $\tau$ is the sampling time. $\tau$ is normally equal to integral fraction of $T_s$( i.e. $\tau = T_s/n$), where $n$ is a positive integer. Unless the channel is nondispersive, $c_k$ contains a zero tap, a single precursor tap (with the largest magnitude) and possibly multiple postcursor taps. On a non-dispersive channel, the optimum sampling point, i.e. the point that minimises the probability of error, occurs at the end of each slot period $T_s$. However, on dispersive channels, the optimum sampling point changes as the severity of ISI changes. The receiver filter output $y_i$ corresponding to the penultimate bit for $\tau = T_s$, in the absence of noise, is given by [19]:

$$y_i = 2R\bar{P}\boldsymbol{a_i} \otimes c_k|_{k=m} ; \qquad (4)$$

where $\boldsymbol{a}_i$ is the $m$-bit sequence, $a_i = \{0, 1\}$ is the value of the penultimate bit in $\mathbf{a}_i$, $m$ is the number of taps. Details analysis and results of the power plenty occurred due to the multipath propagation in DPIM system is further discussed in [12] and interested readers are suggested to refer it. However, it is to be noted that the power plenty in unequalized DPIM increased exponentially with increasing delay spread and the average optical power required to achieve a desirable error performance is impractical for all values of $D_t$ > 0.1. Since symbol boundaries are not known prior to detection, practical implementation of MLSD for DPIM is not feasible. Hence suboptimal decision feedback equalization is preferred choice.

## III. WAVELET TRANSFORM AND ARTIFICIAL NEURAL NETWORK BASED RECEIVER

A substantial work on CWT and ANN based receiver for OOK was done by Dickenson and Ghassemlooy [16, 20, 21]. Similar approach of equalization is considered here for different modulation technique. The system complexity is reduced by implementing DWT and removing redundant WT coefficient.



(b)

Figure 2. (a) The block diagram of the WT-ANN based receiver
(b) The 3-bit sliding window for decoding the central bit

The receiver design for WT-ANN based receiver for DPIM is shown in the Fig. 2(a). Fundamentally, the equalizer block in the traditional digital communication receiver is replaced by the DWT-ANN in the new approach. The received signal (see Fig.1) $Z(t)$ is sampled at $T_s/n$, where $n$ >1, an integer, i.e. multiple samples per slot are taken. The received signal is decimated into discrete $W$-slot sample lengths, where the sample information content is changed by one slot. Fig. 2(b) shows an example for $W = 3$, which can be thought of a 3-slot sliding window that can slide by one slot at a time. The DWT of each sliding window is taken and wavelet coefficients with/without further processing are applied to the ANN for signal classification. A different sliding window length is possible but the previous results for OOK showed that the sliding window of 3 is the optimum.

There is a possibility to use different mother wavelet and our study had shown that the performance variation of ~1 dB occur with the choice of mother wavelet. The discrete Meyer wavelet shows the best performance and hence it is adopted for all simulation results presented in this paper.

The wavelet coefficients can be further processed to denoise the signal. Denoising can be done either by 'soft' or 'hard' thresholding on the detail coefficients [22]. The mathematical analysis and algorithm for thresholding can be found in [22] and references there-in. The thresholding forces a number of coefficients to zero values. The coefficients with zero magnitude have no significant contribution to the training of the ANN. In fact, these coefficients make the learning task difficult. Hence the redundant detail coefficients are discarded before applying to ANN. It is observed that discarding these detail coefficients makes the training of ANN more efficient and leads to quick convergence of computation.

ANN used for the detection proposed is a feedforward backpropagation multilayer perceptron (MLP) with an input layer, a hidden layer and an output layer. The number of neurons in the hidden layer and output layer is 4 and one respectively and the transfer functions utilized are log-sigmoid and tan-sigmoid respectively. The ANN is first trained using 100 DPIM symbols at the operating signal-to-noise ratio (SNR) to adjust free parameters (weights and bias). The trained ANN is used for signal detection and equalization. The target of the learning process is to reduce the error signal, the difference of the actual output from ANN and the target output. Different algorithms exist for adjusting these free parameters, but to save space, it will be discussed elsewhere. The interested readers can refer to the standard texts on ANN like [23]. The output of ANN is sliced to force the output to binary values. The output of slicer (see Fig. 1) is compared with the original DPIM sequence to calculate the error rate.

TABLE I.
SIMULATION PARAMETERS

| Parameters | Value |
|---|---|
| Data rate $R_b$ | 200 Mbps |
| Channel RMS delay spread $D_{rms}$ | 1-10 ns |
| No. of samples per bit | 16 |
| Mother wavelet | Discrete Meyer |
| ANN type | Feed-forward back propagation |
| No. of neural layers | 2 |
| No. of neurons in hidden layer | 4 |
| No. of neurons in output layer | 1 |
| ANN activation function | log-sigmoid, tan-sigmoid |
| ANN training algorithm | Scaled conjugate gradient algorithm |
| ANN training sequence | 100 symbols |
| Minimum error | $1^{-30}$ |
| Minimum gradient | $1^{-30}$ |
| DWT levels | 3 |

## IV. RESULTS AND DISCUSSION

Based on the system diagram shown in Fig. 2, the SER of DPIM system with DWT-ANN based receiver simulated in Matlab. The simulation flowchart is given in Fig.3 with detail simulation parameters listed in Table I.

Figure 4 shows the SER performance against the SNR for DPIM system with DWT-ANN based receiver at the data rate of 200 Mbps for delay spreads ranging 1-10 ns. Also shown is the SER performance of the unequalized and the adaptive linear equalizer DPIM for the same range of delay spread. The DWT-ANN based receiver show the best SER performance for all range of delay spread while unequalized DPIM reveal the worst error performance. The unequalized error performance is not practically acceptable for highly diffuse channel like channels with $D_{rms}$ of > 5ns. The results also illustrate that equalization and denoising based on the DWT-ANN show a marked improvement in the SER performance compared with the linear equalizer for all values of the delay spread. The SNR gain at the SER of $10^{-5}$ is ~8.6 dB closely matching the previously reported SNR gain of 7.5dB for the OOK with return-to-zero signal format [20]. The extra gain can be attributed to the proper selection of the wavelet. For example, a performance difference of ~1 dB in SNR at SER of $10^{-5}$ can be achieved by using a discrete Meyer wavelet compared to the Haar wavelet. The gain is higher for low values of the delay spread. Further improvement in SER performance can be achieved by using error control coding.

## V. CONCLUSION

In this paper, we have conducted a comparative study of the DWT-ANN and the linear equalizer for non-LOS diffuse indoor OW channel. Results presented show that the former display a marked improvement in the error performance offering an SNR gain of almost 8 dB at SER of $10^{-5}$ at data rate of 200 Mbps for all values of channel

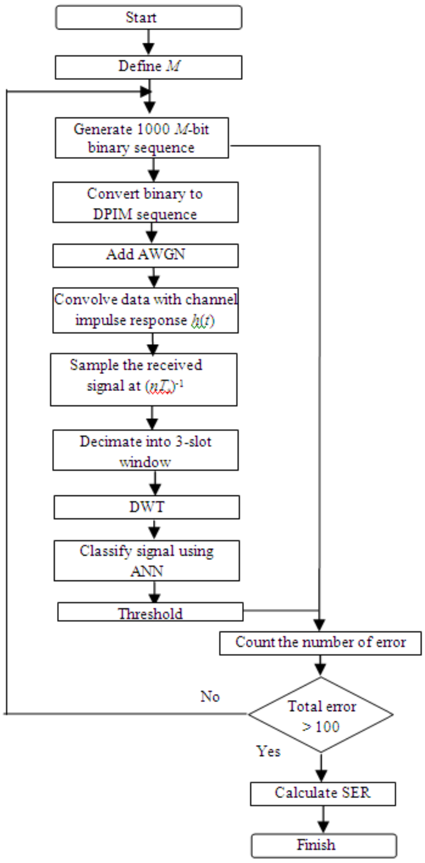


Figure 3. The simulation flowchart for the SER of DPIM using the DWT-ANN receiver in non-LOS links

delay spread. However, at the present time DWT-ANN equalizer is complex but with the rapid increase in the processing time of computer this will no longer be an issue.

## REFERENCES

[1] T. Miki, T. Ohya, H. Yoshino, and N. Umeda, "The overview of the 4th generation mobile communication system," in *ICICS'05*, Singapore, 2005, pp. 1551-1555.

[2] D. C. O'Brien, M. Katz, P. Wang, K. Kalliojarvi, S. Arnon, M. Matsumoto, R. Green, and S. Jivkova, "Short-range optical wireless communications," *Wireless World Research Forum*, pp.1-22, http://cictr.ee.psu.edu/research/wc/Short%20range%20Optical%20Wireless.pdf, last access 10 Feb. 2008

[3] A. M. Street, P. N. Stavrinou, D. C. Obrien, and D. J. Edwards, "Indoor optical wireless systems - A review," *Optical and Quantum Electronics*, vol. 29, pp. 349-378, 1997.

[4] J. M. Kahn and J. R. Barry, "Wireless infrared communications," *Proceedings of IEEE*, vol. 85, pp. 265-298, 1997.

[5] F. R. Gfeller and U. Bapst, "Wireless in-house data communication via diffuse infrared radiation," *Proceedings of IEEE*, vol. 67, pp. 1474- 1486, 1979.

[6] J. M. Kahn, W. J. Krause, and J. B. Carruthers, "Experimental characterization of non-directed indoor infrared channels," *IEEE Transactions on Communications*, vol. 43, pp. 1613-1623, 1995.

[7] J. R. Barry, "Sequence detection and equalization for pulse-position modulation," in *International Conference on Communication*, New Orleans, LA, 1994, pp. 1561-1565.

[8] R. D. Wisely, "A 1 Gbit/s optical wireless tracked architecture for ATM delivery," in *IEE Colloquium on Optical Free Space Communication Links* London, UK, 1996, pp.14/1-14/7.

[9] C. R. Lomba, R. T. Valadas, and A. M. Duarte, "Efficient simulation of the impulse response of the indoor wireless optical channel," *Int. J. of Com. Systems*, vol. 13, pp. 537-549, 2000.

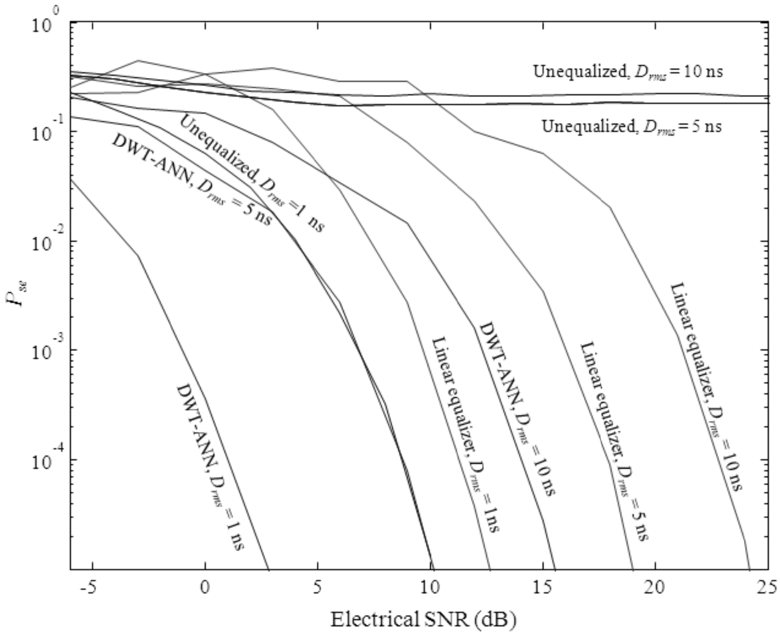


Figure 4. The SER performance against the SNR for unequalized, Linearly equalized and a DWT-ANN based receiver at data rate of 200 Mbps for diffuse links with $D_{rms}$ of 1, 5 and 10 ns.

[10] N. M. Aldibbiat, "*Optical wireless communication systems employing dual header pulse interval modulation (DH-PIM)*," Sheffield Hallam University, UK, 2001.

[11] D. Shiu and J. M. Kahn, "Differential pulse position modulation for power-efficient optical communication," *IEEE Transaction on Communication*, vol. 47, pp. 1201-1210, 1999.

[12] A. R. Hayes, "*Digital pulse interval modulation for indoor optical wireless communication systems*," PhD Thesis, Sheffield Hallam University, UK, 2002.

[13] A. Hussain, J. J. Soraghan, and T. S. Durrani, "A new adaptive functional-link neural-network-based DFE for overcoming co-channel interference," *IEEE Transactions on Communications*, vol. 45, pp. 1358-1362, 1997.

[14] S. Haykin, J. Nie, and B. Currie, "Neural network-based receiver for wireless communications," *IEE Electronics Letter*, vol. 35, pp. 203-204, 1999.

[15] J. Choi, M. Bouchard, and T. H. Yeap, "Decision feedback recurrent neural equalization with fast convergence rate," *IEEE Transactions on Neural Networks*, vol. 16, pp. 699-708, 2005.

[16] R. J. Dickenson and Z. Ghassemlooy, "Wavelet-AI equalization and detection for indoor diffuse infrared wireless systems," *Int. Journal of Communications Systems*, vol. 18, pp. 247-266, 2005.

[17] S. Haykin and D. J. Thomson, "Signal detection in a nonstationary environment reformulated as an adaptive pattern classification problem.," *Proceedings of the IEEE,* vol. 86, pp. 2325-2344, 1998.

[18] Z. Ghassemlooy , W. O. Popoola, S. Rajbhandari, M. Amiri, and S. Hashemi, "A synopsis of modulation techniques for wireless infrared communication," in *ICTON-MW' 2007*, Tunisia, 2007, pp.1-7.

[19] J. R. Barry, J. M. Kahn, W. J. Krause, E. A. Lee, and D. G. Messershmitt, "Simulation of multipath impulse response for indoor wireless optical channels," *IEEE Journal on Selected Areas in Communications*, vol. 11, pp. 367-379, 1993.

[20] R. J. Dickenson and Z. Ghassemlooy "BER performance of 166 Mbit/s OOK diffuse indoor IR link employing wavelets and neural networks," *Electronics Letters*, vol. 40, pp. 753 - 755, 2004.

[21] R. J. Dickenson and Z. Ghassemlooy, "A feature extraction and pattern recognition receiver employing wavelet analysis and artificial intelligence for signal detection in diffuse optical wireless communications," IEEE Wireless Communications, vol. 10, pp. 64-72, 2003.

[22] D. L. Donoho, "De-noising by soft-thresholding," *IEEE Transactions on Information Theory*, vol. 41, pp. 613-627, 1995.

S. Haykin, *Neural networks: A comprehensive foundation*, 2nd ed. New Jersey, USA: Prentice Hall, 1998.