Wavelet packet transform based de-noising receiver for indoor optical wireless system

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Abstract: This paper reports systematic appraisal of wavelet transform based de-noising receiver, for high speed indoor optical wireless communication. For upcoming high speed indoor optical wireless communication systems, wavelet transform based de-noising receiver in indoor environment represent grand consideration. Performance evaluation is carried out in the presence of natural (sunlight) and artificial light sources (incandescent light) in typical room environment. The performance of receiver is considered in two arrangements: They are single channel imaging receiver (SCIR) and wavelet transform based de-noising receiver. The second scheme provides better results than first scheme (SCIR). The simulation results for both SCIR and wavelet transform based de-noising receiver are shown. The simulation results indicate that the wavelet packet transform (WPT) based de-noising receiver offers increased received optical power, signal to noise ratio (SNR), and reduced bit error rate (BER), path loss compared to the SCIR and discrete wavelet transform based de-noising receiver.

Keywords: de-noising, optical wireless communication, SNR, BER, path loss, wavelet transform

Classification: Fiber optics, Microwave photonics, Optical interconnection, Photonic signal processing, Photonic integration and systems

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1 Introduction

Optical Wireless Communication (OWC) links transmit information by light-emitting diode or laser light through an atmospheric channel as shown in Fig. 1. Optical wireless communications represent a feasible alternative to radio frequency for short-range indoor transmission. It has advantages of enormous bandwidth, immune to electromagnetic interference (EMI) and jamming [1, 2, 3, 4, 8]. Furthermore, they do not cause EMI themselves and operate at frequency bands (around 300 THz) where the spectrum is unlicensed and frequency is reused. OWC is clearly an optical technology and not a wireless technology for two primary reasons. One, OWC enables optical transmission at the speed of up to 2.5 Gbps and in future 10 Gbps using WDM. This is impossible using any fixed wireless/RF technology existing today. Two, OWC obviates the need to buy expensive spectrum (it requires no municipal license approvals), which distinguishes it clearly from fixed wireless technologies. Thus, OWC should not be classified into wireless technology. The indoor optical wireless communication system is mainly classified into two configurations, viz., line of sight link and diffuse link. In a Line of sight, any moving object between the transmitter and receiver can easily obstruct the signal. Diffuse link does not need such a line of sight and so the receiver can be moved in and around the room.

Fig. 1. Block diagram of optical wireless communication system

In indoor environment the foremost sources of ambient light include sunlight, incandescent light and fluorescent light sources. These sources emit a significant amount of power within the wavelengths of silicon photodetectors, inducing shot noise in the receivers [3]. Shot noise is a main degrading factor in the indoor wireless optical communication. Here, the case of sunlight and incandescent illumination are considered, [2], and so elimination of this noise in indoor environment is a great challenge. Presently, discrete wavelet transforms (DWT) based de-noising method is used to eliminate natural light.
artificial light interference (ALI) [9]. This paper reports systematic appraisal of wavelet packet transform based de-noising receiver, for high speed indoor optical wireless communications in the presence of sunlight and incandescent light sources. Compared to the SCIR, the wavelet transform based de-noising receiver offers increased received optical power, signal to noise ratio (SNR), and reduced bit error rate (BER), path loss. This paper is organized as follows: Section 2. Discusses on indoor optical wireless channel; Section 3. Discusses on performance of SCIR with wavelet de-noising, Section 4. Conclusion of the paper.

2 Indoor optical wireless channel

The most feasible modulation and detection techniques for indoor optical wireless links are intensity modulation and direct detection (IM/DD). The indoor optical wireless channel is modeled with IM/DD as shown in Fig. 2. Indoor optical wireless channel model is represented [4, 6] as

\[ Y(t) = RX(t) * h(t) + N(t) \]  

(1)

Where \( Y(t) \) is the received signal, \( R \) is the photo detector responsivity (A/W), \( X(t) \) is the transmitted signal, “*” symbol is the convolution operator, \( h(t) \) is the channel impulse response and \( N(t) \) is the Additive white Gaussian noise (AWGN) and the channel input is positive.

\[ X(t) \geq 0 \]  

(2)

The average transmitted optical intensity \( P_{tx} \) is given by

\[ P_{tx} = \lim_{T \to \infty} \frac{1}{2T} \int_{-T}^{T} X(t)dt \]  

(3)

The average received optical intensity \( P_r \) is given by

\[ P_r = H(0)P_{tx} \]  

(4)

Where the channel dc gain is

\[ H(0) = \int_{-\infty}^{\infty} h(t)dt \]  

(5)

The performance of SCIR [8] indoor optical wireless links is related to the receiver electrical SNR and measurement of path loss. SNR of the indoor optical wireless link is limited due to the interference of natural light noise, artificial light noise and multipath distortion. These channels need high level of optical power to achieve a sufficient SNR and limit the data rate. There are
many possible ways to avoid such a problem by changing the transmitter and receiver designs as proposed [7]. In this analysis multibeam transmitter (MBT) formed by combination of transmitter and holographic component with produces multiple narrow beams pointing in different directions towards the ceiling of the room. Several MBTs are implemented as line strip, diamond, and uniform transmitter. In this case uniform patterns are best suited to the operation of SCIR. In order to improve the performance of indoor optical wireless links, single channel imaging receiver is proposed as an alternative to angle diversity receiver (ADR) [5, 9]. The SCIR can automatically aim at selective ceiling areas in terms of illumination. Self-orienting capability of imaging SCR, together with the very narrow field of view (FOV), significantly reduces path loss, background noise and multipath distortion. Moreover, its single-channel structure minimizes hardware complexity to a minimum level and consequently also reduces power consumption, compared to ADR, which uses multiple channels [5]. The optical wireless system performance is estimated by SNR under natural and artificial light sources. The average signal to noise ratio is given [8] by

$$SNR = \frac{RP^2}{2qB_rP_{amp}}$$  \hspace{1cm} (6)

Where \(q\) is the charge of an electron, \(B_r\) is the receiver equivalent noise bandwidth, and \(P_{amp}\) is the received ambient light power. The value of \(P_{amp}\) is obtained by adding sunlight power and lamp power. The path loss is given by

$$Path\ loss = \frac{P_{tx}}{P_r}$$  \hspace{1cm} (7)

Substituting equation (4) in equation (7) is given as [4]

$$Path\ loss = -10\log_{10}[H(0)]$$  \hspace{1cm} (8)

Path loss is defined as the ratio of the transmitted optical power to the received optical power. It is measured in dB.

3 Performance of SCIR with de-noising receiver

The Fourier transforms recover the global frequency content of a signal. Therefore, the Fourier transform is only useful for stationary and pseudo-stationary signals. The Fourier transform does not give satisfactory results for signals that are highly non-stationary, noisy, and a-periodic. These types of signals can be analyzed using the local analysis method called wavelet analysis. Wavelet transform (WT) is relatively a recent transform compared to the Fourier transform (FT). WT provides the time-frequency representation of signals, whereas FT provides only the frequency representation. WT is used to analyze non-stationary signals whose frequency response varies in time.

The WT, at high-frequencies, gives good time resolution and poor frequency resolution, while at low frequencies. It gives poor time resolution and good frequency resolution. Discrete wavelet transform, a non-redundant approach is a powerful tool for many non-stationary signal processing applications, but suffers from major limitations like poor directionality, absence of
phase information and aliasing. The wavelet packet method is a generalization of wavelet decomposition, which offers better representation of high-frequency information.

Discrete Wavelet Packet Transform (DWPT) is now becoming an efficient tool for signal analysis. Compare with the normal discrete wavelet analysis, it has special abilities to achieve higher discrimination by analyzing the higher frequency domains of a signal. The frequency domains divided by the wavelet packet can be easily selected and classified according to the characteristics of the analyzed signal. So the wavelet packet is more suitable than discrete wavelet in signal analysis and has much wider applications such as signal and image compression, de-noising and speech coding [10]. Wavelet packet transform uses a pair of low pass and high pass filters to split a space corresponds to splitting the frequency content of a signal into roughly a low-frequency and a high-frequency component.

In discrete wavelet decomposition we leave the high-frequency part alone and keep splitting the low-frequency part. In wavelet packet decomposition, we can choose to split the high-frequency part also into a low-frequency part and a high-frequency part. So in general, wavelet packet decomposition divides the frequency space into various parts and allows better frequency localization of signals [10]. So we used the Wavelet Packet transform for de-noising. So DWPT based de-noising receiver provides better performance compared to the DWT based de-noising receiver. MBT along with wavelet packet de-noising receiver structure is shown in Fig. 3.

In the simulation db9 (daubechies) wavelet is used to decompose and reconstruct the original signal. The process of de-noising is shown as a flow chart in Fig. 4.

Observing Fig. 5(a), it is clear that the received optical power of wavelet packet transform based de-noising receiver in indoor environment, has significantly increased compared to the SCIR based indoor optical wireless system.

Considering a very short distance, received optical power is high in DWT and SCIR based optical wireless systems because signal reflectivity is high in LOS configuration compared to diffuse system.
From Table I and Table II, it is clear that DWPT based de-noising receiver increases received optical power, signal to noise ratio (SNR), and reduces bit error rate (BER), path loss, compared to the SCIR and discrete wavelet transform based de-noising receiver.
A. SNR

In DWT there was no improvement in SNR in the horizontal separation from 1 m to 2.45 m. However, DWT based de-noising receiver provides significant SNR improvement in horizontal separation beyond the 2.45 m as shown in Fig. 6. For short separation distances between transmitter and receiver, the SNR of the DWT and DWPT based de-noising receiver are approximately same as that of SCIR. As the distance between transmitter and receiver increases, the SNR of DWT based de-noising receiver increases (approximately 1 dB for separation distances of 4 m and above) compared to that of SCIR, whereas the SNR of DWPT based de-noising receiver increases even more (approximately 2 dB for separation distance of 4 m and above) compared to that of DWT based de-noising receiver.

B. Path loss

In DWT there was no reduction in path loss for the horizontal separation of 1 m to 2 m. However, DWT based de-noising receiver provides significant path loss reduction for the horizontal separation of more than 2 m as shown in

| Horizontal Separation (m) | SNR without De-noising (dB) | SNR with De-noising (dB) | Path Loss without De-noising (dB) | Path Loss with De-noising (dB) |
|--------------------------|-----------------------------|--------------------------|----------------------------------|------------------------------|
|                          | DWT | DWPT | DWT | DWPT | DWT | DWPT |
| 1                        | 45  | 44   | 42.5 | 46   | 48  | 50   |
| 2                        | 43.25 | 43 | 42.75 | 49 | 49 | 49.5 |
| 3                        | 41.5 | 42   | 42.5 | 51.65 | 50.25 | 50 |
| 4                        | 40  | 40.75 | 41.80 | 53.65 | 52.45 | 51 |
| 5                        | 38.25 | 39.25 | 40.75 | 55.75 | 55 | 52.5 |
| 6                        | 37  | 38   | 39.25 | 57.65 | 56.35 | 54.5 |
| 7                        | 35.75 | 36.80 | 37.75 | 58.5 | 58 | 56.5 |
| 8                        | 34.5 | 35.80 | 36.25 | 61.5 | 59.5 | 58.5 |

Table I. SNR and path loss comparisons

| SNR (dB) | BER without De-noising $\times 10^{-8}$ | BER with De-noising |
|----------|----------------------------------------|---------------------|
|          |                                       | DWT $\times 10^{-8}$ | DWPT $\times 10^{-8}$ |
| 45       | 0.0009                                 | 0.0016              | 0.00353              |
| 43.25    | 0.0024                                 | 0.0027              | 0.00311              |
| 41.5     | 0.0058                                 | 0.0046              | 0.00353              |
| 40       | 0.0135                                 | 0.0087              | 0.00506              |
| 38.25    | 0.0296                                 | 0.0186              | 0.00865              |
| 37       | 0.0611                                 | 0.0354              | 0.01864              |
| 35.75    | 0.1190                                 | 0.0654              | 0.04021              |
| 34.5     | 0.2203                                 | 0.1093              | 0.08678              |

Table II. SNR and BER comparisons
For short separation distances between transmitter and receiver, the SNR of the DWT and DWPT based de-noising receiver are approximately same as that of SCIR.

As the distance between transmitter and receiver increases, the path loss of DWT based de-noising receiver decreases (approximately 1 dB for separation distances of 4 m and above) compared to that of SCIR, whereas the path loss of DWPT based de-noising receiver decreases even more (approximately 2 dB for separation distance of 4 m and above) compared to that of DWT based de-noising receiver.

C. BER

From Fig. 5(b), it is clear that DWPT based de-noising scheme gives better BER compare to the other two schemes (DWT based de-noising and imaging receiver). However, initially imaging receiver and DWT based de-noising schemes provide better BER performance for very short distance, due to LOS configuration. Increasing the horizontal separation between transmitter and receiver, diffuse links play a vital role. So DWPT based de-noising
receiver provides better performance in BER reduction compared to DWT based de-noising receiver and SCIR based optical wireless system.

4 Conclusion

This paper reported and simulated systematic performance appraisal of wavelet transforms based de-noising receiver for indoor optical wireless communications. We also quantified impulse response, SNR, BER and path loss of DWPT de-nosing receiver. There is approximately 2 dB increases in SNR of the DWPT based de-nosing receiver for separation distance of 4 m and above, compared to that of SCIR, Whereas a 1 dB increases in DWT based de-nosing receiver for separation distance of 4 m and above, compared to that of SCIR. Path loss of the DWPT based de-nosing receiver decreases approximately 2 dB for separation distance of 4 m and above compared to that of SCIR, Whereas DWT based de-nosing receiver decreases approximately 1 dB for separation distance of 4 m and above compared to that of SCIR. Thus the DWPT based de-noising receiver play major role in indoor optical wireless commutation. The system analyzed in this paper to some extent represents the wavelet packet transform. This system may be combined with artificial neural network (ANN) equalizer which may lead to creating a system that can use a more compact receiver. This is worthy of future work for indoor optical wireless communication.