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Research Paper

Wavelet Based Multiplexing For A Visible Light Communication (VLC) System

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ABSTRACT: *The OFDM scheme has been proven as one of the spectrally efficient modulation schemes for multicarrier modulation which renders a compelling performance improvement for a band limited system. In this paper the feasibility of a wavelet-based multiplexing for a VLC system has been studied since wavelet bases are also orthogonal. Thus, the model of the wavelet-based multiplexing scheme for a VLC system model was presented and its performance was studied over an AWGN channel of which its impulse response was modelled based on a ceiling bounce model due to its simplicity and excellent matching properties with the measured data, a detailed system analysis and comparison with the OFDM as well as the evaluation of the impact of some parameters such as (wavelet families, signal level and Normalized delay spread Dt) on the system performance was presented and the performance of the wavelet-based multiplexing scheme was found to be quite similar to the OFDM..*

KEYWORDS: *Wavelet-Based Multiplexing, OFDM, AWGN, DWPT, AM, EM, FFT, RF, VLC.*

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I. INTRODUCTION

The wireless form of communication has been in existence for quite a number of centuries, where the smoke signal could be regarded as the earliest scheme for the wireless communication during the pre-industrial age. The wireless communication has since then pass through many evolutions, and now it stands to be the fastest growing section of the communication industries [11].

The radio frequency (RF) transmission which involve transmission of signal via a free space using electromagnetic waves (EM) having a frequency range of 3 kHz to 300 kHz is one form of wireless communication system and which might be considered the most widely used one and available globally. This technology was invented in the late 1890s and continuous to experience a rapid progress till date [4]. In this system the effect of interference between the RF transmissions is mitigated by allocating different transmission to their respective spectrum [16]. This system's capability has now been pushed to its limit as a result of the fast-growing number of users due to the contemporary introduction of smart phones and mobile devices which lead to the rapid running out of the bandwidth that can enable a spatial coverage. Thus, necessitate the need for an extra spectrum.

Therefore, interest in the use of other frequency ranges in the EM spectrum increases due to the congestion in the RF spectrum. The visible light communication (VLC) is one of the options and also attracted a huge interest for the past couple of years due to its ability to address the problem of spectrum in an RF and also effect of interference with the existing system does not occur [4].

The VLC has larger spectrum than the RF which is about 1000 times larger and has a frequency range of 400 THz to 800 THz, hence, VLC is classified under optical communication, which until just of recent dealt mostly with guided waves and lasers. The term VLC refers to a system of communication which employs electromagnetic radiation (light) that is visible to human in either free space or optical fiber [17].

The most widely used device for a VLC system as a source of illumination is the visible Light emitting diode (LED) due its fast modulation capability.

This paper involves simulation of a wavelet based multiplexing schemes for a visible light communication system using MATLAB.

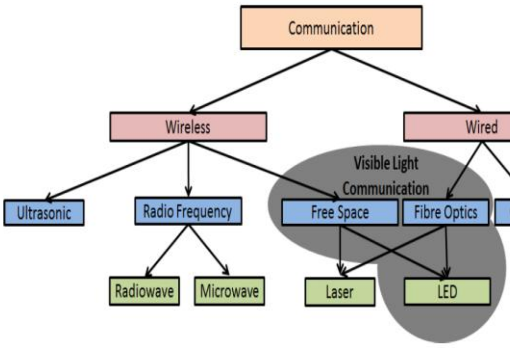

Figure. 1: Division of communication with VLC highlighted in grey area [16].

TABLE I. COMPARISON BETWEEN VLC AND RF [4]

Property	VLC	RF
Bandwidth (Wavelength / Frequency range)	Very wide (400nm – 700nm / 400 THz – 800 THz)	Wide (1mm – 100km / 3 kHz – 300 GHz)
Carrier frequency	Determined by optical source material	Determined through the oscillating electrical field
Wave	Incoherent	Coherent
Transmission	Optical Intensity (LED)	Electrical field
Signal Polarity	Unipolar	Bipolar
Signal Type	Real value only (scalar)	Complex value (Vector)
Distance	Short	Medium to Long
Line of Sight limitation	Yes	No
Security	Higher security. Signals are secured within the illumination range	Lower Security as RF signal can penetrate wall
Spectrum availability and sharing restrictions	Unlicensed and widely available	Under regulatory and limited for sharing
Noise sources	Ambient light and interference from other users	Interference from other users
Health Hazard	No health hazards to human body at regular level of illumination	No health hazard at regular level of exposure
Standard	Beginning (new, in R&D stage)	Matured

II. SIMULATION DESIGN OF A WBM SCHEME

This paper was designed and simulated using a step by step approach by following the flowchart shown in fig. 2:

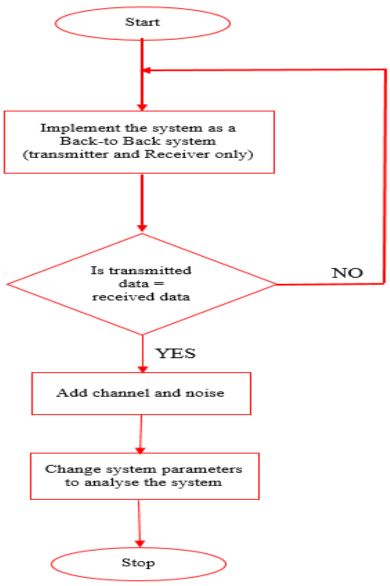

Figure. 2: The MATLAB simulation flowchart of a WBM scheme

The flow chart shown in fig. 2 above illustrate how the main blocks that made up the wavelet based multiplexing scheme for a VLC i.e. (Transmitter, channel and receiver) was implemented one after the other in a MATLAB environment. Though in this paper the system was firstly implemented as a back to back and then later the noise and the channel were added. Therefore, these main blocks that made up the WBM schemes were elaborated as follows:

A. The WBM Transceiver Structure

The block diagram of the wavelet-based multiplexing for a VLC system is shown in figure 3., which is elaborated as follows. Similar to the OFDM where the modulation and the demodulation (multiplexing and de-multiplexing) are achieved via IFFT and FFT respectively. Therefore, in this case IDWPT and DWPT are employed at the transmitter for reconstruction of the transmission signal composite and at the receiver for recovering the transmitted signal respectively.

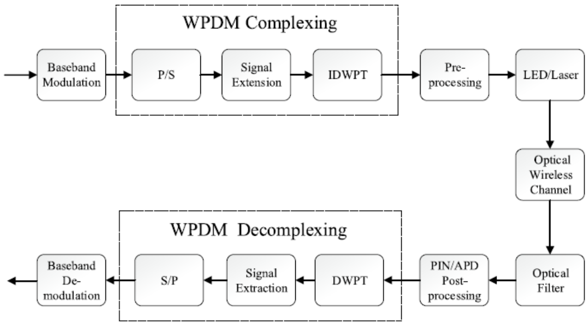

Figure. 3: Block diagram of the WBM Transceiver

B. Multiplexing/De-Multiplexing (Modulation/Demodulation) using DWPT

The mechanism of tree structure coding was employed to perform the symbol synthesis as shown in figure 4, the input symbols x0[n], . . .xN – 1 [n] are multiplexed through N-sub-channels with the help of QMF filters pairs h[n] and g[n] applied successively [8]. However, log2N levels of QMF pairs are required at the transmitter for an N-subcarrier system, and then up sampling a signal by a factor of 2 at each level and subsequently passed through pair of QMF h[n] and g[n] in the succeeding level.

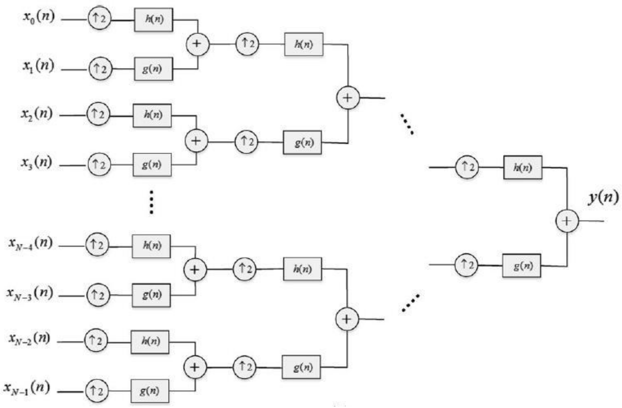

Figure. 4: IDWPT tree structures

De-multiplexing is on the other hand performed at the receiver by adopting time-reversed conjugate complex version of the QMF. Just like in the IDWT process, the output signal of the filters is passed through the QMF filters in each level and then down sampled by the same factor (two filters for each sample/stage) as shown in figure 5.

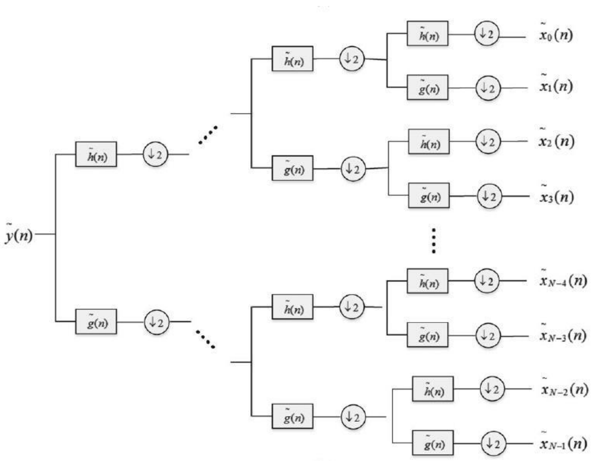

Figure. 5: DWPT tree structures

However, the selection of the wavelet scaling filter is critical because these filters entirely defines the wavelet packet basis construction and also determines the transform specific characteristics such as out of band energy which is the basic characteristics of the multiplex signal waveform [10]. Fig. 6 represents the equivalent diagram of the wavelet based multiplexing system.

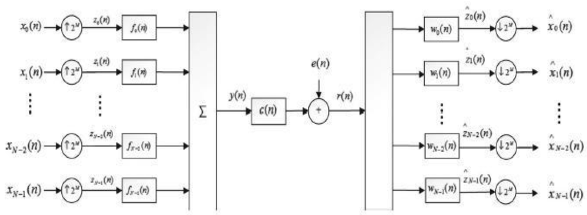

Figure. 6: Equivalent diagram of the wavelet based multiplexing system

The wavelet based multiplexing system was implemented as shown in Figure 6 where by the input signal symbols x0(n), x1(n), . . . xN-2(n), xN-1(n) are up sampled by 2M factor after been multiplexed on to the N-sub channels and then filtered by the filters functions f0(n), f1(n), . . . fN-2(n), fN-1(n) respectively summed and then multiplexed via a single channel. These modulation filter functions were composed from successively applying M number of stages QMFs i.e.(h(n) and g(n)) at each stage and up sampling by a factor of 2 as well. But M=log2N.

III. CHANNEL MODELLING

In order to combat and analyze the effect of channel distortion it is of paramount importance that the system channel characterization is clearly understood. This channel characterization is implemented from the impulse response of the channel for an efficient operation, implementation and design of the VLC system. In this paper the channel impulse response was modelled based on the ceiling bounce model due to its simplicity and excellent matching properties with the measured data. In this model the receiver and the transmitter were assumed to be co-located parallel to the floor usually in planes in the direction of the ceiling. The multipath VLC channel here is characterized basically using two parameters i.e. RMS delay spread Drms and the optical path loss. Therefore, for a ceiling bounce model the impulse response h(t) is given by Eq 1:

$$h(t,a) = H(0)\frac{6a^6}{(t+a)^7}u(t) \qquad (1)$$

Where u(t) is the unit step function, a = 2Hc/c, and Hc is the height of the ceiling above the receiver and transmitter and c is the velocity of light. The parameter ‘a’ is related to Drms as:

$$D_{rms}\big(h(t,a)\big) = \frac{a}{12}\sqrt{\frac{13}{11}} \qquad (2)$$

The approximate 3-dB cut-off frequency is given as also given as:

$$f_{3db} = \frac{0.925}{4\pi D_{rms}} \qquad (3)$$

IV. SIMULATION DESIGN OF A DC-CLIPPED OFDM

The DC-OFDM type of optical OFDM was simulated for the purpose of comparison between the wavelet based multiplexing schemes for a VLC system and the optical orthogonal frequency division multiplexing OFDM in order to analyses the performance of the WBM scheme.

Therefore, in an optical OFDM, the OFDM signal has to be a non-negative, this necessitate the requirement of a DC bias in order to make it non-negative. This DC is usually very high due to the high peak to average amplitude ratio nature of the OFDM signal. The high DC bias required can be reduced by adopting a simple approach of hard-clipping the peaks of the negative signals [3]. This technique is referred to as DC-OFDM. The transmitter side of a DC-OFDM system is shown in the figure 7 below.

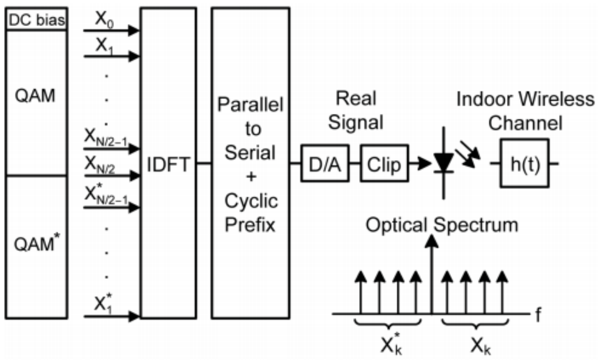

Figure. 7: the transmitter side of a DC-OFDM system [3]

From figure 7 above, the Hermitian symmetry is enforced on the input signal/symbols to the IDFT in order to have real time-domain waveforms. The DC zero bias can be noted not modulated from the figure above which is equivalent to the DC bias. The waveform is converted into a non-negative by performing a hard clipping after converting it from digital to analogue form using a D/A converter and then finally modulating the signal onto the carrier signal using intensity modulation, and transmitted via the wireless indoor channel.

When dealing with a large number of subcarriers as in this project, the OFDM signal x(t) can be modelled as a Gaussian random variable having a mean equivalent to the DC bias ɤ with a variance equivalent to the electrical power σ2 = [|x(t)|]. Hence, a positive side of the Gaussian distribution is obtained only after performing a hard clipping at zero. For DCO-OFDM system the average optical power is given as:

$$P_{DC-OFDM} = E[x_{clip}(t)] = \frac{\sigma}{\sqrt{2\pi}} e^{-\frac{\gamma^2}{2\sigma^2}} + \gamma\left(1 - Q\left(\frac{\gamma}{\sigma}\right)\right) \quad (4)$$

where, Q = Gaussian function. However, if the DC bias is properly chosen then the optical power will be equal to the DC bias ɤ and hence no clipping is required.

V. RESULTS AND DISCUSSION

A. The WBM Analysis

The wavelet based multiplexing scheme for a visible light communication has been simulated to transmit symbols over an (AWGN) channel of which its impulse response has been modelled based on a ceiling bounce model. The simulation was implemented using MATLAB 2016a. The performance of the scheme was however examined at different SNR values. These examination and evaluation were performed under the following headings.

1) WBM System Using Different Wavelet Families

The ceiling bounce model was employed in modelling the channel impulse response due to its simplicity and excellent matching properties with the measured data. The system was firstly simulated using different wavelet families in order to analyses its performance based on each wavelet family, therefore in this case db2, db5 and coif5 wavelets families were used and the additive white Gaussian noise AGWN was added to the channel. However, since the system was implemented as an indoor optical wireless communication system based on a ceiling bounce model, the parameter Dt known as normalized delay spread was set to 0.1, which is a dimensionless parameter used in studying the performance of a system in a dispersive channel at different data rate figure 8 below shows the BER performance of the WBM with different wavelet families.

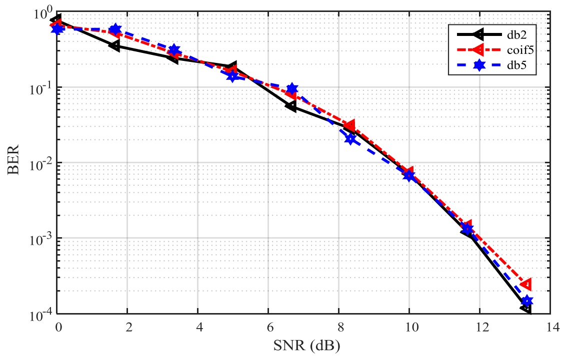

Figure. 8: The BER performance of the WBM with different wavelet families

From figure 8 above, it can be seen that the BER performance of the wavelet-based multiplexing is almost the same using any of the wavelet families although some little differences in performance exist when using different wavelet family i.e. db2, db5 and coif5 in this case. From the above result it can be seen that each wavelets family present or yields better performance than the other interchangeably at some ranges of the SNR values. Although, such differences are not that pronounced, therefore it can be concluded that the wavelet family used in a WBM has an impact on its BER performance.
This feature of a wavelet-based multiplexing schemes presents remarkable advantages from the architectural point of view.

2) WBM SYSTEM USING DIFFERENT LEVEL

The wavelet based multiplexing system was implemented using a scheme known as tree structure coding as explained above where by the input signals *xo[n]……, xN-1[n]* are multiplexed over N-sub-channel through the QMF filter pairs *h(n)* and *g(n).* As such log2N levels of QMFs are required at the transmitter for N-sub-carriers. The N represents the number of stages/bands which must be an integer of power of 2.

Therefore, figure 9 shown below represents the BER performance of the WBM with different levels i.e. (at N=8, 16 and 32 that is 3, 4 and 5 level respectively).

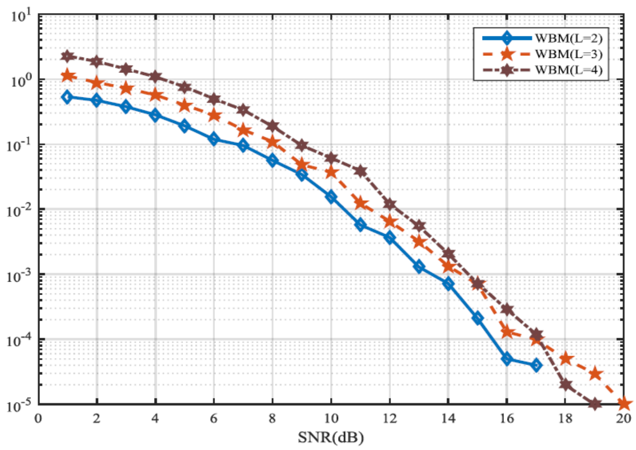

Figure. 9: The BER performance of the WBM with different levels

From figure 9 above, it can be seen that the level of the signals has impact on the performance of the wavelet-based multiplexing for a VLC system. As it can be seen that the WBM present a better BER performance with less signal level, i.e. (the BER performance reduces with an increase in the level of the signal). However, this feature serves as a major source of interference when the transmitted signals losses its orthogonality as a result of propagation through the channel. Hence longer time supports enable the waveform having higher frequency domain localization to be obtained. Hence, it is desirable to use a short duration waveform in order to have as far shorter symbol duration than the coherence time of the channel, thus the modulation/demodulation delay is limited, less computation and memory is required in a short waveform. Therefore, these requirements cannot be independently chosen as it results to a good localization in both frequency and time domain.

C. DCO-OFDM

The orthogonal frequency division multiplexing (OFDM) scheme was simulated based on the DC-OFDM. In DC optical OFDM the OFDM signals were made non-negative using a DC bias. Even though the DC required normally used to be very high due to the high PAPR nature of the OFDM, as such the peaks of the negative signals are clipped using hard clipping approach in order to reduce DC value required. The DC-OFDM was simulated and its BER behavior was shown below and compared with the theoretical OOK scheme.

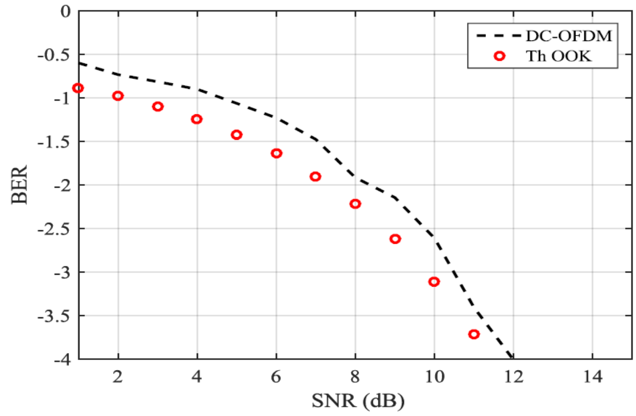

Figure. 10: The simulated result of the OFDM with the theoretical OOK

From figure 10, it can be seen that the DC-OFDM system behave similar to the OOK system as expected, though the OOK system has better performance than the DC OFDM.

D. WBM AND DCO-OFDM IN A DIFFUSE CHANNEL USING DIFFERENT Dt VALUES

The wavelet based multiplexing scheme for a VLC system as well as the DC-OFDM were simulated using diffuse channel based on the ceiling bounce model at different values of normalized delay spread Dt. The WBM and the DCO-OFDM were simulated using four different values of Dt i.e. (0.035, 0.1, 0.2 and 0.35). Figure 11 and 12 below shows the simulation results for the WBM and DCO-OFDM.

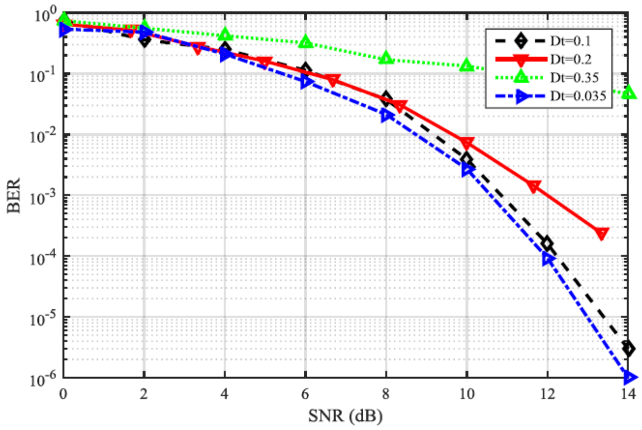

Figure. 11: the simulation result of the WBM scheme at different values of Dt

From the figure 11 above it can be seen that the normalized spread delay has some effects on the performance of the wavelet based multiplexing scheme. From the above result the BER increases with an increase in the value of the normalized delay spread (Dt) at a given SNR value although the effect is more pronounced at a high value of SNR. It can be seen at an SNR values of 0-2 no effect exists (no change in the BER). Therefore, the wavelet based multiplexing scheme yield better performance at a lower value of a normalized delay spread Dt. That is to say the WBM scheme gives better performance when Dt is 0.035 followed by when it is 0.1 and hence reduces as the value of Dt is increased.

Similarly, the DCO-OFDM was simulated using different values and its simulation result was shown in the figure 12 below

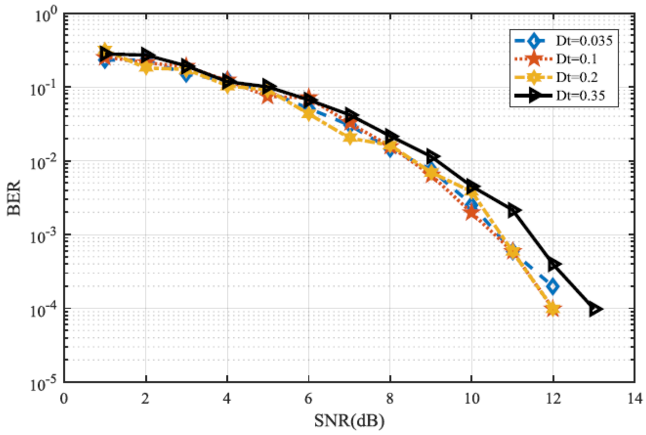

Figure. 12: the simulation result of the DC-OFDM scheme at different values of Dt

The simulation result shown above in figure 12 for the DC-OFDM at different values of the normalized delay spread Dt shows similar behavior to that of the wavelet based multiplexing scheme. However, the effect of increase in BER with an increase in the values normalized delay spread Dt is high in the WBM than in the case of OFDM.

E. COMPARISON BETWEEN WBM AND THE DCO-OFDM

The wavelet based multiplexing schemes and the DC-optical OFDM schemes for a LED-based visible light communication system was compared comprehensively as discussed below. The comparison was performed based on the following aspects i.e. BER performance and the PAPR (peak to average power ratio).

1) BER PERFORMANCE

In this section a comparative analysis between the BER performance of WBM and that of the DCO-OFDM schemes are presented. In order to fairly compare the two systems i.e. (WBM and DCO-OFDM), the addition of a cyclic prefix which is a techniques employed in an OFDM system that can be regarded as a kind of equalization was not included as there is no provision for such similar artefact in the case of wavelet based multiplexing schemes. This is because the addition of the cyclic prefix would lead to the loss of bandwidth efficiency and conversely leading to the much differences between the modulation schemes. Both systems were simulated at a Dt values of 0.1 as the system impulse responses were simulated using ceiling bounce models.

The BER performance of WBM and that of the DCO-OFDM schemes is shown in figure 13. However, two different wavelets were used i.e. db2 and coif5.

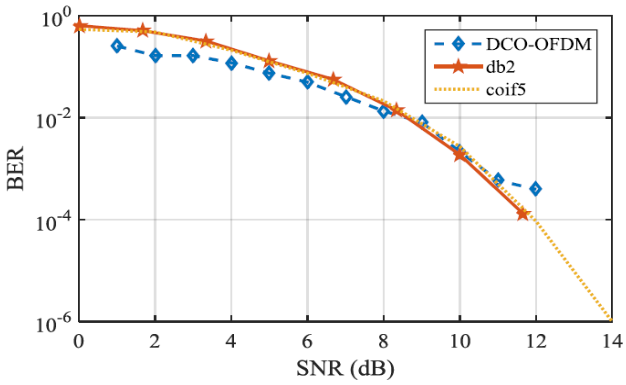

Figure. 13: The BER performance of the WBM and DCO-OGFDM

Figure 13 above shows BER curve for WBM (db2), WBM (coif5) and DCO-OFDM. From the above simulation result it can be seen that the BER curve for the WBM (db2) and WBM (coif5) shows a very close resemblance which indicate that the wavelet families have less impact on the performance of the WBM. While the curve for the WBM and OFDM are not exactly the same but they are looking quite similar which shows that the WBM and OFDM have similar BER performance. As such the potential of a wavelet based multiplexing scheme to have an improved performance over the OFDM relies on an efficient equalisation scheme design for the modulation scheme.

VI. CONCLUSION

In this paper the transceiver model of a wavelet based multiplexing scheme for a VLC system has been provided. The system BER performance was also compared to that of the DCO-OFDM where by the curve was found to be quite similar and hence enable us to conclude that WBM schemes behave similar to the OFDM system and hence it could be considered as a viable alternative to an OFDM system. The performance of the WBM was moreover studied using different wavelet families, different signal levels and at different values of a normalized delay spread (Dt Values) and the system performance was found to be decreasing with an increase in the Dt. The wavelet families used and signal levels were found to be having an impact on the WBM system performance as the system performance was found to be degraded with an increase in the signal level.

Therefore, the major interest of the WBM schemes resides in its capability to meet up the wide requirement of a contemporary communication world, thus, it possess the advantage and potential of being a generic scheme of modulation whose characteristics can actually be customized widely to meet up and fulfil the requirements in the world of communication systems, and hence this generic schemes would have the potential of being a multicarrier communication schemes that can be uniquely employed by devices having various constraints.

VII. FUTURE WORK

The comparison between the wavelet based multiplexing scheme and the DCO-OFDM can be based on the PAPR by plotting the complementary cumulative distribution function (CCDF) against the PAPR. The CCDF is the probability that the PAPR value will be equal to or larger than some threshold values from which the robustness of the system to both linear and nonlinear distortion due to the photodiodes (PD) and LEDs dispersions can be analyzed.

REFERENCE

[1]. Armstrong, J. and Lowery, A. (2006). Power efficient optical OFDM. *Electronics Letters*, 42(6), p.370.

[2]. Badoi, C., Prasad, N., Croitoru, V. and Prasad, R. (2010). 5G Based on Cognitive Radio. *Wireless Personal Communications*, 57(3), pp.441-464.

[3]. Barros, D., Wilson, S. and Kahn, J. (2012). Comparison of Orthogonal Frequency-Division Multiplexing and Pulse-Amplitude Modulation in Indoor Optical Wireless Links. *IEEE Transactions on Communications*, 60(1), pp.153-163.

[4]. Bao, S. (2013). LED Visible Light Communication System Design and Performance Optimization Based on Ethernet. *Applied Mechanics and Materials*, 336-338, pp.1920-1924.

[5]. Dimitrov, S. and Haas, H. (2013). Information Rate of OFDM-Based Optical Wireless Communication Systems With Nonlinear Distortion. *Journal of Lightwave Technology*, 31(6), pp.918-929.

[6]. Dimitrov, S., Sinanovic, S. and Haas, H. (2012). Signal Shaping and Modulation for Optical Wireless Communication. *Journal of Lightwave Technology*, 30(9), pp.1319-1328.

[7]. Dissanayake, S. and Armstrong, J. (2011). Novel Techniques for Combating DC Offset in Diversity Combined ACO-OFDM. *IEEE Communications Letters*, 15(11), pp.1237-1239.

[8]. Ghassemlooy, Z., Popoola, W. and Rajbhandari, S. (2013). Optical wireless communications. 1st ed. Boca Raton, FL: CRC Press.

[9]. Haigh, P., Ghassemlooy, Z., Rajbhandari, S. and Papakonstantinou, I. (2013). Visible light communications using organic light emitting diodes. IEEE Communications Magazine, 51(8), pp.148-154.

[10]. Huang, W., Gong, C. and Xu, Z. (2015). System and Waveform Design for Wavelet Packet Division Multiplexing-based Visible Light Communications. Journal of Lightwave Technology, pp.1-1.

[11]. Komine, T., Tanaka, Y. and Nakagawa, M. (2011). Basic Study on Visible Light Communication using Light Emitting Diode Illumination. in Proceedings of 8th International Symposium on Microwave and Optical Technology (ISMOT), Montreal, Canada.

[12]. Lee, S., Randel, S., Breyer, F. and Koonen, A. (2009). PAM-DMT for Intensity-Modulated and Direct-Detection Optical Communication Systems. IEEE Photonics Technology Letters, 21(23), pp.1749-1751.

[13]. Li, A., Shieh, W. and Tucker, R. (2010). Wavelet Packet Transform-Based OFDM for Optical Communications. Journal of Lightwave Technology.

[14]. Lindsey, A. (1997). Wavelet packet modulation for orthogonally multiplexed communication. IEEE Transactions on Signal Processing, 45(5), pp.1336-1339.

[15]. Lindsey, A. and Dill, J. (1995). Wavelet packet modulation: a generalized method for orthogonally multiplexed communications. IEEE 27th Southeastern Symposium on System Theory, pp.392–396.

[16]. Mahmood, A. (2015). High Performance Drive Circuits for Integrated MicroLED/CMOS Arrays for Visible Light Communication (VLC). Ph.D. The University of Edinburgh.

[17]. Nassar, N. (2016). Integrated broadband power line and Visible Light Communication (VLC) system using OFDM and turbo code. International Journal of Sensor Networks and Data Communications, 05(02).

[18]. Negash, B. and Nikookar, H. (2000). Wavelet-based multicarrier transmission over multipath wireless channels. Electronics Letters, 36(21), p.1787.

[19]. Okamoto, E., Iwanami, Y. and Ikegami, T. (2003). Multimode transmission using wavelet packet modulation and OFDM. IEEE 58th Vehicular Technology Conference, 3, pp.1458-1462.

[20]. Rajbhandari, S., McKendry, J., Herrnsdorf, J., Chun, H., Faulkner, G., Haas, H., Watson, I., O'Brien, D. and Dawson, M. (2017). A review of gallium nitride LEDs for multi-gigabit-per-second visible light data communications. Semiconductor Science and Technology, 32(2), p.023001

[21]. Saengudomlert, P. (2014). On the Benefits of Pre-Equalization for ACO-OFDM and Flip-OFDM Indoor Wireless Optical Transmissions Over Dispersive Channels. Journal of Lightwave Technology, 32(1), pp.70-80.

[22]. Suzuki, N., Fujimoto, M., Shibata, T., Itoh, N. and Nishikawa, K. (1999). Maximum likelihood decoding for waveletpacket modulation. IEEE Vehicular Technology Conference (VTC), pp.2895–2898.