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Kalman Filtering for VLC Channel Estimation of ACO-OFDM Systems

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Abstract:

A Kalman filter (KF) is employed for estimating a VLC channel. Two modulation techniques; asymmetrically clipped optical-orthogonal frequency-division multiplexing (ACO-OFDM) and direct current optical-orthogonal frequency-division multiplexing (DCO-OFDM) are applied. The results show that KF estimator outperforms other traditional estimators for both modulation techniques.

Keywords: KF, MMSE, LS, DCO-OFDM, ACO-OFDM, channel estimation, visible light communication (VLC).

1. INTRODUCTION

Visible light communication (VLC) is a recent interesting technology that uses the visible light for data transmission in addition to illumination. A number of modulation techniques has been used in VLC systems such as PWM, PPM, OOK, and OFDM. In this paper, OFDM based on DCO and ACO techniques are adopted because of their higher transmission rates. In order to improve the bit-error rate (BER) system performance, Kalman filter (KF) is used in VLC channel estimation as in [1] for both DCO-OFDM and ACO-OFDM systems where the results are compared with LS and MMSE estimators.

The DCO-OFDM and ACO-OFDM system models are described in Sec. 2. The VLC channel characteristics are presented in Sec. 3. The channel estimation methods are demonstrated in Sec. 4 while the KF algorithm is shown in Sec. 5. The system analysis is demonstrated in Sec. 5 where the work conclusions are highlighted in Sec. 6.

2. SYSTEM MODEL

2.1 DCO-OFDM

The block diagram of a DCO-OFDM VLC system is illustrated in Fig. 1. An input data stream $X(k)$ is modulated using QAM techniques and follows by inverse fast Fourier transform (IFFT) using N subcarriers to obtain a time domain signal $x(n)$. Since for IM/DD system the transmitted signal must be real-valued, the modulated complex symbols $X(k)$ is applied to a Hermitian symmetry process as shown in Fig. 2.

The sub-carriers X_0 and X_N are set to zero. To avoid inter-symbol interference (ISI), a cyclic prefix (CP) is added in front of each OFDM symbol. In addition, a DC bias is added to get a non-negative signal, $x_c(n)$. After electrical-to-optical conversion, the optical signal is transmitted through the channel.

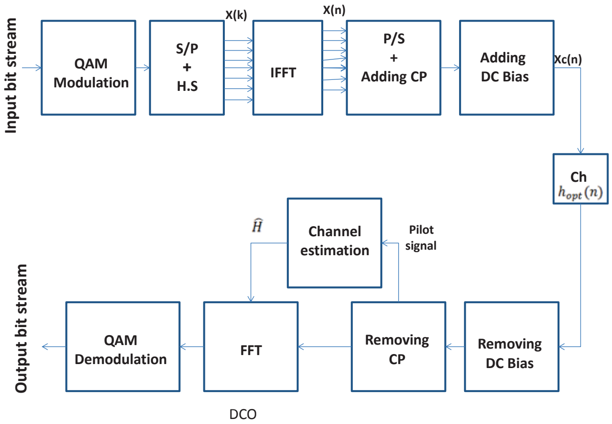

Figure 1. Block diagram of a DCO-OFDM system.

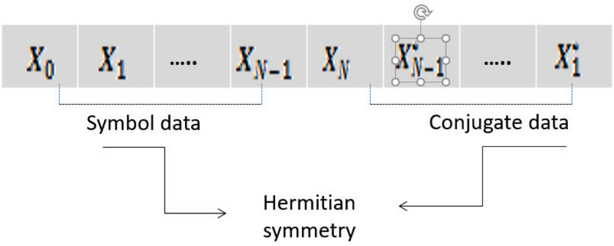

Figure 2. Hermitian symmetry method for ACO-OFDM system.

At the receiver side, the optical signal is collected by a photodiode which converts the optical signal to an electrical one. Both the receiver noise and ambient light are modeled as additive white Gaussian noise (AWGN). Accordingly, the received noisy signal can be expressed as:

$$y(n) = x_c(n) * h_{opt}(n) + n_g(n) \quad (1)$$

where $h_{opt}(n)$ and $n_g(n)$ denote the discrete forms of the channel response and AWGN, respectively. Here $x_c(n)$ is the signal after adding a DC bias. Fast Fourier transform (FFT) is performed to recover the symbols from the sampled data. The channel estimation block is used to recover the transmitted signal at the receiver. The estimation is based on the transmission of pilot symbols that are known to the receiver.

2.2 ACO-OFDM

Like DCO-OFDM, the block-diagram of the ACO-OFDM VLC system is illustrated in Fig. 3. For pure imaginary odd data input, the output of the IFFT is purely real and odd signal as stated in IFFT symmetry property [4,8]. Depending

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on this, ACO-OFDM uses a pure imaginary odd input signal to produce pure real odd output. The oddness of the output signal adds advantage on the clipped signal, such that clipping odd real signal does not affect its amplitude and the distortion is added on the imaginary part of the subcarrier only. $X\ (k)$ Follows Hermitian symmetry as shown in Fig. 4.

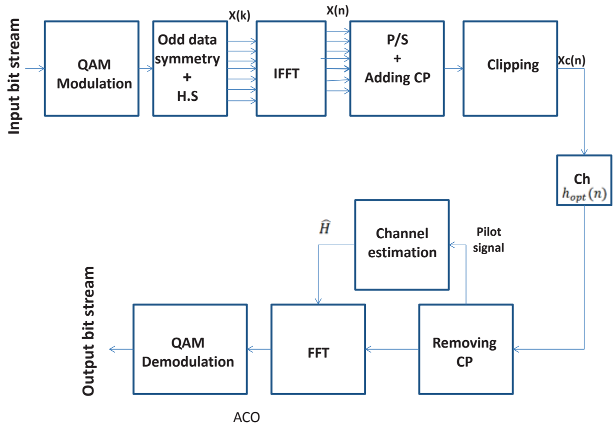

Figure 3. Block diagram of a ACO-OFDM system.

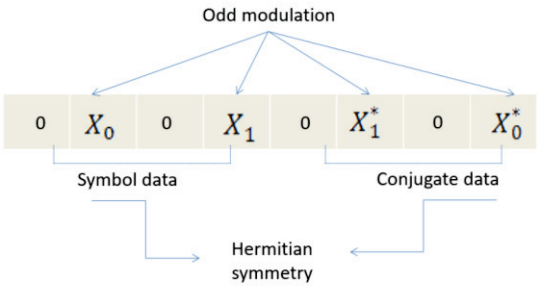

Figure 4. Hermitian symmetry method for ACO-OFDM system.

3. VLC CHANNEL CHARACTERISTICS

Consider a VLC link with a Lambertian source, a receiver with an optical filter of transmission $T_s(\varphi)$, and a non-imaging concentrator of gain $g(\varphi)$. The DC gain for VLC channel with a distance d between transmitter and receiver and an incident angle φ is approximated as

$$H_{los}(0) = \begin{cases} \frac{A_r(m_1+1)}{2\pi d^2} cos^{m_1}(\theta) T_s(\varphi) g(\varphi) cos\varphi, & 0 \leq \varphi \leq \varphi_c \\ 0, & elsewhere \end{cases} \tag{2}$$

where $\varphi_c \leq \frac{\pi}{2}$ is the FOV. In indoor application, the line of sight (LOS) response depends on the length between light source and photodetector where its power is higher than that of non-line of sight (NLOS) components. The latter is caused by a number of reflections, thus we consider here the LOS only.

4. CHANNEL ESTIMATION METHODS

For enhancement detection of the modulated signal at the receiver, a channel estimation technique is required. Several channel estimation techniques have also been proposed in [2, 3]. A common method used for OFDM is the pilot based channel estimation. We use a comb-type pilot arrangement for each symbol where there are subcarriers reserved for pilots. In this section, different methods of channel estimation such as LS, MMSE, and KF are explained briefly.

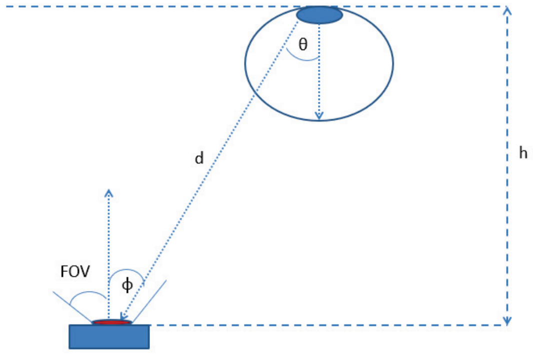

Figure 5. Geometry for a LOS propagation model

LS method is the simplest method where the estimated channel is given by

$$H_{LS} = Y_k / X_k, \tag{3}$$

where k is a pilot index, X_k and Y_k are the transmitted and received pilot signals, respectively.

On the other hand, MMSE estimated channel is represented as

$$H_{MMSE} = R_H \left[\frac{1}{R_H + \sigma^2 \frac{1}{\bar{X}\bar{X}^H}} \right] H_{LS}, \tag{4}$$

where $R_H = E\,[HH^H]$ is the covariance matrix of the channel coefficient in the frequency domain, σ^2 is the noise variance, and $\bar{X} = diag\{X_k\}$.

For the Kalman Filter, a Kalman filter (KF) is an algorithm that uses observation of measurements and produces an estimation of unknown variables. The algorithm works in two stages. The first stage is prediction which produces the estimation of the current state variables. Once the outcome of the next measurement is observed, these estimates are updated in the second stage to estimate the variables. The algorithm is recursive by using only current measurement and there is no need to know additional past information.

5. KALMAN FILTER ALGORITHM

Here, we propose the KF based on the autoregressive (AR) predictive model. The proposed scheme is based on the idea of Kalman filtering to compare the performance of two systems: DCO- and ACO-OFDM. As referred in [1,5,6], the autoregressive (AR) model is used to facilitate channel model manipulations where using the first-order model is enough to capture most of the channel tap dynamics. Kalman filter can be stated as: the channel coefficients h_k can be modeled by the following dynamic AR process $h_{k+1,n} = a_n\, h_{k,n} + v_{k,n}$, where $n \in \{1,2,\dots,N\}$. Here, a_n represents the time correlation of the channel response between k^{th} and $(k+1)^{th}$ OFDM symbols at the n^{th} subcarrier , $v_{k,n}$ is a process noise. Given the matrix X_k of known transmitted pilot symbols and received signal Y_k at k^{th} OFDM symbol, the channel tracking algorithm works as shown in Fig. 6.

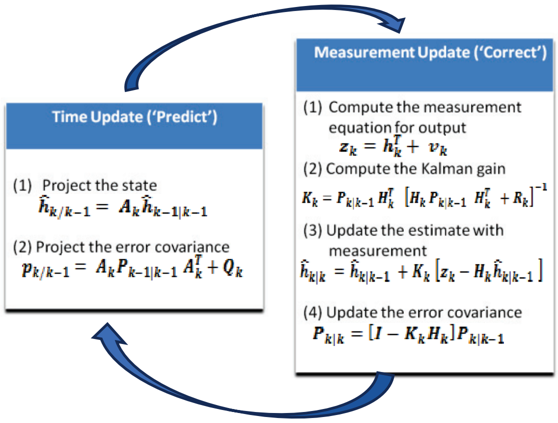

Figure 6. Kalman Filter algorithm.

6. SIMULATION ANALYSIS

The above mathematical model is simulated using MATLAB. The simulation parameters and room geometry are given in Table 1.

Table.1 System Parameters

Parameter	Value
Channel estimation scheme	LS, MMSE, KF
Power per LED	20 mW
Room size	(5 5 3) m
Locations of transmitters	(1. 25, 1.25, 3), (1.25, 3.75,3), (3.75, 1.25, 3), (3.75, 3.75, 3)
FOV	70°
Number of LEDs per array	60, 60
Active area of PD	1cm^2

Our simulation results are plotted in Figs. 7 and 8. In Fig. 7, we compare the bit-error rate (BER) performance of our schemes as shown in Figs. 2 and 3 with that of other algorithms under the same channel conditions. Four transmitters located in a room with dimensions (5,5,3) are used in our simulations. ACO-OFDM and DCO-OFDM are simulated using KF with $N = 1024$ subcarriers. The simulated systems are modulated by 64 and 128 QAM levels. It is configured with a cyclic prefix of $N/8$. We use the comb-type pilot with the number of pilots of $N/8$.

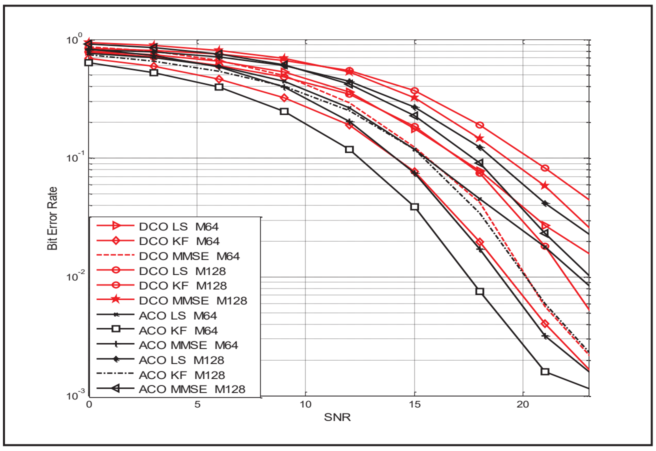

Figure 7. comparison between DCO- and ACO-OFDM systems.

From the Fig. 7, it can be seen that ACO-OFDM system has a better performance than of DCO-OFDM system. Also, the KF channel estimation method performs better generally than that of both LS and MMSE channel estimation methods. Specifically, ACO-OFDM performs better than DCO-OFDM by about 1.8 dB and KF performs better than the MMSE channel estimation method by about 1.5 dB. In addition, KF has the least value for BER for different mapping. At higher constellation orders, the results show that all types of estimators have a higher BER. Nevertheless, the KF method maintains a lower BER than both methods for all QAM orders.

Figure 8 shows a comparison of the responses of KF for both DCO- and ACO-OFDM systems, respectively.

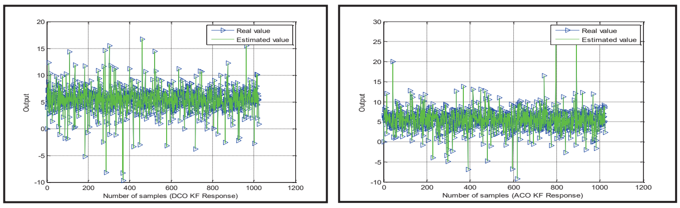

Figure 8. KF response for DCO-OFDM system (left) and ACO-OFDM system (right).

7. CONCLUSION

The performance of ACO-OFDM when using Kalman Filter method for channel estimation is presented and compared to that of DCO-OFDM system. The best performance is obtained by KF in comparison with LS, MMSE for both systems. In addition, ACO-OFDM system using KF has a better performance than that of DCO-OFDM system for different QAM levels.

8. REFERENCES

[1] E. Shawky, M. A. El-Shimy, H. M. H. Shalaby, A. Mokhtar, E.-S. A. El-Badawy, and A. Srivastava, “Optical channel estimation based on Kalman filtering for VLC systems adopting DCO-OFDM,” in *Proc. 20th Int. Conf. Transparent Optical Networks (ICTON 2018)*, Bucharest, Romania, July 1–5, 2018. 2018, pp. We.P.13(1–4)

[2] T. Zhang, S. Guo, H. Chen, F. Zhong, “Enhancing the bit error rate of indoor visible light communication systems using adaptive channel estimation algorithm, *IET Commun.*, vol. 9, no. 4, pp. 501-507, Mar. 2015.

[3] Yaseein Soubhi Hussein, Mohamad Yusoff Alias, Ayad Atiyah Abdulkafi, “On Performance Analysis of LS and MMSE forChannel Estimation in VLC Systems”, *IEEE 12th International* Colloquium Signal Processing, 2016

[4] QiWang, Chen Qian, Xuhan Guo, Zhaocheng Wang, David G.Cunningham,3 and Ian H. White2 "Layered ACO-OFDM for intensity-modulated direct-detection optical wireless transmission"

[5] Rashi Jain, “Kalman filter based channel estimation,” *International Journal of Engineering Research and Technology*, vol. 3, no. 4, April 2014.

[6] H. S. Wang and P. C. Chang, “On verifying the first-order Markovian Assumption for a Rayleigh Fading Channel Model”, *IEEE Trans. on Vehicular Tech.*, vol. 45, no. 2, pp. 353–357, May 1996.

[7] L. Ros, H. Hijazi, and E. P. Simon, “Paths complex gain tracking algorithms for OFDM receiver in slowly-varying channels”, in *Proc. IEEE ISCCSP*, Limassol, Cyprus, Mar. 2010.

[8] Sarangi Devasmitha Dissanayake, S, and Jean Armstrong, "Comparison of ACO-OFDM, DCO-OFDM and ADO-OFDM in IM/DD Systems" JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 31, NO. 7, APRIL 1, 2013.

[9] Z. Ghassemlooy, W. Popoola, S. Rajbhandari"Optical Wireless Communications" © 2013 by Taylor & Francis Group, LLC