# The Performance Analysis of K-Nearest Neighbors Based Detection Algorithm in Visible Light Communication Systems

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***Abstract-*** The Visible Light Communication (VLC) is a promising technology to assure the wireless data transmission for optical wireless communication system. Some modulation methods used in VLC systems require to apply a threshold value on the receiver side. In this paper, therefore, it has been investigated the classifier based demodulator architectures to solve the data detecting problem for threshold-based transmission methods such as On-Off Keying (OOK) scheme, under the condition of the unknown threshold level value. The presented receiver schemes use the K-Nearest Neighbors (KNN algorithm to classify the logical level of received OOK signal. These classification method requires a few training data to detect data bits for OOK receiver system. It can be observed from the simulation results that the receiver system is affected from the number of the neighbor employed in the KNN algorithm. Addition to this, Observation of the result clearly shows that the training set size is crucial for the Bit Error Rate (BER) Performance. According to simulation results, the transmission distance can be increased 2.451 m to 2.530 m at the BER of approximately 10-3 by using KNN method at the receiver side.

***Index Terms***- VLC, OOK, KNN, Classification

## I. Introduction

The approaching saturation of Radio Frequency (RF), the VLC networks have been considered as an alternative communication systems during the past decade. Moreover, major advances in solid state technology enable the usage of light emitting diode (LED) for both effective lighting and huge data sharing at the same time in indoor VLC links [1]. However, there are some problems in terms of high data transfer over the VLC channels due to the effect of Inter Symbol Interference caused by the limited frequency responses of LED technologies and photodiodes [2]. Addition to this, it is crucial to provide the user mobility condition depending on characteristic of data transmission methods.

The communication systems require to employ the detection threshold schemes due to the variation of detected power level at the receiver side caused by distance between receiver and transmitter if the modulation methods used in data transmission systems encode the signal amplitude taking into consideration transmitted data bit.

Many modulation methods have been proposed to implement to the VLC systems [3]. One of these modulation technologies is OOK modulation scheme which is the simplest scheme [4]. The OOK scheme transmits either logical '1' or logical '0' signal by taking into account the data bits [5]. The requirement of threshold value is one of the difficulties in OOK systems. Hence, it must be achieved the estimation of threshold value or classification of logical levels for OOK systems [6]. Another modulation scheme is Pulse Position Modulation (PPM) scheme which has better performance in terms of power efficiency compared to OOK. Especially, the performance of power efficiency can be improved when the order of PPM scheme is increased [7]. Both OOK and PPM have been improved to provide the dimming level control. The proposed dimmable schemes are defined as Variable OOK (VOOK) and Variable PPM (VPPM) techniques [8].

The classification methods have been used in many fields, such as biomedical systems, food technology, energy systems, communication, etc [9]. Addition to these, the classification methods are also integrated to VLC systems. A paper uses to achieve the classification of Quadrate Amplitude Modulation schemes in orthogonal frequency division multiplexing [10]. A constellation classification method for QAM schemes is implemented to seamless integrated fiber and VLC technology. The proposed system can significantly mitigate signal distortion by using support vector machine (SVM) technique [11]. In another paper, researchers propose a new classification method which is referred as nearest transmitter classification [12]. It is shown that the proposed method improves the accuracy of VLC positioning system.

OOK transmission scheme requires a threshold value to detect the data bits. Hence, many the threshold detection methods have been proposed to improve the performance of VLC systems. A paper proposed an artificial neural network based threshold detection system [6]. The detection method successfully estimates the threshold level when change optical transmission power and the distance between transmitter and receiver. In [13], it is focused on adaptive VLC systems which are used OOK transmission scheme with combination of pulse width modulation (PWM) and run-length limited (RLL) codeword. From experimental results, it is shown that the proposed method gives acceptable BER performance under transmission distance of 10 cm. In the paper [14], it is improved a SVM-based detection method for 8-superposed pulse amplitude modulation (8-SPAM) scheme which is proposed to use in VLC systems. It is demonstrated that the proposed scheme has better BER performance when compare direct detection scheme.

In this paper, we propose a KNN-based receiver system to demodulate the OOK signal without using any threshold value. The classification of data bits is obtained by considering the optical power of received signal. Hence, the signals at the similar optical power level is assigned to same class. In order to observe the performance of KNN-based receiver system, a traditional direct detection method that has perfect threshold level knowledge is used for some transmission distances. From simulation results, it is observed that the proposed system has better BER performance compared to traditional method which has not perfect threshold level knowledge. Addition to this, the system that has perfect threshold level knowledge gives close BER performance to proposed KNN-based receiver system. According to simulation results, it is shown that the data bits can be successfully classified by using KNN method.

The remainder of this paper is organized as follows. The Section II briefly describes KNN based VLC receiver system for OOK transmission method. In section III, we observe that simulated results obtained by proposed receiver model. Finally, in Sections IV, we summarize our findings.

## II. KNN Based OOK Receiver Model

In this section, we give the KNN model which is regulated to OOK receiver system. The KNN classification method is one of the most used techniques due to its low-complexity framework. Hence, we propose that KNN model can be integrated to OOK receiver scheme.

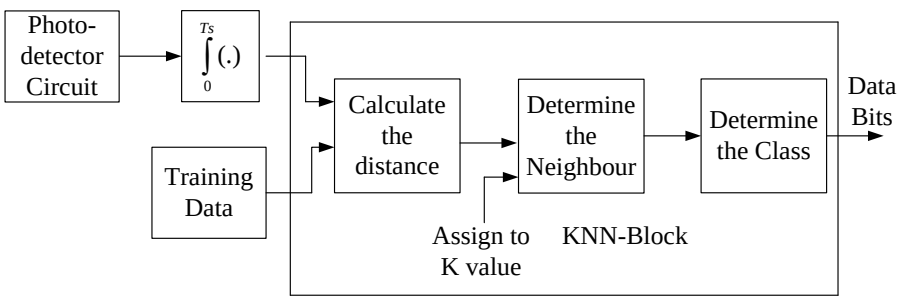


Fig. 1. OOK-KNN System

In Fig. 1, it is given a KNN based VLC receiver system. According to scheme, a photo-detector structure that can consist of a photodiode, a current to voltage converter, and an amplifier. The receiver optical signal is converted to electrical signal at the output of Photo-detector circuit. The received electrical signal is passed through an integrator block during to one-bit period. Therefore, the test data can be obtained at the output of integrator block. The received signal at the output of integrator block can be written by,

$$y = \sum_{i=0}^{s} r_i \tag{1}$$

where, y and r are defined as integral value of received signal during one period and one sample value of received signal, respectively. The KNN method can be consisted of the VLC systems follow as:

$$d_j = \left| y - t_j \right| \tag{2}$$

where, tj and dj are can be expressed as jth training data and jth hamming distance between received test data and jth training data. The hamming distance can be calculated by using absolute value since the samples can be pointed by one dimensional matrix. The neighbors can be expressed as,

$$n = \{d_0, d_1, ....., d_{k-1}\} \tag{3}$$

$$n_{data} = \{td_0, td_1, ....., td_{k-1}\} \tag{4}$$

where, k presents the number of neighbors. The data bits gets either logical '0' or logical '1' value. Therefore, it can be considered that there are two classes for OOK transmission method. The sets of classes and distance are defined by ndata and n, respectively. Each distance dj belongs to the class tdj. As mentioned above, the tdj becomes '1' or '-1' since there are two classes. A comparison can be given to detect the data bits from received OOK signal hence, the logical '0' class is coded by -1. A comparison can be given by,

$$C = sum\{td_0, td_1, ....., td_{k-1}\} \tag{5}$$

$$(C < 0 \rightarrow data = 0) \wedge (C > 0 \rightarrow data = 1) \tag{6}$$

The C and data can be described as sum of element in coded class and data bit, respectively. If the number of zero class is more than the number of one class, the C has negative value. Hence, the detected data bit will become logical '0' as shown in Eq. (6). Otherwise, the data bit will get logical '1'.

## III. Simulation Results

In this section, we give the simulation results of proposed KNN-based receiver model. According to simulation results, the traditional direct detection method has perfect threshold value for the transmission distance of 2.135 m. Hence, this model has better BER performance than that of KNN-7 and KNN-13. In the simulation results, the number of neighbor is defined by k. The distance between receiver and transmitter is considered as 2.305m up to 2.728m. Addition to this, the standard deviation of noise σ is selected as 1.25 to obtain the meaningful BER which is $10^{-3}$ or lesser for the distances mentioned above. The number of transmitted bit is $4x10^6$ in the simulation environment.

The number of neighbor is selected as 5 and 13 to give a performance comparison in terms of k while the it is used training set size of 20, 30, 40 and 50. According to simulation results, both selection are very significant with respect to improving of BER performance of proposed receiver system. In Fig. 2, it is given a classification process that includes test data, training set and neighbor set. The blue sample is defined as test data while red and black samples are presented as training and neighbor sets, respectively. The classification process given in this figure is obtained at the distance of 2.305 m. Addition to these, the training set size is 50. In this case, the data bit is detected as '0' since the test data is nearest to training data of logical '0'.

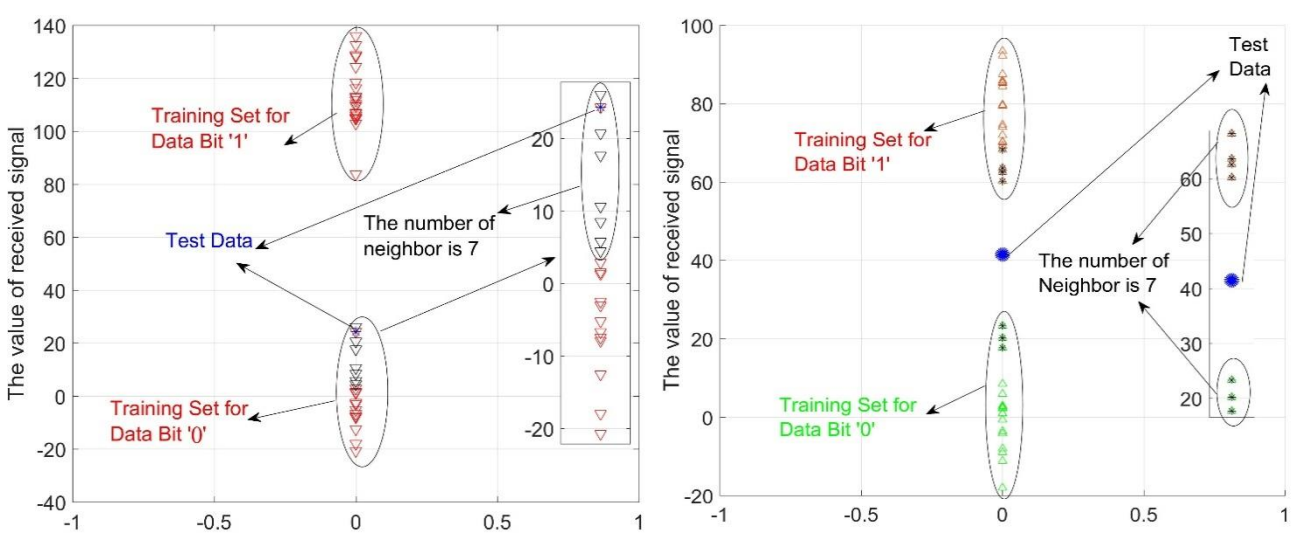


Fig. 2. The KNN classification model. (a) Distance of 2.305m (b) Distance of 2.530m

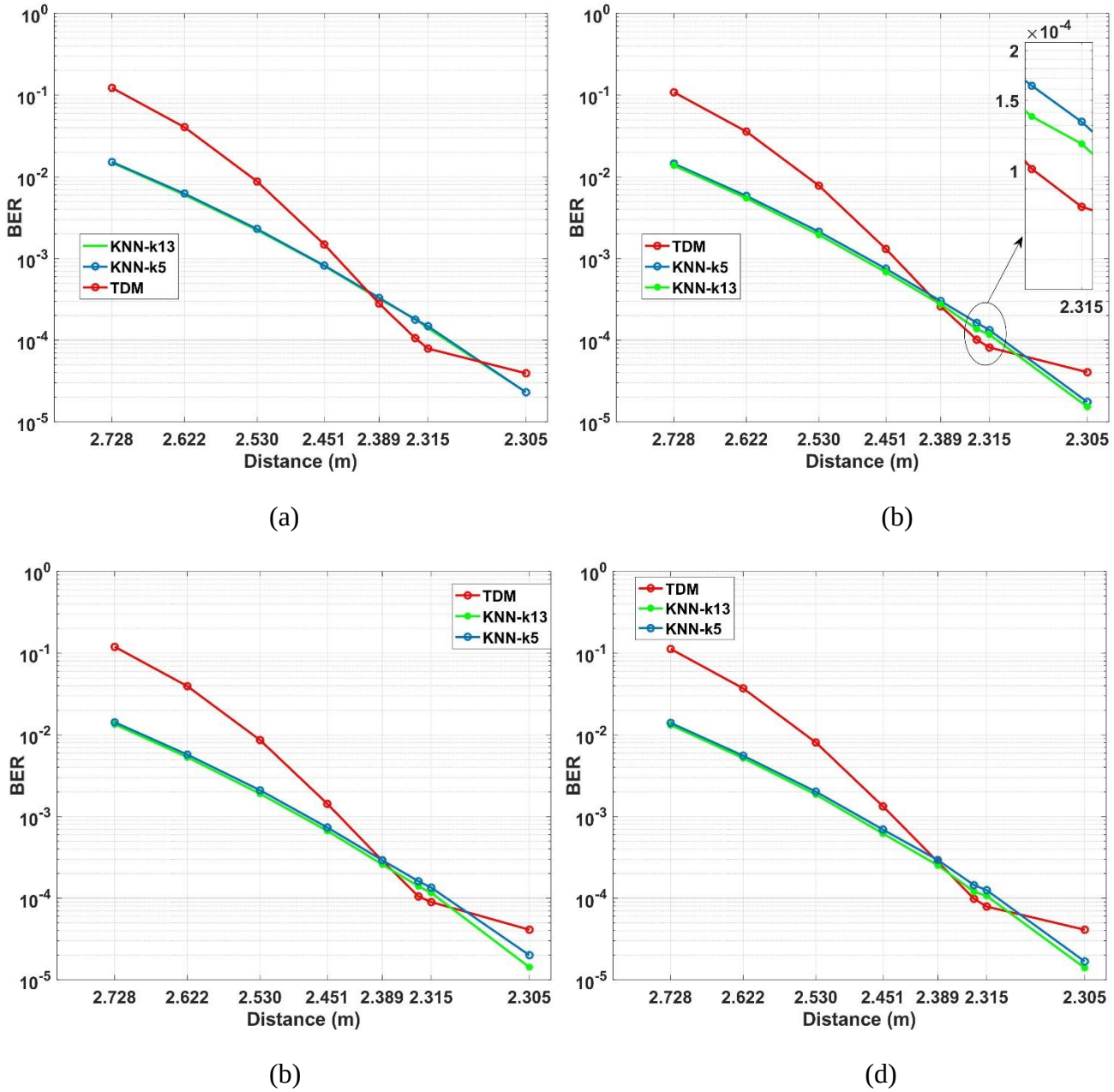


Fig. 4. The performance analysis of Training set size. (a) Training set size of 20 (b) Training set size of 30 (c) Training set size of 40 (d) Training set size of 50

In Fig. 3, the neighbors are selected from both training set-1 and training set-2 since the value of data set is close to both training sets. The reason is that the distance is increased to 2.530 m. The training set size is given as 20 in the Fig. 4 in which the Partial Traditional Method (TDM) have better BER Performance compared to proposed system at the perfect transmission distance knowledge. However, the proposed system gives better BER performance due to its classification structure. As shown in the figure, KNN method has similar BER performance when the number of neighbor is 5 and 15.

When the training size is increased at the receiver side, the BER performance of proposed system gradually improves as shown in the Fig. 4b, Fig. 4c and the Fig. 4d. Addition to this, it is shown that the number of neighbor can advance the BER performance of OOK receiver system. According to simulation results, the transmission distance can be increased 2.451 m to 2.530 m at the BER of $10^{-3}$.

## IV. CONCLUSION

In this paper, we propose a KNN-based receiver system for the demodulating of OOK signal without using any threshold value. The proposed system is compared to traditional system which has perfect threshold level knowledge at the distance of 2.315m. Hence, the traditional receiver has better BER performance at this distance or closer. However, the BER performance of traditional receiver doesn't similar for all transmission distance due to requirement of update threshold level. Hence, the KNN method, which is one of the classification methods, is used to estimate the logical level of On-Off Keying (OOK) signal with a few training data and without any threshold level knowledge. According to simulation results, the number of neighbor k, training set size can affect the BER performance of OOK system. It is shown that proposed system has better BER performance compared with traditional system under unknown threshold level condition.

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