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Spectral Domain Wavelet Transform Based Channel Estimation for VLC Communication

M. Nivedha[1,*]

[1]Assistant Professor, Arasu Engineering College, Kumbakonam, Tamil Nadu, India, nivedha.manivel@gmail.com

ABSTRACT

In the future, future heterogeneous communications networks may use visible light communications (VLC) as a supplementary technology to WiFi. The signal to noise ratio (SNR) of the received signal determines a VLC system's channel capacity, just like it does for any other communications system. The channel estimate for VLC communication proposed in this study is based on spectral domain wavelet transform. Due to their excellent spectrum and energy efficiency for VLC MIMO communication systems, SMTs have become more and more common. This work focuses on SMTs, or entirely generalized spatial modulation, in which multiple active optical antennas and a constant number of antennae are used to transmit data symbols for VLC at any time interval. In this study, an adaptive channel estimation approach over a time-varying MIMO channel is proposed using the Spectral Domain Wavelet Transform. Furthermore, the broadcast data and optical antenna indices are identified using a maximum likelihood (ML) decoder based on the received signal and the predicted VLC-MIMO channel. Matlab software is used in the implementation of this project.

Keywords: Visible light communications, Multiple input Multiple output, Maximum likehood, Free Space optics, Zero Forcing, Fast Fourier Transform.

1 Introduction

LEDs are quickly replacing traditional light sources because they are exceptionally compact, highly adjustable in terms of color and quality, and energy-efficient. However, LEDs are not limited to lighting applications. Being that they have the ability to be turned on and off at a relatively high frequency, they are also appropriate for wireless communication systems. Previously, infrared LEDs were employed for this function [1]; however, modern LED lights can also serve as transmitters for a downlink channel. The entire configuration can be understood as a multiple-input, multiple-output (MIMO) communication system because it includes numerous single illumination units and multiple users with photo detector-based receivers [2]. The primary issue with visible light communication (VLC) multiple-input multiple-output (MIMO) systems is the interference generated by the LED light sources, leading to a high degree of cross-correlation between channels [3]. White LEDs typically create an even illumination level and have the same light hue because that was their initial function when they were designed—to illuminate spaces. This could be the cause of the continued lack of broad use of VLC systems. Special applications for lowering the channel correlation include spotlights and other accent lighting configurations [4]. Therefore, they only make up a portion of the solution. Typically, to prevent or reduce interference, a precoding method is implemented at the transmitter end. The most often used technique is known as "zero forcing" (ZF) or "channel inversion" [5]. Successive interference cancellation at the receiving end can be utilized in conjunction with non-orthogonal or orthogonal access techniques [6]. These approaches are not as successful because there isn't any destructive interference or incoherent light with negative amplitude. Wireless communication, ranging from fourth-generation (4G) to the most recent (5G). Offering a comprehensive solution that permits customers to access high-speed data and voice traffic at any time, location, or point is central to the long-term objectives and aspirations of 5G communication systems [7]. However, the limitations imposed by the scarcity of conventional radio frequency (RF) spectrum prevented wireless communications from reaching these objectives. More recent technology will be needed as a result of the computing era's current technological advancements, such as the Internet of Things (IoT), where every item is able to process and provide connectivity [8,]. Under these conditions, it is imperative to highlight cutting-edge wireless technologies, one of which is visible light communication (VLC), which can lessen the shortage of radio frequency spectrum. With the addition of a communication chip, the VLC system leverages the existing lighting infrastructure to comprehend both high-speed data transfers and lighting capabilities simultaneously. LEDs or laser diodes are used in VLC transmitters to communicate information through fast light flickering [9]. Photo-diodes are used in the receiver to detect changes in light intensity. When compared to an RF-based wireless communication system, VLC offers a significantly wider interference-free bandwidth of about 300 THz. Furthermore, obtaining license approval is not required [10]. The list below demonstrates how the paper is organised: Section I gives a description of the introduction. The recent works are described in Section II. The proposed model and description are explained in Part III. The results are presented in Section IV. In Section V, the conclusion is presented.

2 Recent Works

Muneeb Ahmad *et al* [2023] [11] have presented in the massive multiple-input multiple-output (mMIMO-NOMA) network, the DL-based channel estimation and detection technique described in this research improves the successive interference cancellation (SIC) process over the traditional linear scheme-based SIC. In addition, the symbol error rate (SER) for both perfect and imperfect CSI is compared between the wavelet-based mMIMO-NOMA and the conventional fast-Fourier-transform (FFT) based mMIMO-NOMA. Fast Fourier transform-based orthogonal frequency division multiplexing (FFT-OFDM) is the pulse shaping

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mechanism used in most NOMA systems. However, because of the cyclic prefix (CP) and the rectangular pulse-shaped carriers, FFT-OFDM NOMA has worse noise immunity and decreased bandwidth efficiency. In addition to DNN, there are more deep learning algorithms that are helpful for a range of applications. Convolutional Neural Nets (CNNs) have been extensively researched in the literature and have proven to be incredibly effective at processing spatial data, especially photographs.

Adrian Krohn *et al* [2022] [12] have proposed an employing genetic optimization to identify appropriate patterns for pixels. Inevitably use an iterative process to integrate this type of receiver-side optimization with traditional convex precoding at the transmitter side. The aggregate rate of all users is to be maximized as the overall optimization goal. The interference that results from the LED light sources individually followed by the raised cross-correlation across channels in visible light communication (VLC) MIMO systems. White LEDs typically create an even illumination level and have the same light hue because that was their initial function when they were designed to illuminate spaces. This could be the cause of the continued lack of broad use of VLC systems. They employ a numerical ray-tracing simulation with various settings to demonstrate its efficacy. As cross-correlation is almost completely eliminated, the evaluated sum rate across all users is possible to increase in comparison to a single ZF precoding.

Diego Fernando Carrera *et al* [2022] [13] have introduced a fully sophisticated multilayer extreme learning machine (M-ELM) neural network is proposed here to perform MIMO integration and analysis over mmWave communications. In order to optimize system performance and reduce receiver complexity, they analyze the tuning of the number of neurons in each hidden layer for the suggested technique. The usage of huge arrays of antennas with beamforming, big spectrum signal testing, and baseline transmission processes at gigabit transmission speeds makes it difficult to handle considerable bandwidths at mmWave frequencies. To replicate the stochastic behaviour of a mobile scenario, they have employed hundreds of transmit samplings. mmWave communications using single antenna systems yielded successful outcomes utilizing the MLP method, but, as demonstrated, the MLP neural network is not as capable of doing MIMO processing as the M-ELM strategy with linear MIMO receivers.

Tiantian Guo *et al* [2022] [14] have suggested an examination of the evolution of wavelet theory, covering everything from the building process to the wavelet properties discussion. The development and application of wavelet transforms are then the main topics. There is discussion of the primary wavelet transform models and algorithms. Examples of rational wavelet transform (RWT) construction are given, along with a literature review highlighting the benefits of RWT over conventional wavelet transform. In 16-QAM (Quadrature Amplitude Modulation) and QPSK (Quadrature Phase Shift Keying) modulation, the BER performance of

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DWT-CO-OFDM is superior to that of CO-OFDM. One new multiple access technology that 5G is adopting is called non-orthogonal multiple access (NOMA). Wavelet analysis could improve NOMA's performance. More effectively in terms of augmentation, denoising, compression, and classification than conventional methods in signal analysis. Compared to conventional FFT, wavelet signal processing has also produced better outcomes in developing domains, including biological signals and power systems. .

J. Liu *et al* [2019] [15] have proposed a online fully complex extreme learning machine (C-ELM)-based channel estimation and equalization scheme with a single hidden layer feed forward network (SLFN) for orthogonal frequency-division multiplexing (OFDM) systems against fading channels and the nonlinear distortion resulting from an high-power amplifier (HPA). Computer simulations show that the proposed scheme can acquire the information of channels accurately and has the ability to resist nonlinear distortion and fading without pre-training and feedback link between receiver and transmitter. Furthermore, the robustness of the proposed scheme is well investigated by extensive simulations in various fading channels, and its excellent generalization ability is also discussed and compared with the DNN.

3 Proposed Work Explanation

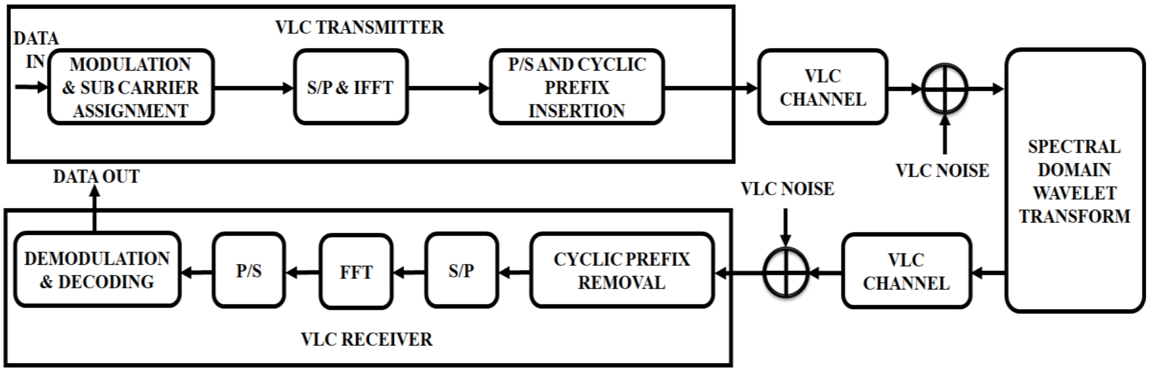

Figure 1: *Proposed Block diagram*

A Spectral Domain Wavelet Transform Based Channel Estimation for VLC Communication is suggested in this system. High spectral and energy efficiency have made VLC MIMO communication systems interested in SMTs. Therefore, the work here concentrates on SMTs like fully generalized spatial modulation, where various and constant numbers of optical antennas are active to transmit data symbols for VLC at any given time period. The Spectral Domain Wavelet Transform is suggested in this paper as an adaptive channel estimate technique for time-varying MIMO channels. Additionally, from the received signal and the predicted VLC-MIMO channel, the greatest likelihood (ML) decoder is employed to determine the broadcast data and optical antenna indices.

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3.1 FGSM

There are several transmit and receive optical antennas in FGSM, but only one transmit optical antenna is ever operational at a time; the others are always silent. Because the data in the input determines which antenna remains active, the spectral efficiency is raised and the antenna index contains useful information. SM is a development of traditional modulation methods. These four bits are transferred to a symbol if we take a modulation scheme with four transmit antennas into consideration. The first two bits of the SM method are designated for use as transmit antennas, and the latter two bits are designated for conventional modulation. The fast rate at which sent signals are detected presents a hurdle for GSM. The fundamental idea of SM is to map a block of data points to two data-carrying units. A distinct transmit antenna number is selected from a group of transmit antennas, and a symbol selected from a constellation diagram serves as one of the information-carrying units. The sent block of information bits was retrieved at the receiver using a Maximum Likelihood technique.

3.2 Spectral Domain Based Wavelet Transform

In essence, the Fourier transform is the source of the wavelet transform. Fourier sine and cosine functions are not spatially localized, but individual wavelet functions are. The process of breaking down a signal into scaled and shifted versions of a certain wavelet is known as wavelet analysis. The wavelet transform combines high-pass and low-pass signal filtering. The low pass filter linked to the scaling function generates coarse approximation information at each level, whereas the high pass filter generates detail information. We keep filtering and decimating till the output level is what they want. The number of levels is determined by the signal's length. Analyzing from wavelet coefficients is the term used to describe the reverse operation of processing a signal through the inverse wavelet transform, which is commonly referred to as synthesizing into wavelet coefficients. Here, approximation and detailed coefficients at every level are up sampled by two, processed through the low pass and high pass synthesis filters, and then added because reconstruction is the opposite process of decomposition. In order to obtain the original signal, this method has the same number of levels as the decomposition process.

3.3 System Model

A specific number of input bits A are mapped by the spatial mapper onto the symbol Bei, where the i-th unit vector is located. There is one non-zero entry in the i-th position of this i-th unit vector. Any constellation of real or complex valued symbols can be used to generate the modulation symbol B. A system's spectral efficiency is determined by the quantity of data symbol B and bits transmitted per channel. The signal point constellation that is used also affects it. Let's examine a modulation method in which each of the four transmit antennas' four

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bits is mapped to a symbol. Conventional modulation uses the last two bits, whereas the first two are utilized to choose transmit antennas. Symbol B is used in the modulation method above. There should only be one active transmit antenna at all times as a result of transmitting the signal that was obtained from Bei, the spatial mapper. The other is symbol demodulation for this antenna at the receiving end, which aids in determining the transmit antenna index using SM detection. But as a result, in SM, only one antenna is turned on at a time, allowing data to flow over one channel while the others are mute. Here, the complex Gaussian noise vector of the R receive antenna is denoted by n. For R receive antennas within a single time slot, the received signal y is shown by,

$$H = Yx + n \tag{1}$$

In this case, H represents a complex channel matrix, and x is a transmitted vector. The symbol hmn represents the channel fading coefficients between T transmit antennas and R receive antennas. Here, we'll suppose that H is a known to the receiver Rayleigh flat fading channel. Assume for the moment that there are numerous inputs at the transmitter's input and numerous outputs at the receiver's input. Any constellation of real or complex valued symbols can be used to generate the modulation symbol B. The precoding matrix is denoted by P. Instead of using a unit vector, i.e., this has a generic beam forming vector B that is made up of a codebook dependent on first input bits. The symbol B is not always transmitted on a single antenna element, as the signal is provided by Bei. A precoding matrix P is multiplied by the output of a standard mapper. The codebook of beamforming vectors that are available is represented by this precoding matrix. The generalized method reduces to conventional spatial modulation if P is selected as the identity matrix.

3.4 ML Dedection

The statistical model parameter is capable of being estimated with the use of maximum likelihood estimation. A machine learning decoder's introduction in a low-complexity channel is contingent upon the sent symbol and transmit antenna indices. An unrestricted channel are additionally used for ML detection. This channel becomes more complex when it’s modulated symbol and overall send antenna change. Reducing the number of candidates will help us lessen the complexity. Normal distribution and a host of other issues lead to a unified method for estimating maximum likelihood. The Maximum Likelihood statistical model, when applied to this data set, yields estimates for the model's parameter. A fixed set of data is able to provided to obtain maximum likelihood chosen values of the model parameter. Nonetheless, the observed data has the highest probability as a result. However, only one transmit antenna is active for data transmission at any given signaling time instant in the spatial modulation system. As a result, the vector only contains one nonzero value. The normalized complex fading gain from transmit antenna j to receive antenna i is indicated by the channel matrix H, which is the

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T2R fading matrix. The noise vector is indicated by the letter n. Assumptions have previously been made regarding the receiver's knowledge of the transmitted symbol vector, which is determined by the maximum likelihood detector, and the channel matrix H for the SM channel.

3.5 Transmitter

The component of the system that generates the transmitted signal and transmits it to the receiver is called the transmitter. Figure 2 provides a schematic overview of the full communication system.

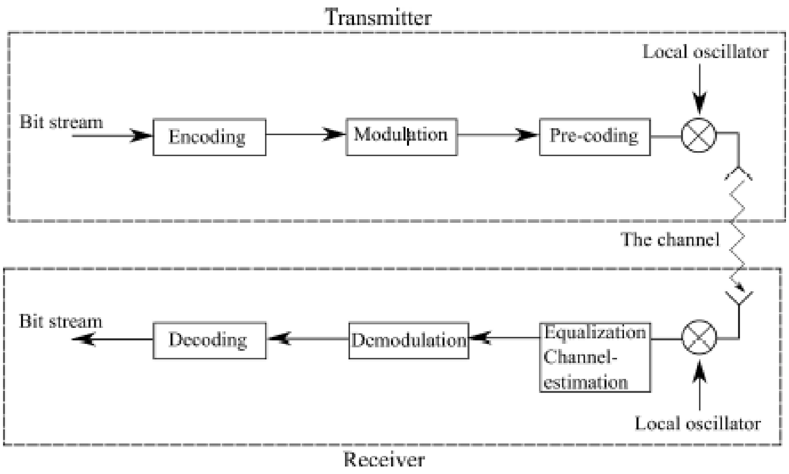

Figure 2: *Transmitter and Receiver Processing*

Initially, an error correcting strategy, like interleaving with parity bits, is used to rearrange the information bits. Although it is not required, using an error-correcting code improves bit error rate performance. The drawback is that more non-data bits are introduced, which can lead to increased complexity and decreased bandwidth efficiency. The next step is modulation, where a symbol from the modulation alphabet of the chosen modulation scheme is used to represent each code word of bits. Since one modulation alphabet symbol can represent many bits, modulation can increase bandwidth efficiency. The transmission becomes more bandwidth efficient the higher the modulation level, which is equivalent to an increase in the size of the modulation alphabet. The information bits must be transformed from the digital to the analog domain after being coded and modulated. By modulating the symbols onto an analog signal which will be covered in more detail later this is accomplished in the pre-coding step. The signal is then up-converted to the carrier frequency, which is accomplished in the mixer by multiplying it by the local oscillator's carrier frequency.

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3.6 Receiver

The receiver, which is the lowermost component of the communication system, is introduced in this section. Initially, the carrier frequency is eliminated through the conversion to base-band. The receiver then equalizes the signal, eliminating any ISI and channel estimation. The symbols are then deciphered and demodulated. Following baseband conversion, the receiver carries out matched filtering, which is equivalent to "sampling" the initial pulse that was received. By sampling the incoming signal at each symbol period T, where the sample is the outcome of matched filtering. One way to conceptualize the outcomes of matched filtering is as a conversion from analog to digital domain. The channel function linked to the current symbol is matched and filtered with the received signal. Conjugation is indicated by the character throughout the paper. Because of Doppler and ISI distortion, the results in vector y do not yet contain the actual transmitted symbols. To counteract these impacts, these still need to be equalized, which was previously explained. Finding a matrix that allows the vector y to be obtained is necessary before writing can begin. The vector denoted by b contains the original symbols. The condition should hold for the "channel" matrix R. The white Gaussian noise vector, with a variance of σ2R but a zero mean after matching filtering, is represented by the noise term n, which is added.

3.7 Channel Mode

Multiple data streams are able to transmit simultaneously via a parallel port. Data is sent via a parallel port by transmitting many bits simultaneously.
A parallel port may transfer eight bits at once across eight separate wires, in contrast to a serial port. Because of this, it operates more quickly than serial communication. It makes use of a 25-pin connector known as a DB-25 connector, as opposed to serial ports. In parallel communication, all bit streams must send data at the same speed in order to prevent errors and crosstalk. However, that is not realistic. Consequently, in parallel communication, small transmission lines are preferred.

3.8 Channel

The previous chapter included a discussion of the causes of the channel effects that are present in the medium. It is expected that all pathways undergo fading, Doppler effects, and delay, and that multipath is present and ISI will occur. These phenomena are mentioned in many UAC references as occurring in acoustic underwater communications. The rate at which the signal is dilated or compressed in relation to the original signal is indicated by the Doppler rate. The initial transmitted signal, s(t), has been compressed or dilated to create the received signal, r(t). Since a Doppler shift doesn't alter the signal's power, it acts as a kind of normalization, the factor p |α| ensures that the overall power stays constant. When α is 1, the channel does not

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exhibit any Doppler effects. Because a signal cannot be dialed to a duration of zero seconds, this always implies that α > 0. If α is greater than 1, it indicates that the signal is compressed; if α is between 0 and 1, it indicates that the signal is dilated. It is also mentioned in the preceding chapter that UAC signals are wideband by nature. The Doppler effects in narrowband transmissions can be roughly represented by a frequency shift of fd ≈ (α−1)fc, where fc is the carrier frequency. Only in the case of narrowband signals is this approximation possible. These two requirements are not met in the UAC, hence a narrowband approximation is not possible. The carrier frequency is typically on the same order as the bandwidth, which is the primary reason why wideband signals are used in underwater acoustic communications, even though the ratio 2vc is typically in the range of 10−1 −10−3. Wideband notation for the Doppler impact on a signal is needed to properly model the Doppler effects. Rayleigh fading of the channel coefficients hl is assumed. The time it takes for delayed versions of the original signal to reach the receiver is represented by the delays, or$\boldsymbol{\tau l}$. The signal that was received in (3.10) does not yet have its carrier frequency (fc) up converted from base-band to pass-band. The carrier frequency is also impacted by the Doppler Effect, which causes a shift in frequency based on the parameter αl. Due to a shift in the carrier frequency that results in a mismatch with the local oscillator, there is still a residual term in the base-band signal after conversion to base-band at the receiver. After adding the noise, which is represented by the symbol $\boldsymbol{n}(\boldsymbol{t})$, it is assumed that the noise is uncorrelated with the signal and is a white Gaussian random noise ($\boldsymbol{CN}(\mathbf{0}, \boldsymbol{\sigma}\mathbf{2})$. Including the noise and the Doppler effects on the carrier frequency that were previously discussed. The carrier frequency is eliminated at the receiver to convert the signal from pass-band to base-band. This is accomplished by multiplying the received signal by e2j_fct. It is evident that the carrier frequency is removed if this is applied to the transmitted signal as demonstrated in. As can be observed, a residual term remains after the conversion from pass-band to base-band.

The total received signal, or $\boldsymbol{r}(\boldsymbol{t})$, is the product of the $\boldsymbol{qn}(\boldsymbol{t})$ functions, also known as the channel functions for the N symbols. Every symbol has a unique channel function, denoted by $\boldsymbol{qn}(\boldsymbol{t})$, which represents how the receiver interprets the signal. The path functions, also known as the L multipath components, are represented by $\boldsymbol{vln}(\boldsymbol{t})$, and their sum equals $\boldsymbol{qn}(\boldsymbol{t})$. There is a $\boldsymbol{vln}(\boldsymbol{t})$ that represents the received signal for a symbol on path for each symbol and path that are present.

The ISI that a symbol suffers in the presence of Doppler depends on the symbol index. The block is squeezed or dilated throughout. A channel with three routes is seen below; the center path is the regular block duration without Doppler effects, the lower path is the dilated version, and the upper path is compressed. The ISI can alter dramatically during the course of a block, particularly for very long blocks and/or if there is a major variation in Doppler rates. The channel model shown here is a channel with a distinct arrival time and a distinctive Doppler

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rate on each direction. This is referred to as a multi-scale/multilag channel, where the delays are represented by the lag and the Doppler effects by the scale. These channels have not been well researched, and currently, there is no accepted method for managing them. If every path has a single common Doppler rate, it can be compensated for by resampling with a factor of$\mathbf{1/\alpha}$. Unfortunately, there is currently no accepted method for accounting for all Doppler effects when using different Doppler rates. Only the portion of the signal with the Doppler rate equal to the one compensated by the resampling factor is eliminated during resampling. Resampling the signal with a Doppler rate equivalent to the path containing the maximum power, on the other hand, is demonstrated to be the optimal approach. However, because it cannot account for the impacts of numerous distinct Doppler rates on each path, this method is still not ideal.

4 Result and Discussion

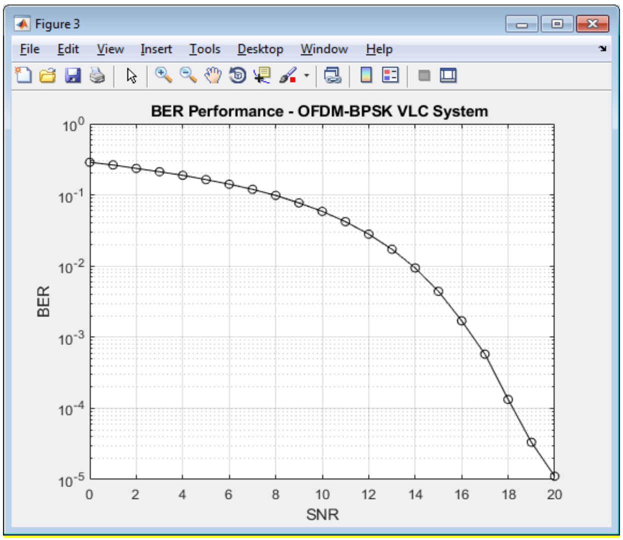

Figure 3: *BER performance-OFDM-BPSK VLC System Performance*

The effectiveness of the OFDM signal using BPSK modulation is shown in Figure 3. The performance of bit error rate (BER) and signal-to-noise ratio (SNR) (dB) is shown in a comparative graph.

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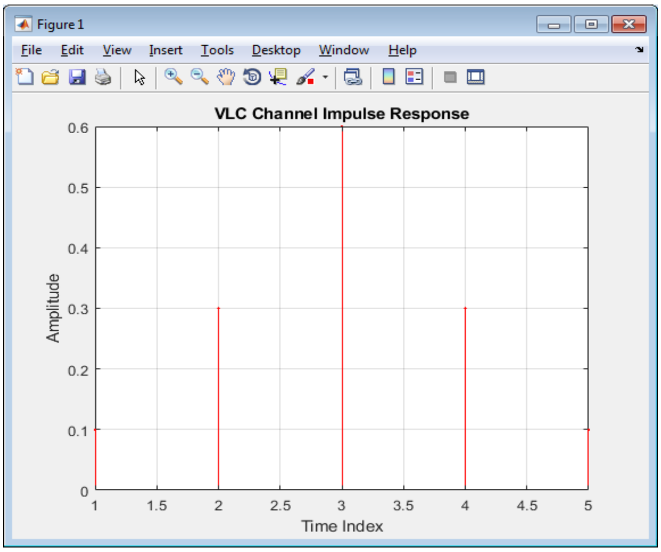

Figure 4: *VLC Channel Impulse Response*

After filtering out the noise in the channel, the amplitude of the signal is displayed in Figure 4.

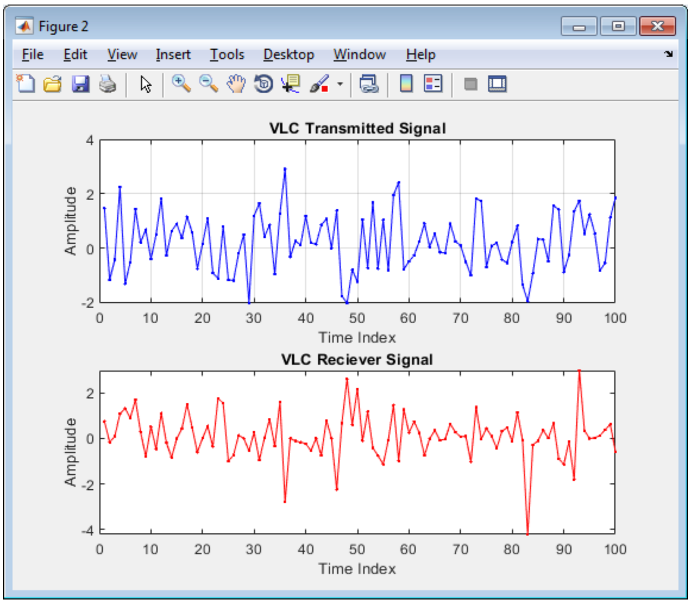

Figure 5: *VLC Transmitted Signal and VLC Receiver Signal*

Rapid data transfer via visible light is possible because to a wireless technology called visible light communication, or VLC. This data is conveyed by altering the brightness of the light emitted by a light source. After the signal has been decoded and demodulated, it is picked up by the VLC receiver.

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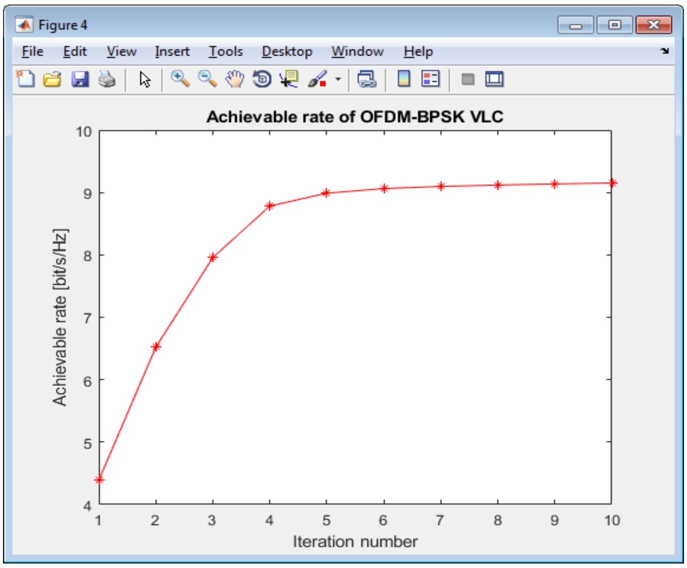

Figure 6: *Achievable rate of OFDM-BPSK VLC*

Figure 6 represents that achievable rate of OFDM-BPSK VLC. OFDM makes resourceful utilization of the spectrum by overlapping. By dividing the channel into narrowband flat fading sub channels, OFDM is more resistant to frequency selective fading than single carrier systems.

5 Conclusion

This study produced a channel estimation for VLC communication based on the spectral domain wavelet transform. Impulse noise (IN), one type of intrinsic noise in VLC channels, is identified by the effectiveness and efficiency of rapidly varying amplitudes brought on by arbitrary switching of electrical devices in a power network. Testing was done on a channel estimation for VLC communication based on the spectral domain wavelet transform. This implies that a signal may have faults when it reaches its destination. Therefore, it is necessary to determine the features of the channel in order to eliminate the noise and distortion effects from the received signal.

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