MIMO Visible Light Communication System

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***Abstract*—The expanding streaming culture of large amounts of data, as well as the requirement for faster and more reliable data transport systems, necessitates the development of innovative communication technologies such as Visible Light Communication (VLC). Nonetheless, incorporating VLC into next-generation networks is challenging due to technological restrictions such as air absorption, shadowing, and beam dispersion. One technique for addressing some of the challenges is to use the multiple input multiple output (MIMO) technique, which involves the simultaneous transmission of data from several sources, hence increasing data rate. In this work, the data transmission performance of the MIMO-VLC system is evaluated using a variety of factors such as distance from the source, data bit rate, and modulation method.**

Keywords: Visible Light Communication (VLC), MIMO (Multiple Input Multiple Output), RZ, NRZ-OOK.

I. Introduction

Visible Light Communications (VLC) is a type of communication that employs visible light emitting diodes (LED) to transmit data at fast speeds. The VLC is a crucial component used to create hotspots for heterogeneous networks and plays an important role in wireless communications for 5G networks and beyond [1], [2]. VLC provides a variety of remarkable qualities that satisfy the demands of 5G systems including high capacity, high data throughput, availability of license-free spectrum, the ability to transmit data rates of many gigabits per second, low energy consumption, and low implementation costs.

Despite its advantages, major challenges with VLC include air absorption, shadowing, and beam dispersion. One technique for addressing some of the challenges is to use the multiple input multiple output (MIMO) method, which involves transmitting data in parallel from several sources, hence increasing data rate. In this work, the data transmission performance of the MIMO-VLC system is evaluated using a variety of characteristics such as distance from the source, data bit rate, and modulation technique. The distance between transmitter and receiver is measured in meters because we are considering an indoor VLC application. When used outside, the distance may be increased to the kilometre range. However, the FSO (Free Space Optical) channel and atmospheric conditions should be considered for outdoor VLC applications.

The paper is organized as follows. Section 2 summarizes existing MIMO-VLC studies. The theory of optical MIMO transmission is discussed in Section 3. Section 4 presents the simulation results. Section 5 includes the paper's conclusion.

II. Related work

VLC systems have various advantages, including unsaturated bandwidth, which is not accessible in RF bands, and they have been shown to be extremely secure. VLC systems, however, have bandwidth restrictions depending on the photodiodes used, leading in a loss in spectral efficiency [3]. Modulation techniques are used to improve spectral efficiency and therefore data throughput. The IEEE 802.15.7 standard contains dimming algorithms that employ modulation methods to ensure that LEDs do not flutter while maintaining high transmission rates [4]. Another technique for enhancing data rate is to use MIMO technology. The literature discusses several MIMO-VLC studies.

Ajit Kumar et al. [5] study the performance of MIMO-VLC systems in a 5m×5m×3m room using three distinct LED radiation patterns. Two scenarios were investigated for BER performance: line-of-sight (LOS) and LOS plus first reflection (L-R1) signals. The authors of [6] perform a comprehensive

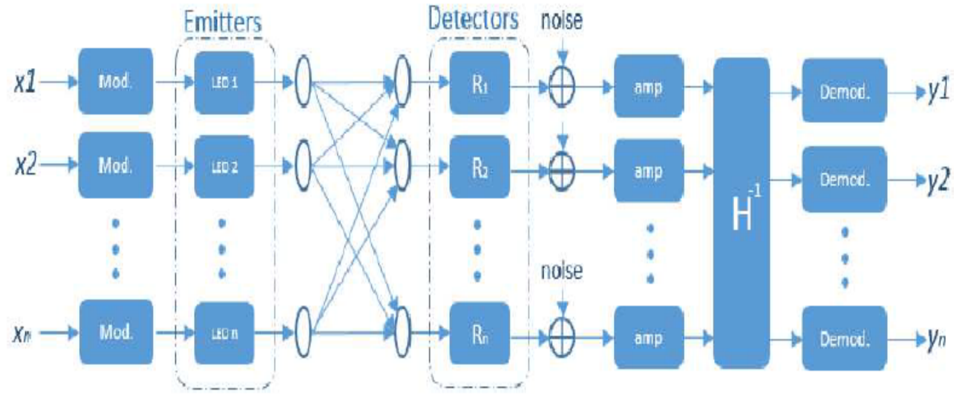


Figure 1: Optical MIMO communication Model.

investigation of a MIMO-VLC data transmission system. An experimental test-bed is set up to evaluate the performance of the MIMO-VLC system under various conditions such as distance from the source depending on luminous flux, ambient illumination and output power. Subjective tests are also carried out in order to assess the quality of an audio MIMO-VLC link as perceived by the user. In [7], the authors describe a VLC system composed of many luminaires powered by light emitting diodes (LEDs) that act as transmitters and an optical image receiver with a large number of separated multiple photodetectors. The massive MIMO-VLC system supports multi-users while also enhancing the data throughput of a single user and improving the received signal to noise ratio (SNR) via spatial multiplication (SM). In [8], the authors propose a centralized network design in which the ceiling LED lights function as transmitter components of a distributed massive MIMO VLC system. They investigate the design of massive MIMO VLC systems with a limited number of Down-link channels.

III. Theory of optical MIMO transmission

In terms of wireless communications, the strategy based on the usage of the MIMO technique means that data is sent in the form of numerous streams, forming several routes of transmission at the same time between multiple sending antennas and multiple receiving antennas [9], [10]. When performing MIMO transmission in the optical domain, we consider a large number of light emitters and detectors rather than radio antennas. However, the fundamental premise remains. When considering indoor VLC systems, the LED light bulbs used as light sources are usually composed of several individual LEDs.

The optical MIMO-VLC system depicted in Figure 1 may be described using a mathematical model. In this form of communication system, where ($M \geq N$), signals are broadcast by N transmitters and received by M receivers at the same time, as stated by the following equation:

$$X = HY + n \tag{1}$$

where X represents the vector of signals transmitted, Y represents the vector of signals received, and H represents the channel transfer matrix.

The gain between the i^{th} receiver and the j^{th} transmitter may be used to estimate the transmittance between each transmitter and receiver, which is represented by this matrix. The following formula shows that by inverting the matrix H, we may get the original signals:

$$Y = H^{-1}X + n \tag{2}$$

Some optimization methods can compute the matrix H^{-1} during the system setup phase. As a result, the system operates in two stages since comprehending the inverse matrix H^{-1} is necessary to extract signals on the receiver side. In the first mode (the initialization mode), the matrix H is calculated,

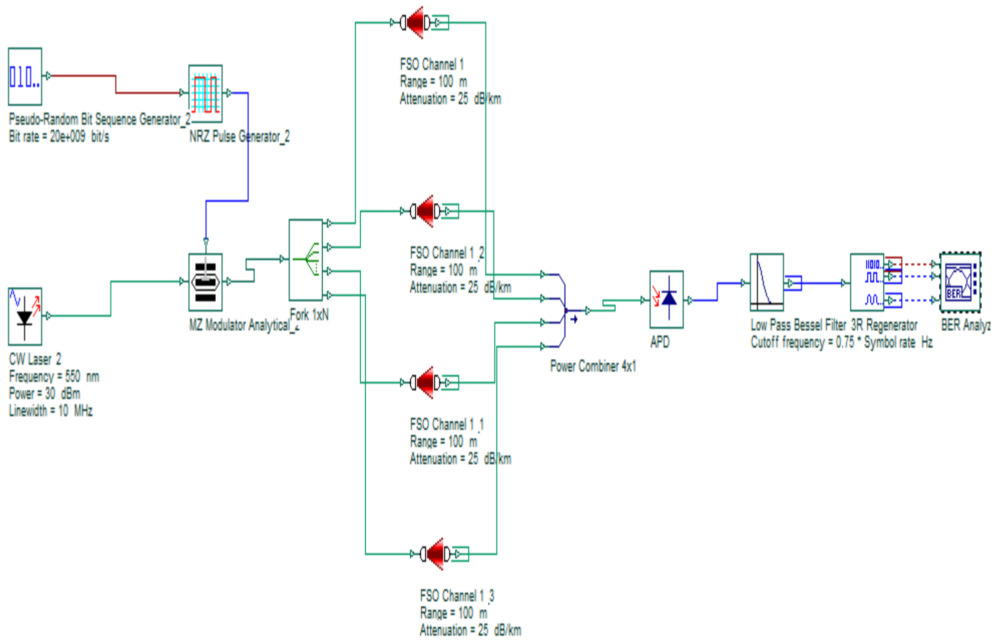


Figure 2: MIMO VLC system design.

usually with the assistance of certain unique pilot signals. The matrix H^{-1} is then calculated. Then, during the second phase, information signals are transmitted (the working mode). The inverse matrix H^{-1} is used to retrieve the initially transmitted signals.

IV. Simulation Results

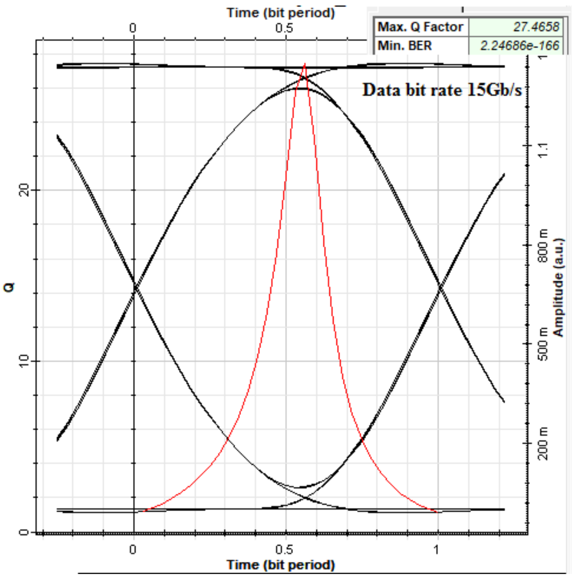
To assess the performance of the MIMO-VLC system, we use the optical system simulation tool OptiSystem 19.0. Figure 2 shows the architecture of a MIMO (Multiple Input Multiple Output) VLC system. A CW (Continuous Wave) laser with 1W power and visible light frequency (550nm) is used on the transmitter side. To generate data bits, a pseudo random bit sequence generator is utilized. Both data bits and laser light will be received via a Mach-Zehnder (MZ) modulator. We consider RZ and NRZ-OOK modulation techniques as modulation approaches and we compare their performance. An FSO (Free Space Optical) channel is used as a communication channel. Data is sent over a maximum distance of 200 meters, which is enough for indoor applications. APD photodetector receives optical signals from the four FSO channels. The simulation parameters and their values are shown in Table 1.

Table I: Simulation Parameters

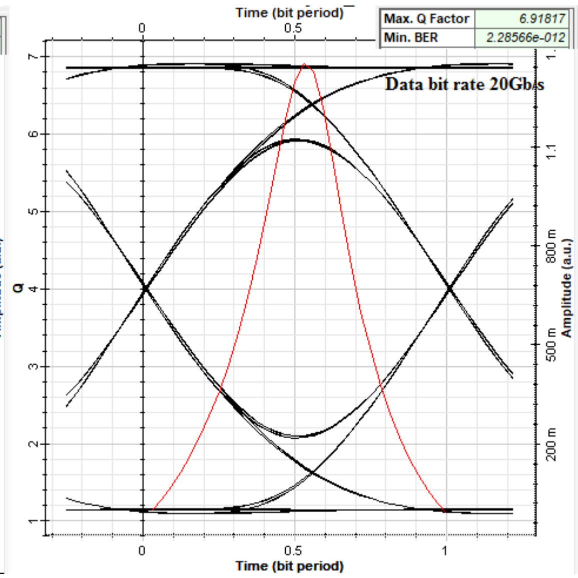
Parameters	Value
Bit rate of PRBS	10,15 and 23 (Gbits/s)
Power of CW laser	1(W)
Frequency of CW laser	550(nm)
FSO channel range	100, 200 (m)
FSO channel attenuation	25 (dB/Km)

In Figure 3, we evaluate the performances of the MIMO VLC system in terms of data bit rates. We remark that for a distance of 100m, and a variation of data bit rate from 15Gb/s to 23Gb/s, the BER decreases considerably with the increase of data bit rate.

In Figure 4, we compare the performances given by the two modulation techniques RZ and NRZ-OOK. To this end, we fix the data bit rate to 20Gb/s and the FSO distance to 200m. We note that RZ modulation technique is more adapted to long distances than NRZ-OOK modulation technique.



(a)



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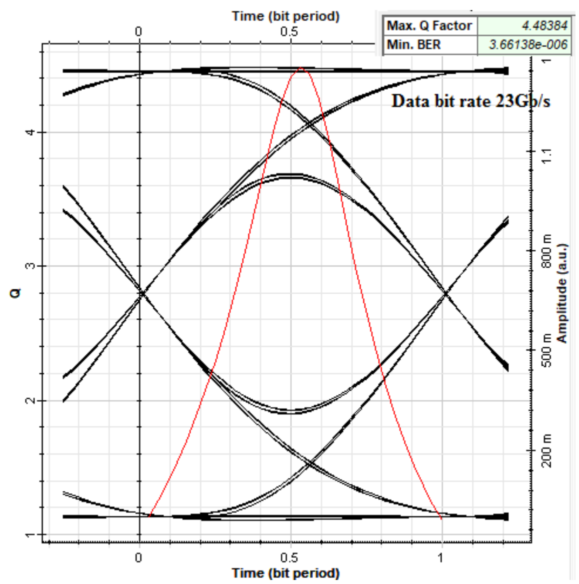


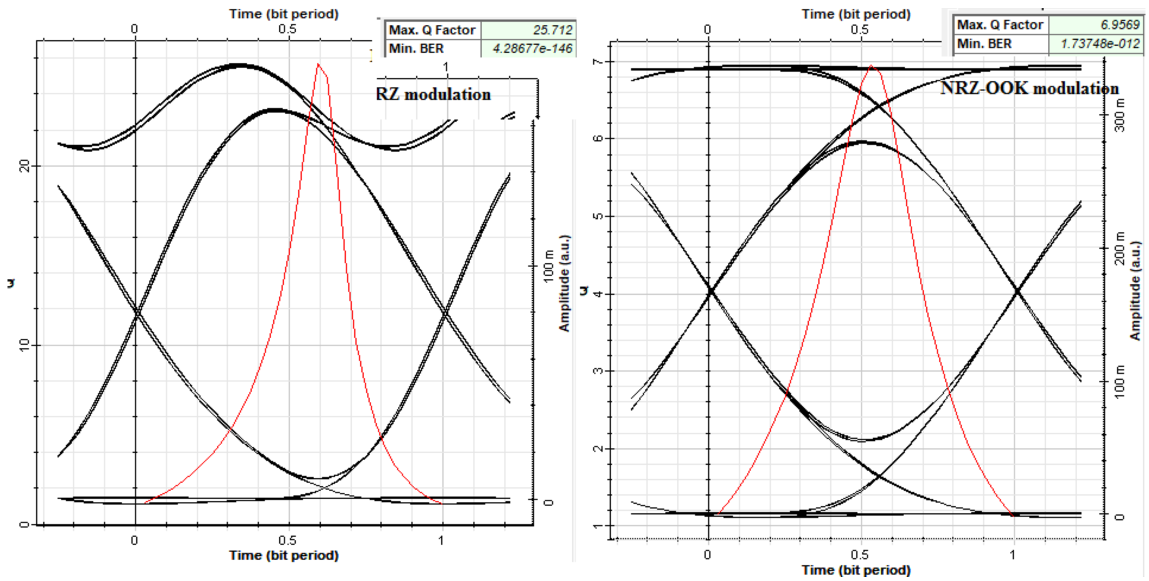
(c)

Figure 3: BER in terms of data bit rates.

Furthermore, Figure 5 compares the two modulation techniques when used with high data bit rates (25GB/s). We remark that RZ modulation technique is more adapted to high data bit rates than NRZ-OOK modulation technique.

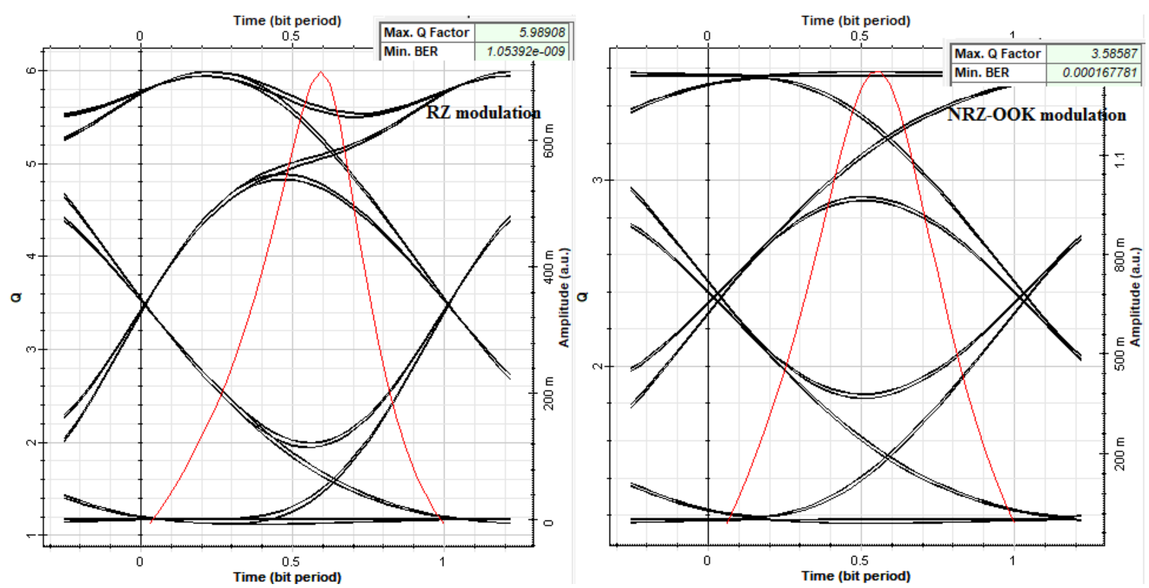
V. Conclusion

This paper is study the data transmission through visible light communication links. To this end, MIMO VLC system is designed and simulated. The distance is set to 100/200 meters which is sufficient for indoor VLC applications. This work assesses the data transmission performance of the MIMO-VLC system under various parameters such as distance



(a) (b)

Figure 4: RZ modulation vs NRZ-OOK modulation performances (Data bit rate 20 GB/s, FSO distance 200m).



(a) (b)

Figure 5: RZ modulation vs NRZ-OOK modulation performances (Data bit rate 25 GB/s, FSO distance 100m).

from the source, data bit rate, and modulation technique. In future work, FSO channels can be implemented for outdoor communication purpose with distance in terms of kilometers. But, in outdoor VLC, atmospheric conditions should be taken into consideration for speedy communication.

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