Multiple Input Multiple Output Visible Light Communication

Brajendra Kumar Ahirwar, Prabhat Patel

***Abstract:** Various transmitters (i.e, LEDs) and receivers (i.e., photo-detectors) are utilized in MIMO systems to enhance the rates of data that fulfil or goes beyond the present IR LAN along with the offering remarkably upgraded security and simplicity of deployment [3-5]. This technique provides extended link range and greater data throughput without the requirement for extra bandwidth or power, by the way of greater spectral efficiency (more bits/s/Hz) and a link reliability and/or diversity. Therefore, we can say that it plays a vital role in wireless communications. In this paper, performance of LED arrays in uniform illumination of light inside the room and associated BER is detailed. Finally, performance of MIMO system is evaluated and BER performance has been evaluated.*

***Keywords:** (i.e, LEDs), MIMO, BER performance, LED, IR LAN,*

I. INTRODUCTION

At present, the researches on VLC are focused on indoor applications. The indoor VLC channels are classified adopted from the conventional IR communication and, since the link configurations of VLC are similar to IR communication. The different characteristics come from the different operating wavelength and wavelength dependent devices (visible LED, silicon photo-detector, etc), and the fact that the VLC has the dual nature of communication and illumination. The other physical principles related to optics can be applied similarly, including the light transmission and reflections [1]. The link configurations are classified into four basic types, according to the existence of obstacles in light path and the directionality of the transmitter to the receiver. The basic link types include the directed line-of-sight (LOS), the non-directed LOS, the directed non-LOS, and the non-directed non-LOS. The decision that the link is directed or non-directed depends on whether the transmitter has the direction to the receiver. The decision that the link is LOS or non-LOS depends on whether there exist a barrier to block the transmission of light between a transmitter and a receiver.

II. LEDS ARRAY

In case of LEDs array more than one LED are used to illuminate the room. The array of LEDs reduces the dark spot inside the room, and more uniform illumination of light is observed inside the room [2].

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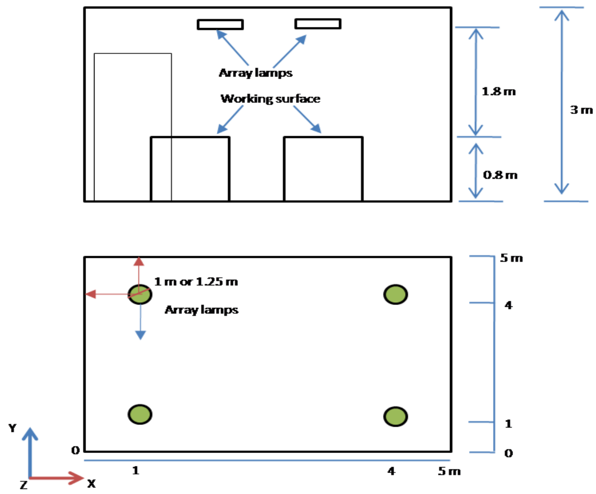

Figure 1 Pictorial Representation of LEDs Array

In figure 1 (a) pictorial representation of LEDs array is shown. In figure 1(b) cross-sectional view of LEDs placement is shown.

In figure 2 (a) pictorial representation of LEDs array with PDs are shown. In figure 2(b) image projection on PD is shown.

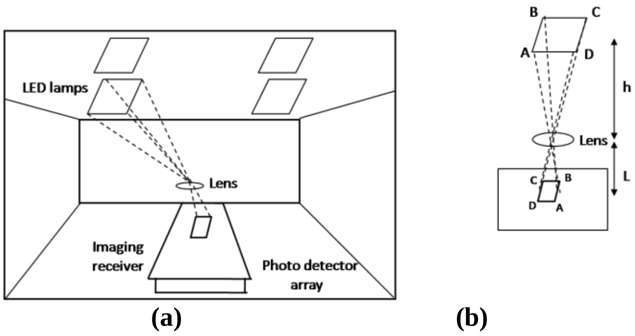

Figure 2 (a) Pictorial Representation of LEDs Array with PDs (b) Image Projection on PD Surface.

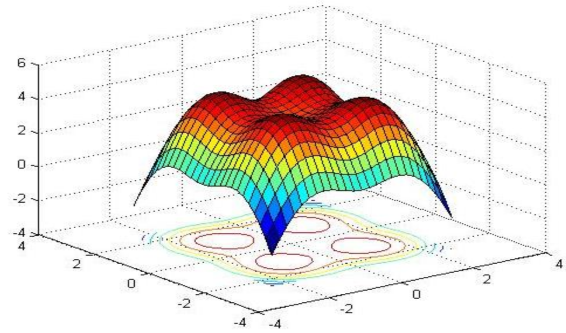

Figure 3 Power Illumination using 4 LEDs with Half Angle 38^0.

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In figure 3, power illumination using 4 LEDs with half angle 38^0, here the illumination is much better than single LED. However, at the centre of the room and at the corner of the room a dip in received power is observed.

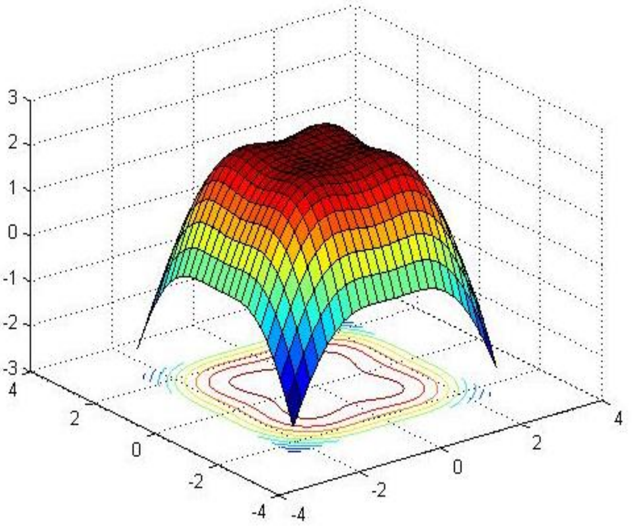

Figure 4 Power Illumination using 4 LEDs with Half Angle 70^0.

In figure 4, power illumination using 4 LEDs with half angle 70^0, here the illumination is nearly uniform. Thus half angle plays a significant role in illumination of light inside the room. Moreover by increasing the number of LEDs illumination in the room can be further improved. This in turn will improve BER.

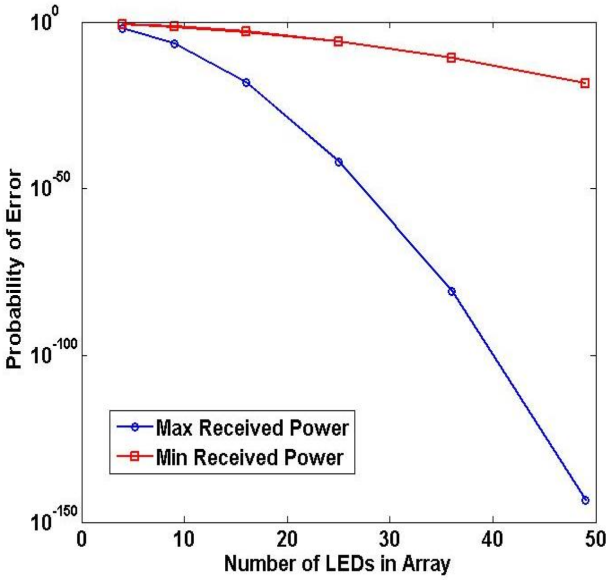

Figure 5 Probability of Error vs. Number of LEDs in Array.

In figure 5, probability of error vs. number of LEDs in array while considering both max and min received power. It is clear from the figure that as the number of LEDs in array increases, the probability of error decreases. Even in case of min received power with 49 LEDs the probability of error can be bring down to 10^{-10}, which is negligible error.

III. MIMO SYSTEMS

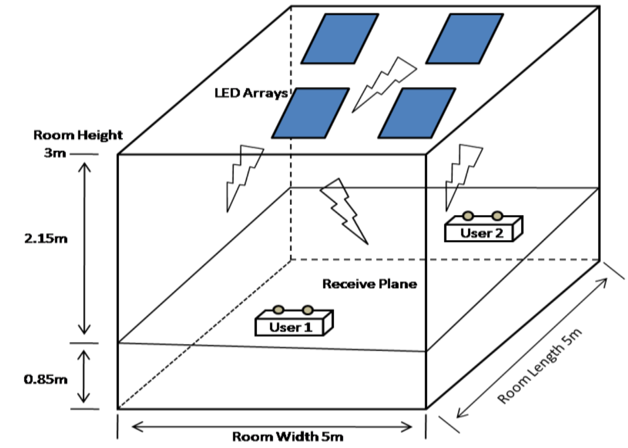

Figure 6 Schematic of Multiple LEDs and PDs System.

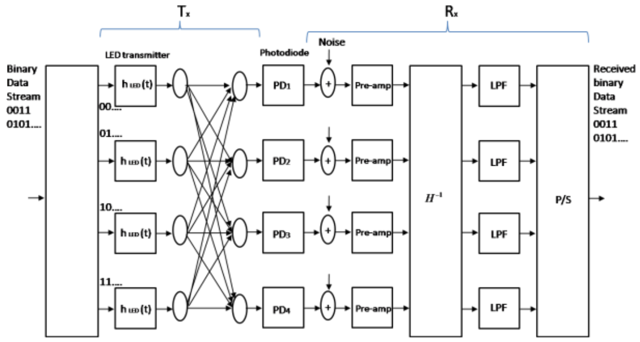

Figure 7 Block Diagram of MIMO System.

In the case of MIMO systems, the transfer function between a receiver and a transmitter is grouped into four components. The first denotes the transfer function between a source and elements of surface. A normal VLC MIMO system block diagram is demonstrated ion the figure 7. We use four LED arrays for room lighting along with for making the transmission of four independent data streams at the same time. A receiver array comprises four elements of photo detector with non-imaging concentrators are applied in order to gather light emitted from all LED arrays however with various strengths because of the geometric configuration [6]. We interleave the serial input data stream and applied in order to modulate the particular LED arrays (transmitters) before propagating via the channel.

In MIMO frameworks, the whole transmit power is confined without having any influence of the measure of transmitters M [7]. The noise composed of the shot noise, background noise, and thermal noise for N optical at the receiver. Output and input symbols of the MIMO channel are nonnegative, real intensities (i e, noncomplex numbers). Due to the fact that the optical channel doesn't present any nonlinearity, the total components of noise can be assumed to be evenly distributed. In a majority of cases, it is likewise sensible to make the assumption that the sources of background and thermal noise are primary in comparison to the shot noise. The H-matrix is an $M \times N$ matrix of channel attenuations that comprises of the data regarding the channel DC gain. In the case there are K-LEDs in the i^{th} array, transmitting to the j^{th} receiver, the DC gain h_{ij} is given by.

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$$h_{ij} = \begin{cases} \sum_{k=1}^{K} \frac{A_{pd-rj}}{d_{ij}^2} R_0(\varphi).\cos(\beta_{ijk}) & \text{for } 0 \le \beta_{ijk} \le \beta_c \\ 0 & \text{for } \beta_r > \beta_{ijk} \end{cases} \qquad (1)$$

where A_{pd-rj} is the collection area of the j^{th} receiver, d_{ij}^2 is the distance from the i^{th} transmitter to the j^{th} receiver, β_{ijk} is the angle of incidence on the receiver and β_c is the receiver field of view. The DC gains of the *H*-matrix is given as

$$H = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \qquad (2)$$

The output of the channel *y* is a vector in terms of *M*-dimensional transmitter ***x*** and the noise *n* and at the receiver is given by

$$y = Hx + n \qquad (3)$$

The j^{th} received signal is given by

$$r_j = R.P_t \sum_{i=1}^{i=N_T} h_{ij}.t_i + \sqrt{\sigma_{nj}^2} \qquad (4)$$

where *R* is the photodiode responsivity, P_t is the average transmit optical power and σ_{nj}^2 is the mean square noise current for the j^{th} receiver. The received signals are inserted into the vector ***y***, where ***y*** $= [r_1,.., r_j,.., r_{NR}]^T$

The received data are estimated using the inverse of the *H*-matrix H^T as [8].

$$d_{est} = y.H^T \qquad (5)$$

IV. SIMULATION RESULTS

In the simulation 4 LEDs and PDs system is considered. The considered parameters and their values are detailed in Table 1. Simulation is again performed in MATLAB.

Table 1 Simulation Parameters

Parameters	**Value**
Speed of Light	3×10^8 m/s
Theta	70^0
Transmitted Power by LED	0.1 W
Detector Physical Area	7.8×10^{-7} m^2
Distance between LED and PD	1.48 m
Gain of lens	10
Refractive index of lens	1.46
FOV	60^0
Room Dimension	5×5×3 m^3 ($L\times L\times H$)
Reflectivity floor	0.15
Reflectivity wall	0.70
Reflectivity ceiling	0.8
Noise bandwidth factor	0.562
Data rate	115200
Ambient light power	7×10^{-8} W
Photo detector responsively	0.55
Electronic charge	1.6×10^{-19} C
Amplifier noise density	5×10^{-12} ampere/√Hz
Electrical bandwidth	2.2×10^8 (Hz)

In case of four LEDs and PDs system channel gain is a 4×4 matrix of the form

h_{11}	h_{12}	h_{13}	h_{14}
h_{21}	h_{22}	h_{23}	h_{24}
h_{31}	h_{32}	h_{33}	h_{34}
h_{41}	h_{42}	h_{43}	h_{44}

will be generated at various positions inside the room. The centre of room is at (0, 0).

CASE 1: the position of first LED is at (1.5 m, 1.5 m) the second LED is at (-1.5 m, 1.5 m), position of third LED is at (-1.5 m, -1.5 m) and finally the position of fourth LED is at (1.5 m, -1.5 m). The positions of four PDs at the ceiling are at the same location as of LEDs in floor.

$h=h_{i,j}\times10^{-4}$			
0.0248	0.0311	0.0947	0.0322
0.0248	0.0245	0.0309	0.0869
0.1004	0.0316	0.0250	0.0328
0.0330	0.1111	0.0333	0.0254

Powers received by four detectors are

$P_{rx}= P_{rx}\times10^{-5}$			
0.1830	0.1983	0.1839	0.1773

CASE 2: the position LEDs is fixed as in case I, The positions of four PDs at the ceiling are at (2 m, -0.5 m), (2 m, 2 m), (-0.5 m, 2 m) and (-0.5 m, -0.5 m).

$h=h_{i,j}\times10^{-4}$			
0.0245	0.0280	0.0775	0.0347
0.0245	0.0227	0.0265	0.0502
0.0821	0.0284	0.0248	0.0358
0.0426	0.2295	0.0436	0.0294

Powers received by four detectors are

$P_{rx}= P_{rx}\times10^{-5}$			
0.1738	0.3087	0.1724	0.1500

CASE 3: the position LEDs is fixed as in case I, The positions of four PDs at the ceiling are at (3 m, 0.5 m), (3 m, 3 m), (0.5 m, 3 m) and (0.5 m, 0.5 m).

$h=h_{i,j}\times10^{-4}$			
0.0260	0.0282	0.0808	0.0457
0.0260	0.0219	0.0239	0.0374
0.0480	0.0248	0.0231	0.0306
0.0685	0.2584	0.0443	0.0341

Powers received by four detectors are

$P_{rx}= P_{rx}\times10^{-5}$			
0.1684	0.3333	0.1720	0.1478

CASE 4: the position LEDs is fixed as in case I, The positions of four PDs at the ceiling are at (4 m, 1.5 m), (4 m, 4 m), (1.5 m, 4 m) and (1.5 m, 1.5 m).

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$h=h_{i,j}\times10^{-4}$			
0.0243	0.0244	0.0427	0.0419
0.0243	0.0209	0.0220	0.0273
0.0342	0.0229	0.0224	0.0296
0.1384	0.1516	0.0603	0.0583

Powers received by four detectors are

$P_{rx}= P_{rx}\times10^{-5}$			
0.2213	0.2197	0.1473	0.1571

CASE 5: the position LEDs is fixed as in case I, The positions of four PDs at the ceiling are at (0.5 m, 0.5 m), (-2.5 m, 0.5 m), (-2.5 m, -2.5 m) and (-2.5 m, 0.5 m).

$h=h_{i,j}\times10^{-4}$			
0.0242	0.0355	0.0626	0.0264
0.0242	0.0337	0.0542	0.3096
0.0657	0.0368	0.0244	0.0267
0.0246	0.0393	0.0247	0.0220

Powers received by four detectors are

$P_{rx}= P_{rx}\times10^{-5}$			
0.1388	0.1453	0.1659	0.3846

CASE 6: the position LEDs is fixed as in case I, The positions of four PDs at the ceiling are at (-0.5 m, 1.5 m), (-0.5 m, 4 m), (-4 m, 4 m) and (-4 m, 1.5 m).

$h=h_{i,j}\times10^{-4}$			
0.0220	0.0277	0.0339	0.0228
0.0220	0.0453	0.1483	0.1516
0.0545	0.0541	0.0260	0.0261
0.0222	0.0288	0.0231	0.0211

Powers received by four detectors are

$P_{rx}= P_{rx}\times10^{-5}$			
0.1208	0.1559	0.2313	0.2216

CASE 7: the position LEDs is fixed as in case I, The positions of four PDs at the ceiling are at (-1.5 m, -1.5 m), (-1.5 m, -4 m), (-4 m, -4 m) and (-4 m, -1.5 m).

$h=h_{i,j}\times10^{-4}$			
0.0220	0.0277	0.0339	0.0228
0.0220	0.0453	0.1483	0.1516
0.0545	0.0541	0.0260	0.0261
0.0222	0.0288	0.0231	0.0211

Powers received by four detectors are

$P_{rx}= P_{rx}\times10^{-5}$			
0.1208	0.1559	0.2313	0.2216

From the considered seven cases, it can be inferred that a small variation in channel gain and received power occurs within the room at various positions. The BER analysis on the received power is done using eqn 3.16 to 3.21. This variation in power leads to change in BER of the received signals. We have plotted power variation vs. BER curve as shown in figure 8. Here, the maximum BER for 1.2 Gbps system is of the order of 6.9×10^{-4} which decreases to 10^{-10} at the received higher power levels (3 micro-watts). These results are obtained with a combination of four LEDs and PDs which are much lesser in number while considering LEDs arrays (figure 5).

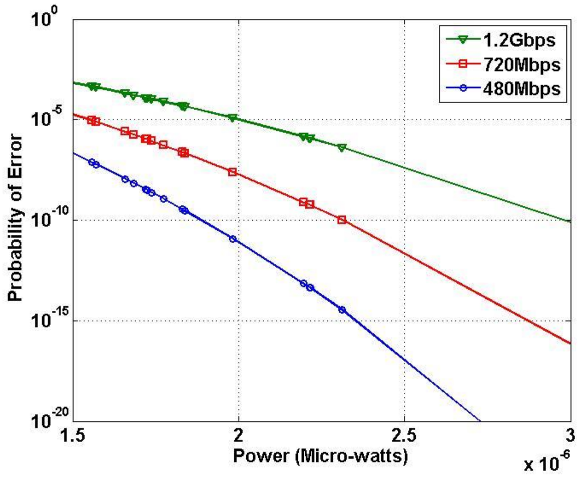

Figure 8 Probability of Error vs. Power for MIMO System

V. CONCLUSIONS

This work presents LED array using MIMO system. In MIMO frameworks, the whole transmit power is confined without having any influence of the measure of transmitters. The noise composed of the shot noise, background noise, and thermal noise for *N* optical at the receiver. The channel gain is obtained via simulations, and bit received power of four detectors at various places of the room is also obtained. Thereafter BER analysis is performed. Finally it has been found that MIMO based LED array performance is much superior than simply placing various LEDs at different positions of the room.

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