Experimental tests for outage analysis in SISO Li-Fi Indoor Communication Environment

Atchutananda Surampudi[1], Sankalp Shirish Chapalgaonkar[1], A.Paventhan[2]
[1]Department of Electrical Engineering, Indian Institute of Technology Madras, India
[2]ERNET, India
[1] {ee16s003, ee15b018}@ee.iitm.ac.in
[2] {paventhan}@eis.ernet.in

***Abstract*—Visible Light Communications, popularly known as Li-Fi for indoor communications is capable of providing internet access at high data rates. This technology utilises visible light waves as the carriers for passband modulation, which can also be called as optical free space modulation on a static, linear time invariant optical wireless channel. For indoor applications, testing such a technology for coverage in both line of sight and non line of sight scenarios becomes advantageous for efficient deployment. In this work, we have practically deployed a single input single output Li-Fi communication pair and have experimentally analysed the performance in terms of power received and outage distance for different colours and installation heights. These tests can be standardised for future works.**

***Index Terms*—Li-Fi, height, colour, received power, Philips.**

I. Introduction

Visible light communications (VLC) had been successfully used for exchange of information long ago even when the telephone was not invented. Intensity modulated light signals can carry information. But because of the lack of efficient light transmission and reception devices, this could not be analysed further. After the invention of the Light Emitting Diode (LED) and its commercialization in 1962, research in VLC took a new turn. The early papers started around the late twentieth century [1]. The use of the LED for VLC is described in [2]. This technology for indoor access has been coined as the Li-Fi technology by professor Herald Hass at the University the Edinburgh, and its capabilities for indoor access was first demonstrated at a TED global in 2011 [3].

The Li-Fi communication technology using visible light as the carrier, can be used to provide reliable and high speed data access because of the huge visible light spectrum available in the range of Terahertz. This technology can also be used in the areas where traditional Radio frequency (RF) communications fail to provide coverage, by acting as a complement for the same. In health care and oil and gas industries, where radio waves may be harmful to operate for communication, the Li-Fi technology can be a potential communication method by utilising the safe, visible light waves [4]. The 5G mobile communication standard introduces the internet of things (IoT), where every device will be interconnected. Here too this technology can help provide high speed data access as well as security. So performing experimental analysis using standard tests becomes very crucial to understand this technology and to deploy it effectively in indoor environments. The received power from a given coloured LED, at a given height and radius, in cylindrical coordinates, provides an idea on the coverage cone or the coverage area provided by the LED transmitter.

To analyse outage in an optical wireless communication scenario is very important. In the traditional wireless communications, the channel is assumed to be linear time variant and various works have been done to analyse the same [5]. But for a static linear time invariant optical wireless channel, the experimental analysis becomes more important because the channel is deterministic. So in this work a set of experimental tests have been conducted for both Line of Sight (LOS) and Non Line of Sight (NLOS) method of Li-Fi communication to analyse the maximum distance at which outage occours. We experiment NLOS communication with the help of coloured reflectors. Also, a Li-Fi transmitter generates a conical flux of light coverage over the given area. This is due to the limited field of view (FOV) of the transmitter. So, over that conical coverage, measuring the received power at every location is important. This also has been included as an experiment.

In this work, the Li-Fi transmitter or LED refer to the same downlink transmitter. The Li-Fi receiver or the photodetector (PD) refer to the same downlink receiver. This convention is used appropriately according to convenience interchangeably. Further this can be used for infrared (IR) uplink Li-Fi transmission also, which will be specified. This paper has been arranged as follows. Section II describes the system model and the components used. Section III describes the experimental tests performed. Section IV presents the experimental results and presents them with appropriate graphs along with the inferences. The paper concludes with Section V.

II. System Model

A single input single output (SISO) LI-Fi communication is considered for both uplink and downlink transmission.

Consider the downlink of the LED-PD communication scenario limited by the modulation bandwidth of the LED as considered in [6]. Let the light source be at an elevation height h from the origin and the PD be at a distance z from the origin as shown in Fig.1.

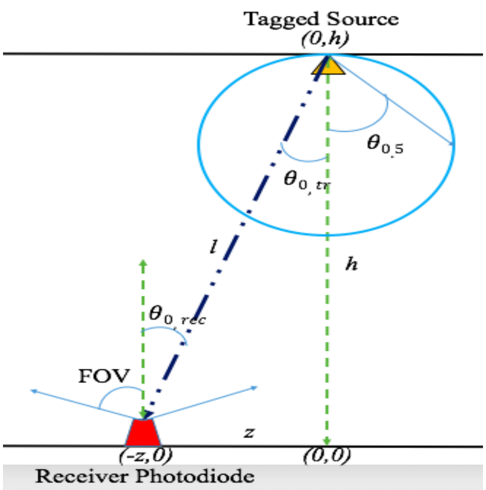

Fig. 1. This figure shows the LOS light propagation geometry. The triangular shaped LED source is at a height h and is tagged to the PD at distance z from the origin, with a given Field of Vision (FOV). The angles $\theta_{0,tr}$ and $\theta_{0,rec}$ are transmission angle at the LED and incidence angle to the PD with respect to the normal as shown by the dotted line respectively. $\theta_{0.5}$ is the Half Power Semi Angle (HPSA) of the LED. This is adapted from [6].

In Fig. 1, $\theta_{0,tr}$ is the transmission angle from the LED and $\theta_{0,rec}$ is the angle of incidence at the PD, from the LED which is at origin (0). FOV denotes the field of view of the PD, which is the maximum solid angle to which the received rays can be detected. $\theta_{0.5}$ denotes the Half Power Semi Angle (HPSA) of the transmitter. Let A_{pd} be the area of the PD. Moreover, from [6] the LTI channel contributes a Gain, $G(z)$, from the LED light source to the given PD receiver at a position z on the ground, which is given in (1).

$$G(z) = \frac{(m+1)A_{pd}}{2\pi l^2} cos^m(\theta_{0,tr}) cos(\theta_{0,rec}). \quad (1)$$

In (1), l denotes the cartesian distance from the LED light source to the PD as given in (2). Also, m is the Lambertian emission order of the light source which is given in (3).

$$l^2 = h^2 + z^2. \quad (2)$$

$$m = -\frac{ln(2)}{ln(cos(\theta_{0.5}))}. \quad (3)$$

A. Components received

The experiments have been performed using a set of Li-Fi transmitter and receiver pair received from The Philips, Eindhoven, for the purpose of academic demonstration and testing of indoor Li-Fi capabilities. The received components are listed in Table I.

TABLE I
COMPONENTS : THIS TABLE SHOWS THE LI-FI COMMUNICATION COMPONENTS RECEIVED FROM THE PHILIPS, EINDHOVEN.

Component	Product Name	Function	Quantity
Li-Fi downlink transmitter (Fig. 2)	Luxspace DN561B	White LED transmitter for Downlink.	1
Modem board (Fig. 3)	Modem board	A central circuitry which contains a microcontroller to control dimming and modulation.	1
Xitanium 20W LED power driver (Fig. 4)	LBRD1514-1	To control and stabilize the current and drive the LED appropriately.	1
Uplink IR Receiver (Fig. 5)	LBRD14016-3	Uplink receiver placed adjacent to the downlink transmitter.	1
Li-Fi Dongel (Fig. 6 and Fig. 7)	Li-Fi Dongel	Is attached to the user device. Acts as both uplink transmitter and downlink receiver. Has an indicator to show Li-Fi connectivity.	1

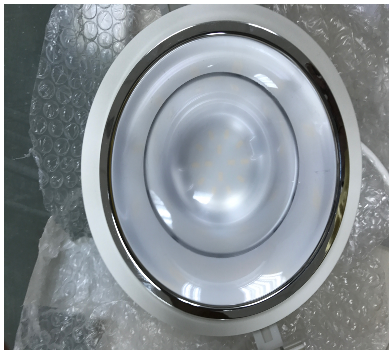

Fig. 2. The Luxspace DN561B downlink LED transmitter. In the inset, there are 14 LEDs present. 4 on the inner ring and 10 on the outer ring. The HPSA of the combined transmitter is 25°

B. Other testing components

These components are used to precise and accurate measurement of experimental values. These are listed as in Table II.

III. Experimental Tests

The tests are performed in a closed laboratory, at night time, so that the effect of ambient constant illumination due to other luminaires or sunlight can be considered negligible. The LEDs for both uplink and downlink have a field of view (FOV). The flux of light emitted and the maximum solid angle is limited by the FOV of LEDs. This flux gives a conical coverage over the entire illumination region. Secondly, using the component parameters used in Table II, we have done the tests. These experimental values obtained, may change as Table II parameters change. For now, the current parameters become the reference.

A. LOS - Received power at different coordinates

The experimental setup is shown in Fig. 10. The schematic is shown in Fig. 1. In this experiment, the average received

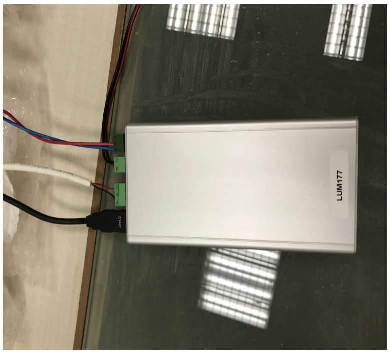

Fig. 3. The modem board. This is a central circuitry to control dimming and modulation using a microcontroller. It has an Ethernet port to receive data from a wired network and convert data suitably for Li-Fi communication.

Fig. 4. The Xitanium 20W LED power driver, LBRD1514-1.

power is measured using an LNA at a given location in free space for a given colour of LED, angle θ_{tr} of the LED and the slant height l of the location along the inclined trajectory. Now the separation height h becomes the trigonometric tangent measure of l with respect to θ_{tr}. The variation of colour, h and θ_{tr} is as shown in Table III.

TABLE II
COMPONENTS : THIS TABLE SHOWS THE COMPONENTS USED FOR ACCURATE EXPERIMENTAL VALUES.

Component	Property	Function
Low Noise Amplifier (Fig. 8)	Internal Resistance = 1000 Ω ; Internal Capacitance = 1μF	To measure free space optical power at a given location.
Meter Tape	Length = 350 cm	To measure the distance between LED and PD.
Protractor	Angle = 0° to 180°	To measure the angle of deviation, from the normal, of the free space coordinate where the average received optical power is measured.
Coloured transparent fiber sheet (red, green and blue) (Fig. 9)	Thickness = 0.05mm	To experiment using different colour wavelengths. This sheet is placed before the LED transmitter, to obtain a coloured LED from the white LED.

Fig. 5. The IR Uplink receiver, LBRD14016-3.

Fig. 6. The Li-Fi dongel. This is connected to the user device using a universal serial cable (USB). There are two circular insets on the right side of the device. The upper inset contains the Uplink IR transmitter. The lower inset contains the downlink receiver PD.

B. LOS - Maximum distance - Outage analysis

The experimental setup is shown in Fig. 10. The schematic is shown in Fig. 1. In this experiment, for a given height installation height h and a given LED colour, the distance z is measured at a point on the ground where the indicator on the Li-Fi dongel stops blinking. This situation we refer to as the outage and the distance we refer to as the maximum distance z_{max}. This we repeat for different LED illumination colours and for each colour, we vary the height h. The outage situation arises when the edge of the coverage cone is reached for that height. The ranges are described in Table IV.

C. NLOS - Reflection colour based outage analysis

In this test, the LED transmitter is kept on a horizontal plane. The experimental setup is shown in Fig. 11. The

TABLE III
PARAMETERS : THIS TABLE SHOWS THE PARAMETER RANGE FOR TEST A.

Parameter	Range
Height h (The downlink LED transmitter is kept fixed, the PD location is varied)	5cm to 150cm (at an interval of 5cm).
Angle θ	0°, 30°, 40°, 50°.
Colour	Red, Green, Blue.

Fig. 7. The Li-Fi dongel. This is connected to the user device using a universal serial cable (USB). There is an indicator which glows on to confirm the Li-Fi connectivity.

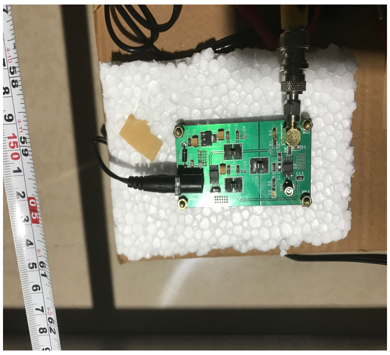

Fig. 8. The Optical Power receiver - Low noise amplifier circuit (LNA).

experimental schematic is shown in Fig. 12. From Fig. 12 we observe that the downlink LED transmitter placed at a distance d_1 faces a colour specific reflector placed at origin. The uplink IR receiver is always placed at the origin. The PD is placed at a distance d_2, facing the reflector, from the origin. Now, for a given d_1 and a given reflector colour, d_2 is varied. We stop at a point on the ground where the indicator on the Li-Fi dongel stops blinking. This situation we refer to as the outage and the distance we refer to as the maximum distance $d_{2,max}$. This we repeat for different reflector colours and for each colour, we vary the distance d_1. The input parameter ranges are described in Table V.

IV. Experimental results and inferences

In this section we describe the experimental results through graphs and make appropriate inferences.

TABLE IV
PARAMETERS : This table shows the parameter range for test B.

Parameter	Range
Height h (The downlink LED transmitter height is varied using a vertically movable stand)	5cm to 150cm (at an interval of 5cm).
Colour	Red, Green, Blue.

Fig. 9. The Blue, green, red colour (in clockwise order) fiber sheets.

Fig. 10. The experimental setup for both LOS - A and B tests.

A. *LOS - Test A*

Here the average received optical power is measured in free space by varying the height h, LED colour and angle of transmission θ_{tr}. Fig. 13 to Fig. 16, show the variation of $P_{opt,rec}$ vs. height h for different θ_{tr} - 0°, 30°, 40°, 50°. We observe that for a given θ_{tr}, for a given h, $P_{opt,rec}$ is more for a colour of larger wavelength. Also, for a given colour and h, as θ_{tr} increases, the average power decreases. Using these graphs, we can infer that the FOV of the downlink LED transmitter is between 40° and 50°, because a drastic difference of received optical power occurs between these angles.

B. *LOS - Test B*

In Fig. 17 we observe that as the installation height h increases, the coverage distance z_{max} also increases. This is

TABLE V
PARAMETERS : This table shows the parameter range for test C.

Parameter	Range
downlink LED transmitter distance d_1 from origin (The downlink LED transmitter distance is varied on a horizontal plane)	35cm, 90cm, 120cm.
Reflector Colour	Red, Green, Blue, White, Black.

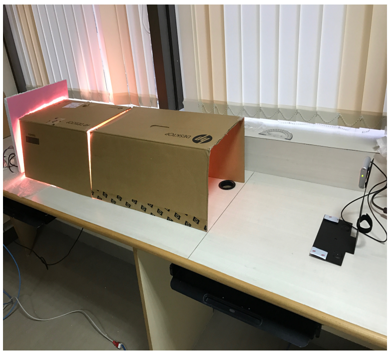

Fig. 11. Experimental setup for NLOS communication scenario. Here only the experimental setup is shown. The actual experiment happens when constant ambient illumination is switched off and the room is dark. Also, because the experiment is NLOS, a tunnel kind of covering is provided to avoid the light waves to spread out. The DN561B is inside the tunnel at a distance d_1. The reflector is at origin and the dongel is at a distance d_2

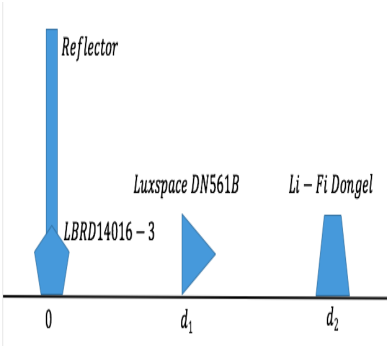

Fig. 12. The experimental schematic for both NLOS test C

due to the limitation of coverage area by the FOV of the LED transmitter. So, as h increases, the area subtended increases due to the coverage cone of light flux. Also, for a given h, as the wavelength increases from blue to red colour, the coverage distance also increases. This reproves the fact that for an electromagnetic wave (even light wave) with larger wavelength travels a larger distance and experiences lesser attenuation.

C. NLOS - Test C

In this figure we observe that as colour of the reflector changes, we get different coverage distances. So, the reflector colour becomes important.

V. Conclusion

In this work a set of tests for outage analysis and received power were described using the Li-Fi components received from the Philips, Eindhoven. These tests may be standardised for Li-Fi hardware that may develop in future.

Acknowledgement

We would sincerely like to acknowledge the Philips, Eindhoven team to have provided us the Li-Fi communication components for indoor experiments. Also, we would like to thank ERNET India to have provided the opportunity to setup a demonstration laboratory, where the tests could be successfully conducted.

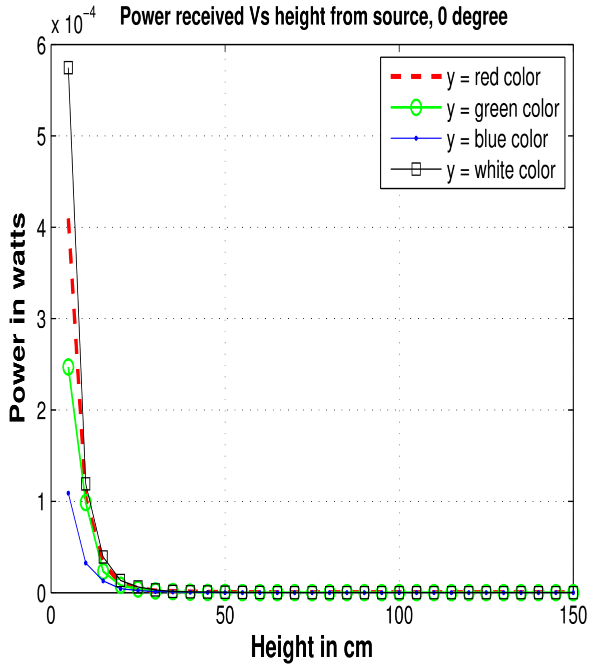

Fig. 13. Test A - θ_{tr} = 0°

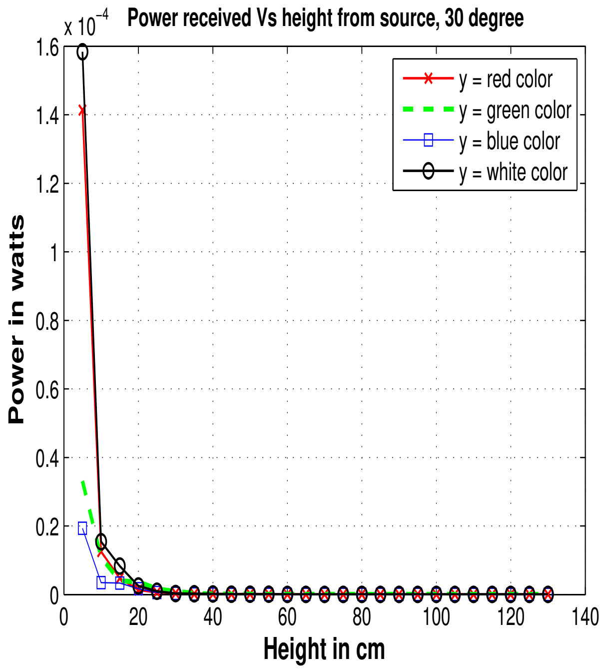

Fig. 14. Test A - θ_{tr} = 30°

References

[1] Barry, John R., Joseph M. Kahn, William J. Krause, Edward A. Lee, and David G. Messerschmitt. "Simulation of multipath impulse response for indoor wireless optical channels." IEEE journal on selected areas in communications 11, no. 3 (1993): 367-379.

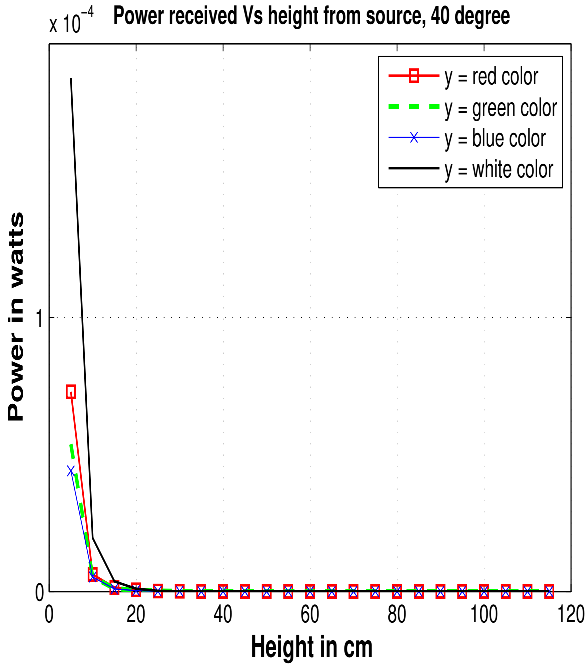

Fig. 15. Test A - θ_{tr} = 40°

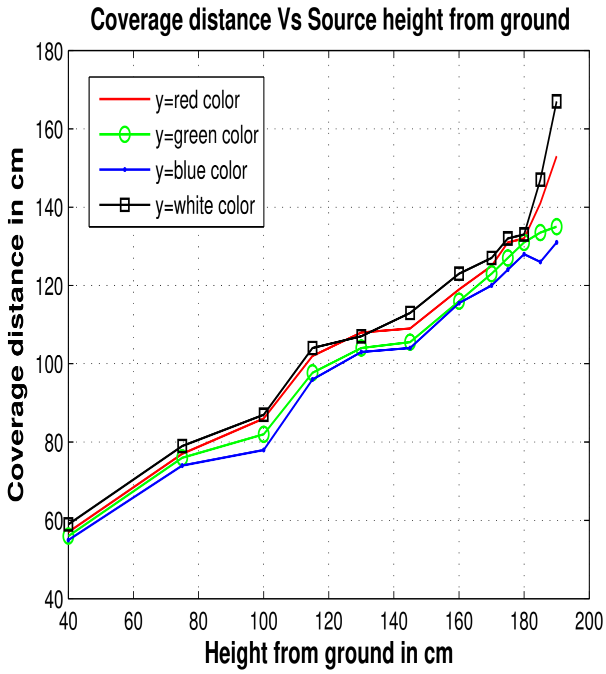

Fig. 17. Graph for Test B.

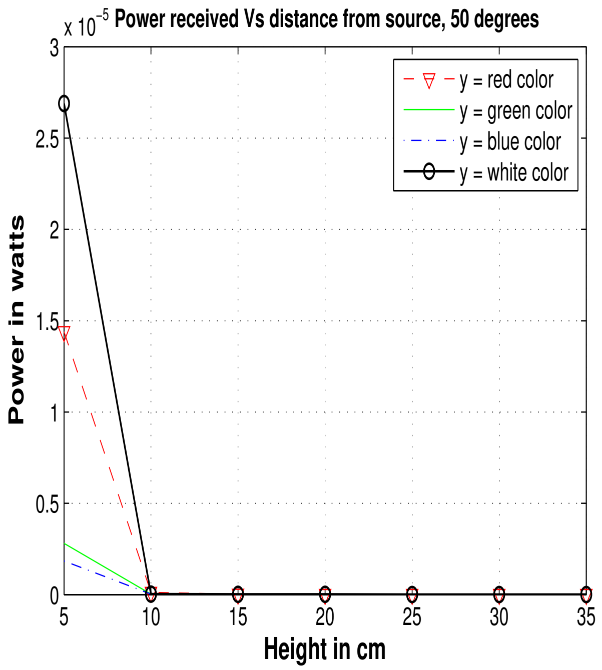

Fig. 16. Test A - θ_{tr} = 50°

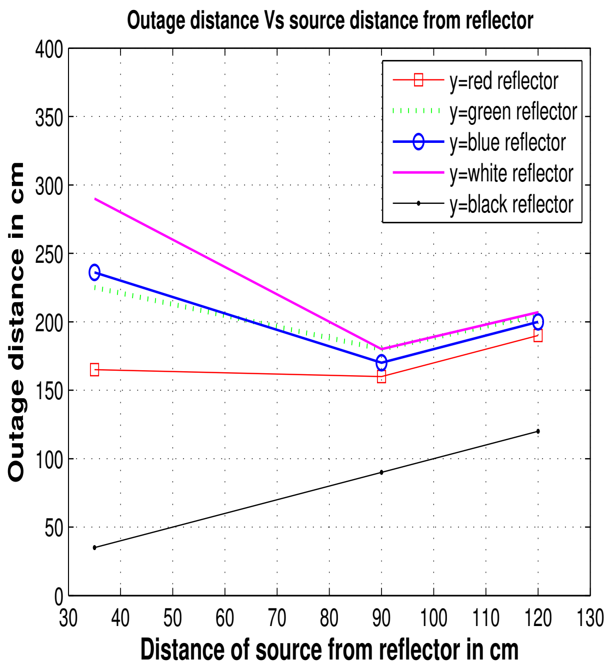

Fig. 18. Graph for Test C.

[2] Komine, Toshihiko, and Masao Nakagawa. "Fundamental analysis for visible-light communication system using LED lights." IEEE transactions on Consumer Electronics 50, no. 1 (2004): 100-107.

[3] Haas, Harald. Harald Haas: Wireless data from every light bulb. TED, 2011.

[4] Haas, Harald. "LiFi: Conceptions, misconceptions and opportunities." In Photonics Conference (IPC), 2016 IEEE, pp. 680-681. IEEE, 2016.

[5] Andrews, Jeffrey G., Francois Baccelli, and Radha Krishna Ganti. "A tractable approach to coverage and rate in cellular networks." IEEE Transactions on Communications 59, no. 11 (2011): 3122-3134.

[6] Chen, Cheng, Stefan Videv, Dobroslav Tsonev, and Harald Haas. "Fractional frequency reuse in DCO-OFDM-based optical attocell networks." Journal of Lightwave Technology 33, no. 19 (2015): 3986-4000.