Optimum Uniform Illuminance and communication in Indoor VLC System using Whale Optimization Algorithm

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CANDIDATE'S DECLARATION

I hereby declare that the work presented in this dissertation entitled, **"Optimum Uniform Illuminance and Communication in Indoor VLC System using Whale Optimization Algorithm"** in partial fulfilment for the award of degree of "**Master of Technology**" in Electronics and Communication Engineering with specialization in Wireless and Optical Communication Engineering and submitted to Department of Electronics and Communication Engineering, Malaviya National Institute of Technology is a record of my own investigation carried under the supervision of Dr. S J Nanda, Assistant Professor, Department of Electronics and Communication Engineering, Malaviya National Institute of Technology.
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This thesis is dedicated to my parents and my brothers for their love, endless support and encouragement

CERTIFICATE

This is to certify that the M.Tech thesis entitled **"Optimum Uniform Illuminance and Communication in Indoor VLC System using Whale Optimization Algorithm "** is carried out by Ishwar Ram Kumawat, Enrollment No. 2015PWC5359 is an authentic work carried out by his at Malaviya National Institute of Technology, Jaipur under my guidance. The matter embodied in this project work has not been submitted earlier for the award of any degree to the best of my knowledge and belief.

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Ishwar Ram Kumawat

ABSTRACT

In 5G, indoor visible light communication is going to use panel of white light emitting diodes (LED) to provide high-speed communication as well as illumination. In this system it is important to maintain uniform illuminance as non-uniformity creates bright and dark spots, which may cause discomfort for the occupants. The uniform illuminance depends upon the position and semi-angle of radiation associated with the LED panel. The objective is to optimize the position of the LED panels so that the received power and SNR at all locations in the room is uniform. The optimization task is carried out using a new meta-heuristics Whale optimization algorithm. Simulation study is performed on a room with dimension 5m*5m*3m, having 4 to 6 LED panels (each with 60x60 LEDs). Results reveal that the proposed approach obtained superior uniformity (received power and SNR achieved in dB) compared to that achieved by particle swarm optimization.

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Chapter 1

Introduction

Visible Light Communication (VLC) is an expanded communication technology for short-range applications. Taking advantage of recent advances in the development of high power LEDs that emit visible light, VLC offers a clean and energy efficient alternative to RF technology, enabling the development of optical wireless communication systems that make use of existing lighting infrastructure. When we talk about VLC we tend to be preferring to an illumination source (e.g. a light bulb) which in addition to illumination can send information using the same light signal. So in our terms: VLC = Illumination + Communication; Imagine a flash light which you might use to send a Morse code signal. When operated mutually this is sending data using the light signal, but because it is flashing off and on it cannot be treated to be a useful illumination source, so it is not really VLC by our definition. Now imagine that the flash light is switched on and off very fast via a computer, then we cannot see the data and the flash light shows to radiate a stable light, so now we have illumination and communication and this does fits our definition of VLC.

The information sent through light signal that cannot seems to the humans eyes but able to see the illuminance. So there seems to be no generally agreed definition of visible light communication is, we can at least agree what mean of visible light communication. Visible light can affect the human life, there for uniform or visible illuminance is very important for a human being. Now we can see that the growing demands of bandwidth requirements is growing day by day. A usual method is wired connections, in wired connections we needs more time to setup and space and also suffering lot of problems such as maintenance, investment of coppers etc. to overcome the problems occurred in wired communication we replace it by wireless communication. In wireless communication a possible way of RF spectrum, but RF spectrum has some limitations like lower data rate, limited bandwidth, there is need of licensee for installation and security issue also. To overcome these issue visible communication is used. Visible light communication (VLC) is data communication from 400 THz to 800 THz frequency range (780-375 nm wavelength range) which comes into the visible region. VLC is subset of optical wireless communication technique. Thus optical wireless communication (visible communication) seems to be ideal for wireless communication due to larger bandwidth and higher date rate.

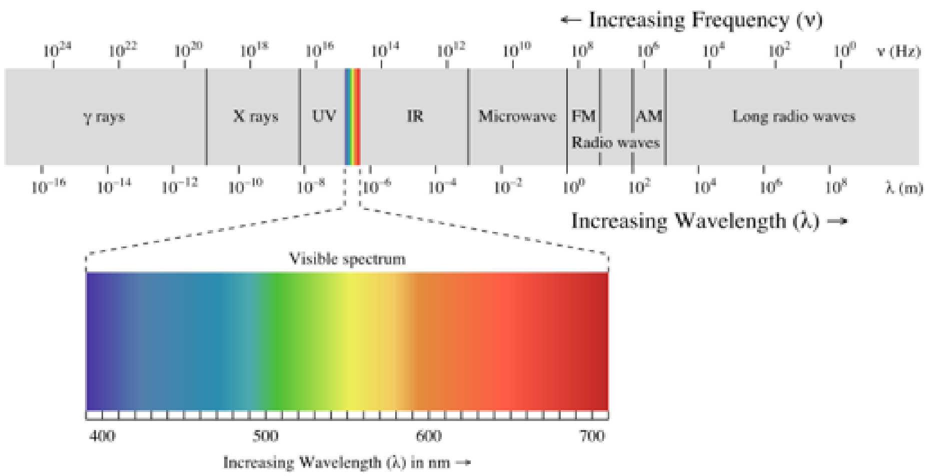


Figure 1.1: wavelength spectrum of visible light

Visible light communication can be divided into two types, Line of sight (LOS) and Non line of sight (NLOS) [0]. In LOS system the communication between transmitter and receiver is directly. LOS system have narrow field of view (FOV) due to direct line of sight communication and provide higher speed data transmission and wide range of bandwidth. In NLOS system communication between transmitter and receiver is affected by reflection from walls, surface and ceiling etc. due to this NLOS have large FOV and which support better for mobility of user. Another type of communication is diffused communication which is the mixer of LOS and NLOS.

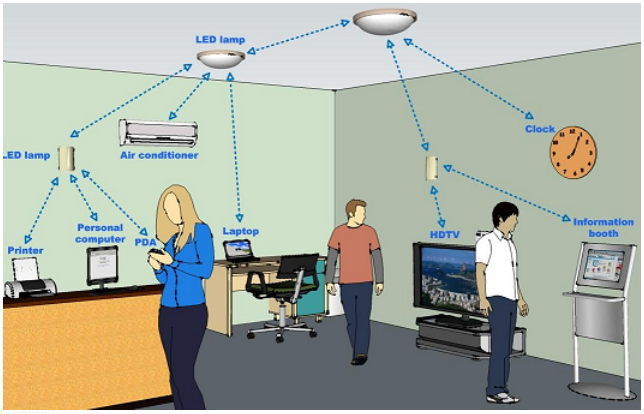


Figure 1.2: optical wireless link LOS Link

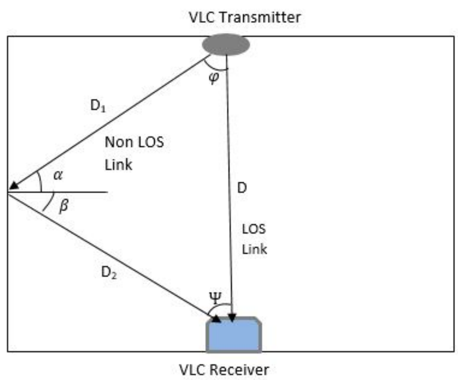


Figure 1.3: optical wireless link NLOS Link

1.1 History of Visible Light Communication

The communication using light signal first comes into mind around 800 BC using metal and polished shield were used to reflect sunlight for signaling, after in 150 BC American used smoke signals for sunlight. In the 1970s first time French sea navigators used semaphore as optical signal technique.

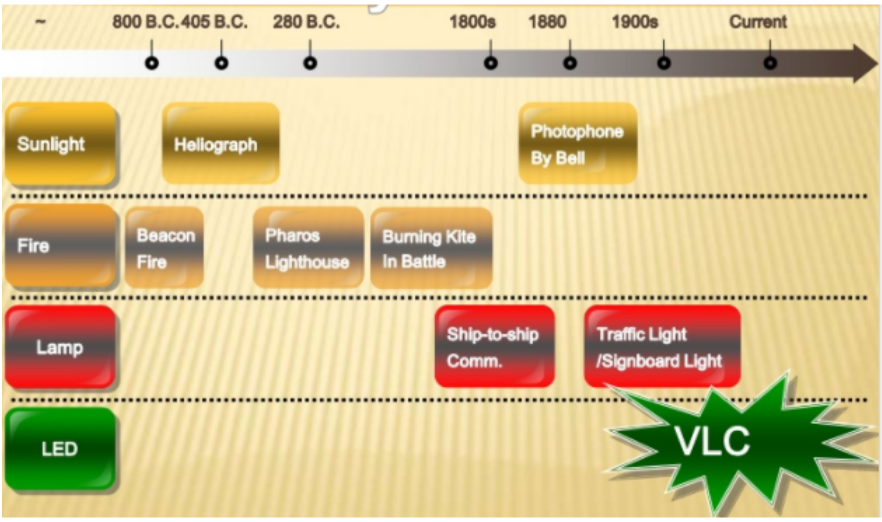


Figure 1.4: history of Visible Light

The first time VLC developed by Alexander Graham Bell on june20, 1880, Graham had demonstrated a system which is capable of transmission voice using sun light as a medium and known as Photo phone. The distance between the transmitter and receiver was around 213m. This is the simplest form of instrument for proceeding voice via using mirrors. When a person voice projected through an instrument due to vibrations of sound signals similar vibration occur at mirror side and sunlight directed into the mirror to capture vibrations and send back into the receiver side and converted into voice signal by using a sensitive Crystal selenium. The main drawback of this method because sun light was not available every time. In 1990s white LED is invented for various uses. White LED can be made by using blue, red, green light which offers advantage

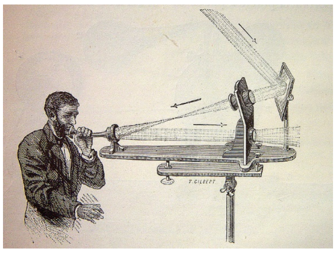


Figure 1.5: photophone transmitter, showing the path of reflected sunlight, before and after being modulated

Figure 1.6: conversion of light signal to sound at receiver

over fluorescent and incandescent light sources such as following:

- Smaller size
- Lower power consumption
- Security
- Harmless for human body
- Less heat generated
- Long lifetime
- Fast switching speed

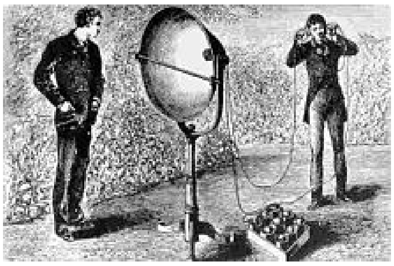


Figure 1.7: A photophone receiver and headset

LED is not used only for illuminance source but also used for communication source due to above advantage LED have provides many applications such smart lighting, traffic light and street light etc. and communication applications as indoor communication, airplane and hospital etc.

1.2 Motivation

Few year back, it is not possible to both communication and illuminance by using illuminance light. But, Now it is possible with the help of white LED. A white LED can be used for both illuminance as well as communication purpose. uniform illuminance is most important in home and office. to get uniform illuminance positioning of LED panels play important role. To resolve from such such problems this system is proposed.

1.3 Objective

- The objective of this project to get uniform illuminance at entire surface which help to get better communication.
- To get uniform illuminance position of LED panels is set by using Whale optimization algorithm.

1.4 Contribution

- Implementation of proposed approach using whale optimization algorithm for positing of LED panels for uniform illuminance.
- Comparison of existing and proposed approach for LED panels position.

1.5 Thesis Organisation

The content of the thesis as follows.

Chapter 1: This section includes the introduction of VLC System and it's historical overview, design challenge in VLC , and motivation. Problem statement and thesis contribution enclosed at the end.

Chapter 2: This section contains comprehensive literature survey and includes the brief introduction about visible light communication system design and its component.

Chapter 3: This section consists of system design with mathematical model and fitness function of our problem .

Chapter 4: This section consists of how to work Whale optimization algorithm and its mathematical modeling.

Chapter 5: This section states about the simulation results of the proposed work.

Chapter 6: This section consists of multi-objective whale optimization and its mathematical model with simulation results.

Chapter 7: This section encompass conclusion of the work and scope of the future work.

Chapter 2

Background

2.1 Related Work

The VLC from an LED traffic light can be used for the broadcasting of audio messages or any traffic or road information by modulated and encoded with information on traffic light [2]. Nakagawa et al. proposed the used of white LED in a wireless home link and it is suitable for private networks such as consumer communication networks [3]. In upcoming fifth generation wireless technology, visible light communication is going to become an essential component for indoor communication as well as illumination [4]. This system uses white light emitting diode (LED) panel which act as both transmitter and illuminator [5]-[7]. In a given indoor environment the users need is for high-speed data download and to obtain uniform illuminance. To achieve it, there is need for uniform SNR and power distribution [8]-[9] across the indoor environment. Komine and Nakagawa [8] proposed a model with white light emitting diode panel for indoor VLC transmitter and illuminator. The authors considered a predefined fixed position of LED panel in a 5m*5m*3m room and analyzed the effect of interference and reflection on illuminance. Nguyen et. al. [10] developed a simulink model considering the same position of LED panel for the same room size as in [11], to analyze the effect of RMS delay spread and illuminance distribution in the room. Recently, Wang et. al. [12] used evolutionary algorithm (EA) to maximize the minimum SNR to achieve effective communication in indoor VLC communication.

2.2 System overview

Generally indoor wireless communication system consists of a transmitter and a receiver with a transmitting medium present. To design VLC system transmitter and receiver design play an important role. A light source can be used as a transmitter where as white LED serve as a very good option as a transmitter. They are generally installed at office, home, airplanes and hospital and also provide illuminance with less power consumption as compare to other light source present. Two types of LEDs are present trichromatic and blue chip [13]-[14] both LEDs are provides up to few hundred Mbps data rates. Transmission medium is used air and photo diode is used at receiver end which filters noise and ISI and then amplification of photo current is done.

2.3 Modulation Scheme

Modulation tecnique involves two stages : in first stage optical carer frequency is modulated by the data signal and in second stage emitted infrared

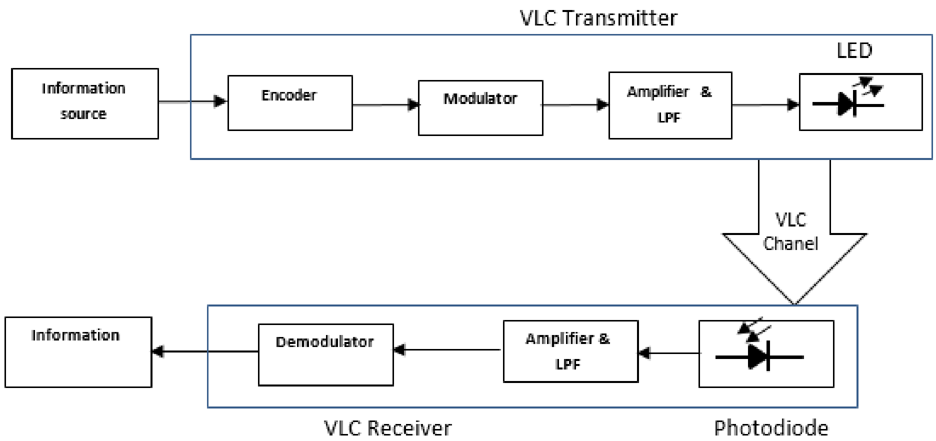


Figure 2.1: basic VLC system

light modulation. Modulatin technique can be measured bandwidth efficiency [15] transmission reliability [16]-[17] and provide best power efficinecy under noise and others multipath channels conditions [18]. Basically four types of modulations technique are present for VLC namely On-Off keying (OOK) [19], color shift keying (CSK) [20], Orthogonal frequency division multiplexing (OFDM) and variable pulse position modulation (VPPM).

OOK is the most habitual modulation technique in which there are two levels 0 and 1 for LED which is used for decide the intensity of light. CSK technique uses bit coding respective to colors of light therefore the LED must be of RGB type. In this technique intensity of light is change and a white light is produce at the output. OFDM technique helps to transmitted data at high speed by using sub carriers. In VPPM signals are characterized according to their pulse position and pulse width is change in accordance to the response of dimming level.

2.4 Different Indoor System

In infrared wireless communication multipath dispresion is serious problem [21]-[22]. Multipath dispersion problems is due to the reflection from walls. Due to this inter symbol interfernce occurs and degrads the performance of the system. Multipath problems may be reduce in NLOS link because some diversity presented [23].

2.5 System Outline

In earlier21st- century data transmission at high speed is main problem. To overcome this problem radio frequency technology is used and archive high speed but in radio frequency electromagnetic interference and also security and license issue. In 1970s optical wireless technology have come in our homes and some indoor area.

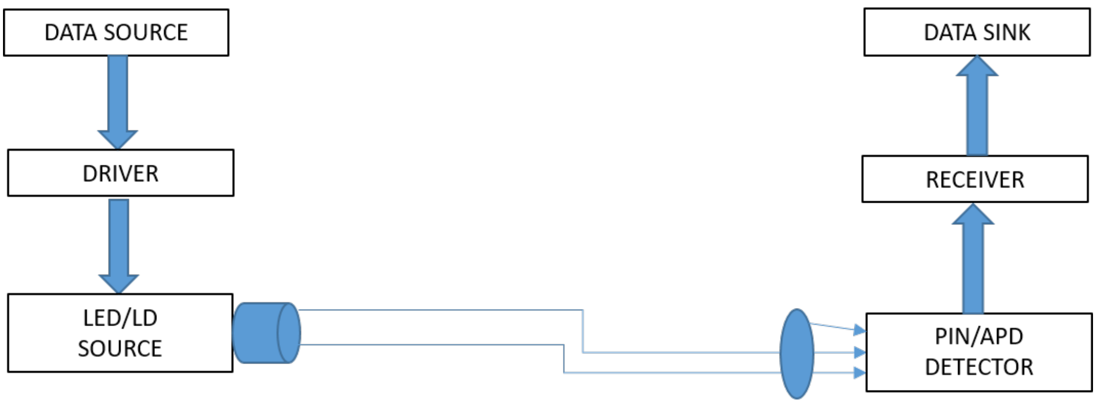


Figure 2.2: Basic Block diagram VLC model

2.5.1 Optical Source

In visible light communication LED and LD are main optical source. LD provide higher power output, higher modulation bandwidth and linear electrical to optical characteristics. LD is harmful for human eyes if human eyes is directly contact with LD can results in permanent blindness that's why reason we use LED for illuminance and communication in indoor wireless communication. Mainly two types of LED: single color LED and White color LED. Mostly white LED is used in visible light communication. White LED is directly not generated and it is generated by two techniques.

- Red, blue and green LEDs are mixed with proper mixer and white LED can be generated. The wavelength of red is 625 nm, blue 470 nm and green 525 nm respectively.
- Another method is conventional technique in which short wavelength is combined with yellow phosphor to produce white LEDs. Blue LED is prefer because in this LED coating of phosphor is presented and emit yellow light.

This technique have better color rendering as compare to RGB white LED. In our work we assume that the radiation pattern of LED is lambertain that's means the brightness of LED is doesn't viewing angle of observer.

2.5.2 VLC Receiver

VLC receiver consits of optical concentrator, an optical filter, photo diode, amplifier etc. to provide illuminance in large area we use optical concentrator because it compensates high spatial attenuation which is caused due to beam divergence. The effective area is chossen by using most suitable

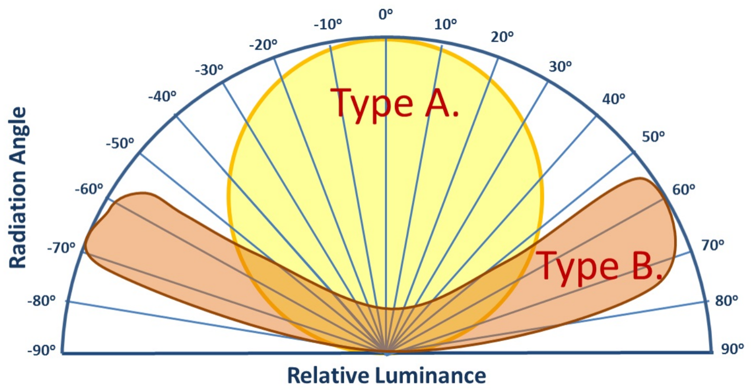


Figure 2.3: lambertain intensity pattern

optical concentrator. Parabolic concentrator is used in infrared wireless communication [24]. The optical filter is required at recevier side because vislible light communication is affected by sunlight and other illuminance source to overcome this optical filter required. Optical filter remove unwanted noise present in data single. Photodiode is used receive light signal from the transmitters. The optica to eletrical conversion can be take place in photodiode. PIN and APD photodiode mostly used in optical wireless communication system. There are two technique at the photo diode for dtection; (1) IM-DD technique (2) Coherent technique. In IM-DD the intensity of the emitted light is used to transmitt the information and mostly IM-DD technique is used in visible light communication. It is also known as envelope detection technique. In coherent technique I and Q components are required for polariazation and carrier phase. There are many option to chosen amplifier but generally two amplifier are used in VLC system such as: (1) high impedance amplifier (2) transimpdeance amplifier.

Chapter 3

System Design

A rectangular room of 5m*5m*3m is considered for analysis as the same dimension is standardized by [10]-[11]. A basic structure of using indoor VLC system in this room using 4 LED panels (each panel comprise of 60x60 rectangular array) is shown in the Fig.4.1. Only line of sight communication (LOS) is considered for analysis. The white LED panels are installed at the ceiling, at height of 3m from the floor. The receiver is placed at 0.85m above form the ground and the distance between LED panels and receiver is 2.15m. thermal and shot noise are considered in our problem

3.1 Mathematical Modeling

The radiation pattern of LED is assume to lambertain and the signal at the receiver side depends upon some parameters like as FOV of the receiver, positions of LED panels, semi-angle at half power of LED and distance between transmitter and receiver. The radiation intensity of each LED

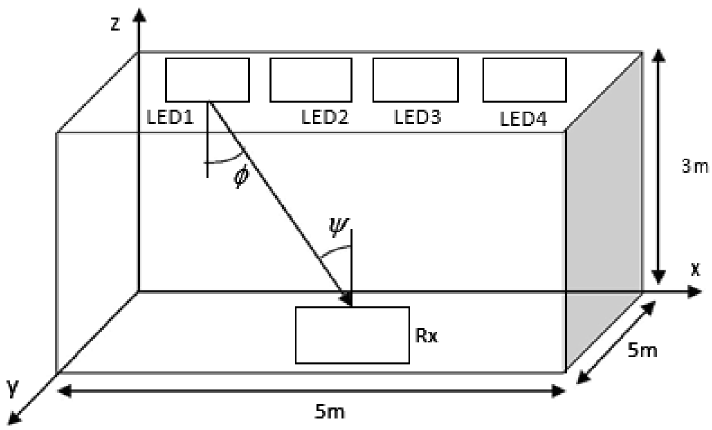


Figure 3.1: Model of an indoor visible light communication environment

panel is described in [10], is given by

$$R_0(\phi) = \frac{(m_l+1)cos^{m_l}(\phi)}{2\pi} \qquad \phi\epsilon[\frac{-\pi}{2}, \frac{\pi}{2}] \tag{3.1}$$

The ϕ is irradiance angle (angle between axis normal to LED panel and receiver) and m_l, is mode of emission (Lambertian mode). The relation between mode of emission and semi-angle at half power is discussed in [24] given by

$$m_l = \frac{-ln(2}{lncos^(\phi_1/2)} \tag{3.2}$$

If P_{LED}, is the power transmitted by the single LED then total transmitted power is calculated as:

$$p_t = P_{LED} * R_0(\phi)) \tag{3.3}$$

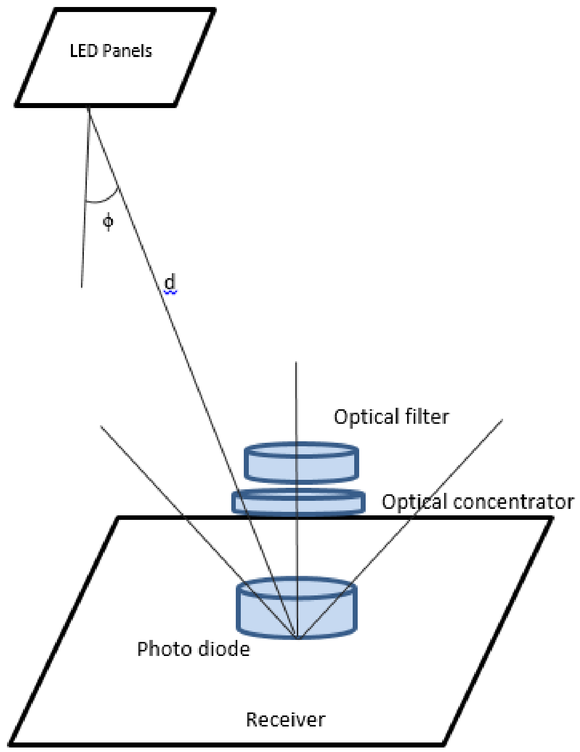


Figure 3.2: line of sight communication in VLC

The transfer function of channel for LOS signal is [24]

$$h_{los} = \frac{A_R x}{d^2} R_0(\phi) cos(\Psi) \quad 0 \leq \Psi \leq \Psi_c \tag{3.4}$$

Where Ψ is denoted the angle between LED panel and axis normal to the receiver. The field of view of the receiver is denoted as Ψ_c. The total transmitted power by the LED panels in line of sight communication is

$$P_{LOS} = \sum_{k=1}^{noofLEDpanels} p_t * h_{los} \tag{3.5}$$

In the receiver side a photodiode is consists of an optical filter and a concentrator. To increase the area of the photodiode (larger area of the photodiode is desirable to compensate attenuation) an optical concentrator is used. The gain of optical concentrator is.

$$g(\Psi) = \begin{cases} \frac{n^2}{sin^2(\Psi_c)} & \text{if } 0 \leq \Psi \leq \Psi_c \\ \\ 0 & \text{if } \Psi > \Psi_c \end{cases} \tag{3.6}$$

The optical power received at the receiver side is given by

$$P_{Rx} = P_{LOS} \times \dot{T}(\Psi) \times \dot{g}(\Psi) \tag{3.7}$$

The optical filter's transmission coefficient is denoted as $T(\Psi)$. To convert optical power to electric current photo diode is used. The output current is define as

$$i = P_{Rx} * r \tag{3.8}$$

The responsivity of photodiode is denoted by r in above equation.
The SNR at the receiver is defined as

$$SNR = \frac{i^2}{\sigma_{Total}^2} \tag{3.9}$$

The variance of shot noise is σ_{total}^2 , described in [24] is given by

$$\sigma_{Total}^2 = \sigma_{shot}^2 + \sigma_{noise}^2 \tag{3.10}$$

The variance of the shot noise and define as

$$\sigma_{shot}^2 = 2qrB_n(P_{Rx} + P_n) \tag{3.11}$$

Here P_n is denoted as the noise power of ambient light, q is the charge of electron and noise bandwidth is define as B_n[25].
The degree of uniformity (U_D) represents amount of fluctuation in received optical power on the floor. It is defined by the ratio of maximum optical power to the minimum optical power at the receiver plane [25]

$$U_D = \frac{p_{max}}{p_{min}} \tag{3.12}$$

Where P_{max} and P_{min} are maximum and minimum received optical power respectively. The illumination gives the brightness on the surface. The radiant intensity at angleϕ is given by

$$I(\phi) = I(0)cos^{m_l}$$

(ϕ)(3.13)The center luminous intensity of an LED panel is I(0). An illuminance at a point (x, y) is given by

$$E_{hor} = \frac{I(\phi)}{D_d^2} cos(\Psi) \tag{3.14}$$

The distance between a LED panel and the detector surface is denoted as D_d.

3.1.1 Fitness Function of Our Problem

The aim is to determine the (x,y) coordinate of the white LED panels which minimize the degree of uniformity defined in [25]-[26]. Thus the fitness function in this problem expressed in dB is given by

$$U(dB) = 10log_{10}\frac{p_{max}}{p_{min}} \tag{3.15}$$

Our objective to minimize the variation of power distribution on the floor by using whale optimization algorithm.

Chapter 4

Whale optimization Algorithm

4.1 Introduction

Whales are the huge beast in the world. The size of an adult whales can become upto 30m long and 190t weight. Whales smartness as compare to human is higher because in whales twice number of more cells are present. Anotehr intersting things is the social behaviour of whales they live either alone or in group. The most intersting thing in humback whalesis that their hunting behaviour this process is known as bubble-net feeding method [27] that is unique behaviour that can be observed only in humpback whales. In bubble net feeding method a group of whales goes around 12m-15m down and then start to create bubble in circular shape near to the prey and swim upwards to the surface.

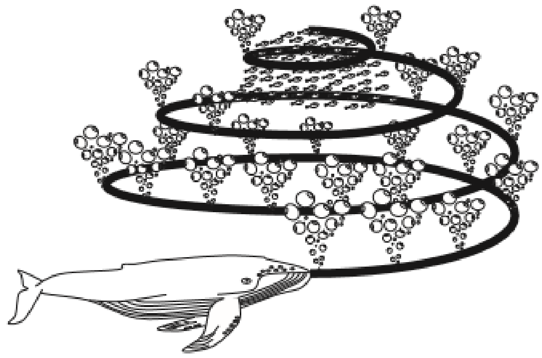


Figure 4.1: bubble-net attacking method of humpback whales

4.2 Mathematical Model of WOA

The mathematical model of WOA as follows: encircling prey, bubble net attacking and search for prey.

4.2.1 Encircling Prey

In this technique the position of search space is not known a before, the WOA is assumed the current position is best position or near to the best solution and other search agent try to update their own position with respect to best optimum position further position can be updated by below given equations.

$$\vec{D} = |\vec{c} \cdot \vec{X}^*(t) - \vec{X}(t)| \tag{4.1}$$

$$\vec{X}(t+1) = |\vec{X}^*(t) - \vec{A} \cdot \vec{D}| \tag{4.2}$$

Where t indicate about present iteration and $\vec{X}$ is the current position while X^* represents the best positions obtained and update in each iteration if their is best solution otherwise not update and . represents bit-by-bit multiplication. Whereas $\vec{A}$ and $\vec{c}$ represent coefficient vector and calculates as.

$$\vec{A} = 2\vec{a} \cdot \vec{r} - \vec{a} \tag{4.3}$$

$$\vec{C} = 2 \cdot \vec{r} \tag{4.4}$$

where as $\vec{a}$ decay from 2 to 0 over in both exploitation phase and exploration phase and $\vec{r}$ is a arbitrary vector [0 1].

4.2.2 Bubble-net attacking method (exploitation phase)

In this technique two approach is designed as follows: shrinking encircling mechanism and spiral updating position. The humpback whales swim near to the prey in both mechanism so we assume that there is 50% possibility to choose either the encircling mechanism or spiral mechanism when probability is less than 50% use encircling technique otherwise spiral.

$$X(t+1) = \begin{cases} \vec{D}' \cdot e^{bl}.\cos(2\pi l) + \vec{X}^*(t) & \text{if } p \geq 0.5 \\ \\ \vec{X}^*(t) - \vec{A} \cdot \vec{D} & \text{if } p < 0.5 \end{cases} \tag{4.5}$$

To define the shape of spiral its depends upon the value of b and l is arbitrary value [-1 1].

$$\vec{D}' = |\vec{X}^*(t) - \vec{X}(t)| \tag{4.6}$$

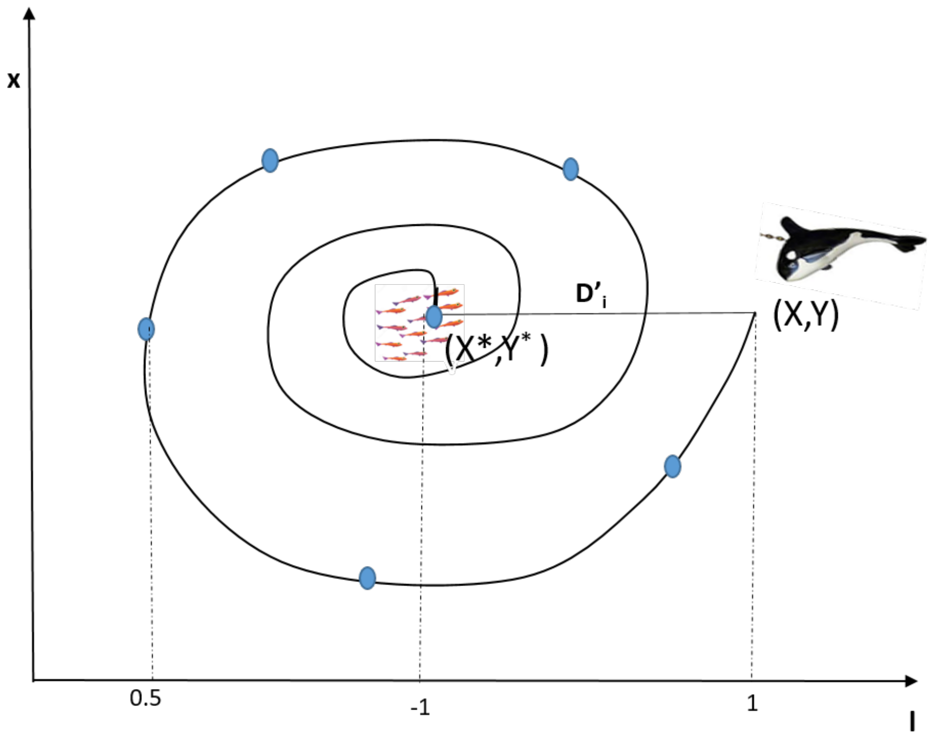


Figure 4.2: spiral updating position

4.2.3 Search for prey (exploration phase)

In this method the location of others whales is recognize by the humpback whales to chose search for prey random. The fitness function is updated by randomly chosen value instead of the best results.To update the position of search space below given equation are used.

$$\vec{D} = |\vec{C} \cdot \vec{X}_{rand} - \vec{X}| \tag{4.7}$$

$$\vec{X}(t+1) = \vec{X}_{rand} - \vec{A} \cdot \vec{D} \tag{4.8}$$

Where X_{rand} is randomly generated position vector chosen from the current populations of whales. The WOA optimization technique start with a set of random solutions. After that position of random solutions is update in each iteration to obtain best solution so far. In WOA algorithm the optimization start with a random solution. After for each iteration, the WOA algorithm update the position of search agent by either randomly chosen solution or best solution obtain so far. The value of parameter a decrease 2 to 0 and decide to provide either exploration or exploitation phase. The position of search agent is depends upon the value of A, if $|A| > 1$ then random solution chosen else if $|A| < 1$ best solution chosen.

4.3 Pseduo Code for WOA Algorithm

ALGORITHM

1. Initialize the random whale's population X_i, $i = 1, 2, ...n$.

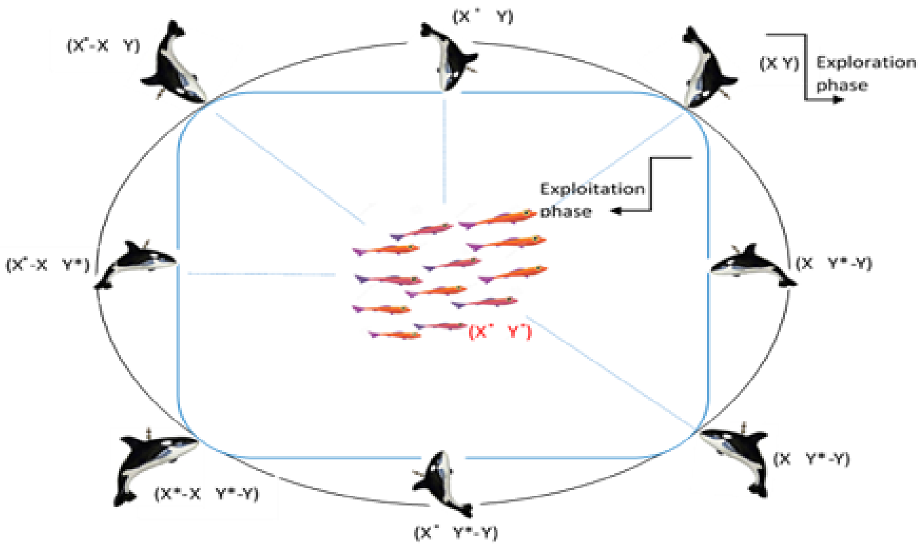


Figure 4.3: Position updating method for search agents and effects of A on it

2. Fitness of each searching whale .

3. For each i: $1 \leq i \leq n$.

4. Calculate the corresponding fitness function U_i.

5. End for .

6. /$*$ obtain the current best searching whale X^* $*$/ .

7. While (t ¡ Max_{itr}.

8. For each searching whale.

9. /$*$ Update a, A, c, l and p $*$/.

10. If (p¡0.5) then.

7. If ($|A| < 1$)

8. Update the position of current agent by equation

$$\vec{X}(t+1) = |\vec{X}^*(t) - \vec{A} \cdot \vec{D}| \tag{4.9}$$

9. Else if ($|A| > 1$)

10. Update the position of current agent by equation

$$\vec{X}(t+1) = \vec{X}_{rand} - \vec{A} \cdot \vec{D} \tag{4.10}$$

.

11. End if

12. Else if $p > 0.5$

13. Update the position of current agent by equation

$$\vec{X}(t+1) = \vec{D}' \cdot e^{bl}. \cos(2\pi l) + \vec{X}^*(t) \tag{4.11}$$

.

14. End if

15. Evaluate the fitness function of all search agents.

16. Update the best search agent with respect to the non-dominated solutions.

17. End for

18. Check if search agent goes beyond the search space and amend it.

19. Calculate the fitness function of search agent.

20. Update X^* if there is better solution.

21. $t = t + 1$

22. End while

23. Return archive.

Chapter 5

Simulation Results

To achieve uniform illuminance distribution in room using single LED it is difficult. So in this thesis we proposed up to 6 different LED panels to archive uniform illuminance which will help for better communication. Illuminance depends upon the positions of LED panels.Each LED panels consists of 3600(60*60) LED's. The indoor room size is 5m*5m*3m. The receiver is placed at desk which is 0.85 m above the ground surface. The distance between LED panels and receiver is kept fixed 2.15 m.The spacing between in one LED panels of each LED are fixed. To determine the direction of LED panels with respect to receiver two types of angel consider: zenith angel (angle between the LED normal vector and the vertical axis)and azimuth angel(angel between measuring clockwise to the perpendicular projection of the LED panels normal vector on the ceiling) but in our simulation we neglect both angels. In our simulation, the performance of illuminance, received optical power and SNR is estimated for indoor VLC system only for line of sight link.

The simulation of the proposed indoor VLC model is carried out in MAT-

LAB 2013a environment. The program is allowed to run in an Intel i3 laptop with 4GB ram and 1.90GHz clock frequency with windows 10, 64-bit operating system.

In this thesis, Whale optimization algorithm is applied to find the optimum position of LED panels for minimum (variation) in received power. In this optimization task the initial population of whales is taken 20, WOA algorithm run for 500 iterations to get minimum variation in the received optical power i.e. to get uniform illuminance at entire room.

5.0.1 Non-Uniform Power Distirbution Pattern and Possible Solution

In LOS system using a single transmitter, the power level in entire room was different at each point of room. Hence reliable communication might be possible to achieve and also maximum to minimum power level variations may be exceed the allowable range of indoor system. When the size of room is large then problem is more serious due to non- uniform power distribution. The power distribution at the corner of room may be lower and unreliable detection. One solution is there for this problem to increase the power level of single source to get sufficient power distribution at the corner but this solution gives high power distribution near to the source which may harmful for human. Sivabalan et al [25] calculate the maximum to minimum power variation for single transmitter and get above 7 dB. To get uniform power distribution many approaches have been suggested, such as Pakraven et al [28] use of holographic diffusion system, Kahn et al [29] suggest use image diversity receiver and quassi-diffuse transmitter, Bakalidis

Table 5.1: Optimization Parameters

parameter Name	parameter Value
Room size	5m*5m*3m
Number of LEDs in each panels	3600(60*60)
Transmitted power of single LED	20 mw
FOV of receiver	70 deg.
Transmission coefficient of optical filter	1
Amplifier BW	50 MHz
Center luminous intensity	0.73 cd
Physical area of PD	1 cm
receiver height from ground	0.85m
Noise bandwidth factor	0.562
refractive index of glass	1.5
Ambient noise power	19.272
PD responsivity	0.4 A/W
Semi angle at half power	70 deg.

at al [8] and Yang et al[9]suggest to use multiple transmitters. Above all suggestions the using multiple transmitters technique is less complex and quite attractive. Sivabalan et al [25] compute the degree of uniformity for different multiple transmitters configuration. Results are shown on Table 6.2. Also calculate the degree of uniformity for different semi-angle at half power of LED. Results are shown on Table 6.3.

According to ISO(International Organization for) [10] the value of illumination should be between 300 lx to 1500 lx for office work, and kept under also maximum threshold for eye-safety. Fig. 6.1 illustrates the indoor received optical power distribution and illumination distribution after optimization for single LED panel. From fig.6.1 the maximum and minimum illumination of the proposed simulated system for single LED panels are 915 lx and

Table 5.2: Degree of uniformity achieved at room with before optimization of LED panels position

No of LED Panels	Optimal LED Panel locations	Degree of uniformity (dB)
1	(2.5, 2.5, 3)	10.3674
2	(0.5, 2.5, 3), (4.5, 2.5, 3)	6.6078
3	(0.25, 4.75, 3), (4.75, 4.75, 3), (2.5, 0.25, 3)	6.432
4	(0.5, 0.5,3), (0.5, 4.5, 3), (4.5, 0.5, 3), (4.5, 4.5,3)	2.8456
5	(0.5, 0.5, 3), (0.5, 4.5, 3), (4.5, 4.5, 3), (4.5, 0.5,3), (2.5, 2.5, 3)	2.45

600 lx and average illumination 850 lx ,the variation between maximum and minimum illuminance is high because single LED panels gives maximum illumination under LED panels position and gives minimum in corner of the room.The degree of uniformity is the ratio of minimum to average illuminance and in this case we get uniformity upto 70.58% which is low. Fig.6.2 illustrates the indoor received optical power distribution and illumination distribution after optimization for two LED panels.From fig.6.2 the maximum and minimum illumination of the proposed simulated system for two LED panels are 750 lx and 570 lx the variation between maximum and minimum illuminance is lower than single LED panel due to this uniformity ratio increase 78.62%. From fig. 6.3 the maximum and minimum illumination are 760 lx and 560 lx respectively and degree of uniformity is 82.35%.

Fig. 6.4 illustrates the indoor received optical power distribution and illumination distribution after optimization for Four LED panels. From fig.6.4 the maximum and minimum illumination of the proposed simulated system for single LED panels are 740 lx and 610 lx and the average illuminance

Table 5.3: Degree of uniformity achieved at room with optimal locations of LED panels determined by WOA

No of LED Panels	Optimal LED Panel locations with WOA	Degree of uniformity (dB)	uniformity Ratio(%)
1	(2.5020, 2.4995, 2.15)	10.3674	70.58
2	(0.3765,2.4448,2.15),(4.3498, 2.5066, 2.15)	60.2146	78.62
3	(2.9050, 0.1173, 2.15),(0.1508, 2.6921, 2.15),(3.8711, 3.9621, 2.15)	4.9536	82.35
4	(1.1184,0.3032,2.15),(4.7447,0.8283,2.15), (0.4211,3.9302,2.15),(3.9927,4.5277,2.15)	1.9602	88.40
5	(4.0226,0.6150,2.15),(3.0465,2.7494,2.15), (4.6939,4.6397,2.15), (0.2834,4.4316,2.15), (0.0574,0.4762,2.15)	2.3502	85.56s
6	(1.2183,2.4798,2.15),(0.4265,4.7003,2.15), (0.1910,0.2871,2.15), (4.2413,0.3531,2.15), (4.0169,4.47693,2.15),(4.1693,2.6143,2.15)	2.1020	87.63

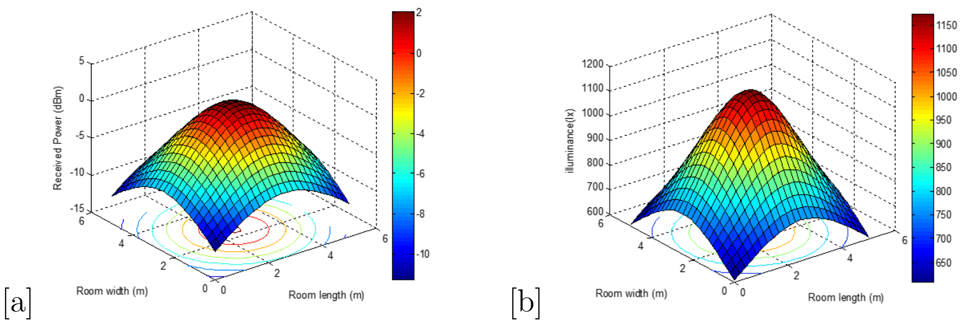


Figure 5.1: Distribution of Received optical power and illuminance in the room obtained with 1 LED panels placed at optimal locations using WOA (a) Received optical power(b) illuminance.

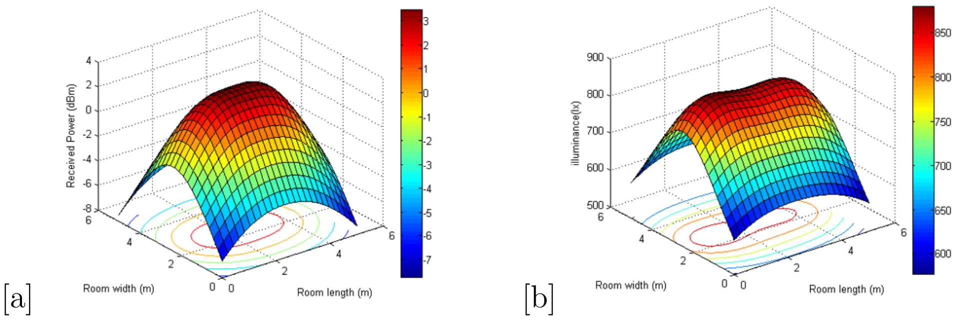


Figure 5.2: Distribution of Received optical power and illuminance in the room obtained with 2 LED panels placed at optimal locations using WOA (a) Received optical power(b) illuminance.

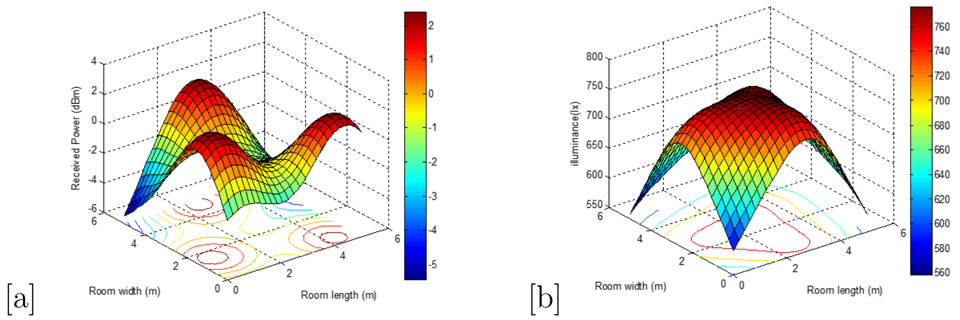


Figure 5.3: Distribution of Received optical power and illuminance in the room obtained with 3 LED panels placed at optimal locations using WOA (a) Received optical power(b) illuminance.

is 690 lx which gives the degree of uniformity is 88.40% which is good for office work. Above tables results show that four LED panels gives better results as compare to other configurations so we can say that the number of LED panels is not important the important thing is the location of LED panels. So high speed communication the location of LED panels play an important role.

Fig. 6.5 in case of five LED panels the average illumination is 680 lx and of uniformity nearly 85.29%. Here we can say that increase the number of LED panels not gives better degree of uniformity.

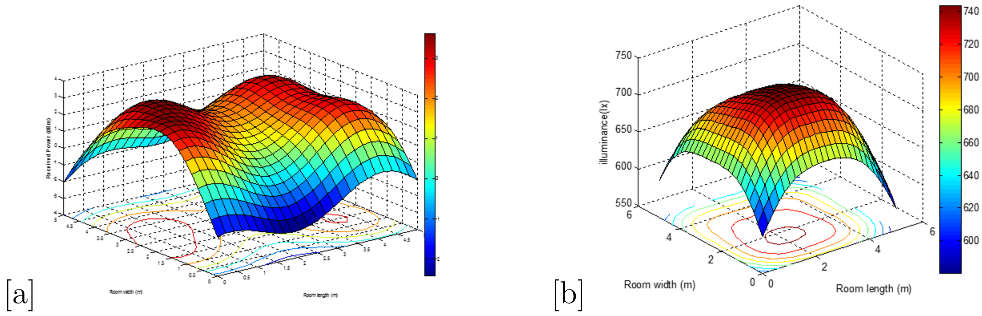


Figure 5.4: Distribution of Received optical power and illuminance in the room obtained with 4 LED panels placed at optimal locations using WOA (a) Received optical power(b) illuminance.

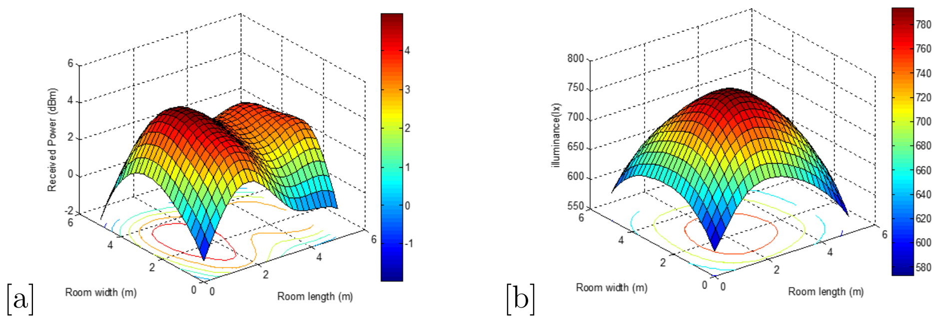


Figure 5.5: Distribution of Received optical power and illuminance in the room obtained with 5 LED panels placed at optimal locations using WOA (a) Received optical power(b) illuminance.

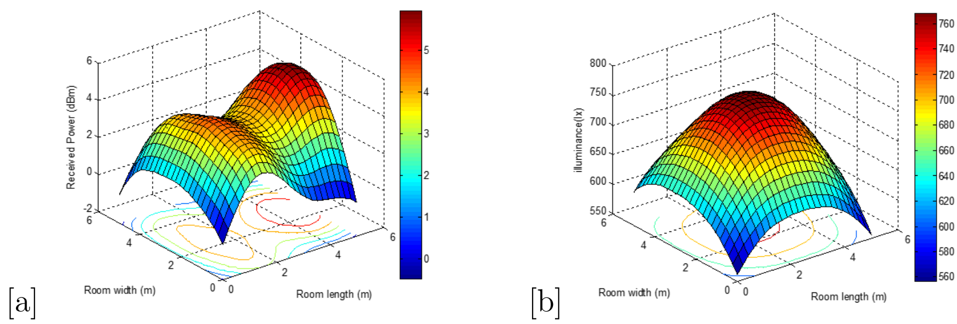


Figure 5.6: Distribution of Received optical power and illuminance in the room obtained with 6 LED panels placed at optimal locations using WOA (a) Received optical power(b) illuminance.

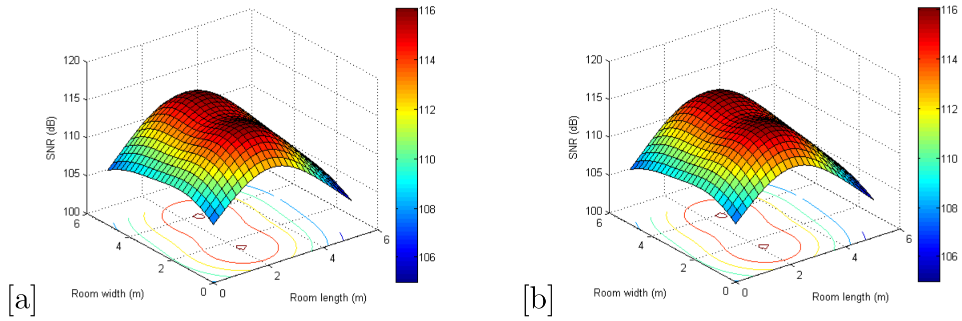


Figure 5.7: Distribution of SNR in the room obtained with LED panels placed at optimal locations using WOA (a) 1 LED panels (b) 2 LED panels.

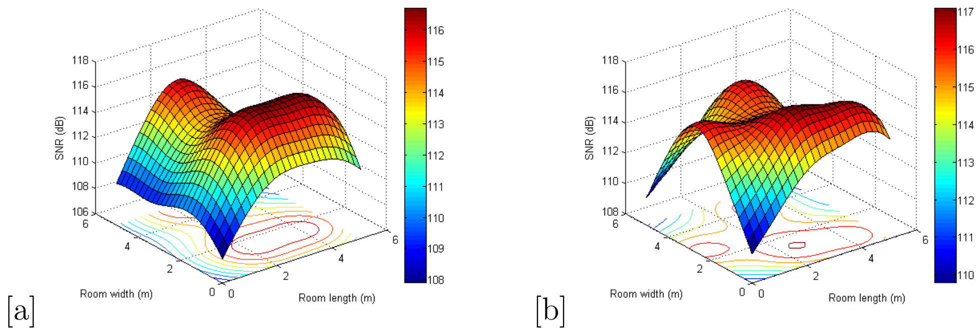


Figure 5.8: Distribution of SNR in the room obtained with LED panels placed at optimal locations using WOA (a) 3 LED panels (b) 4 LED panels.

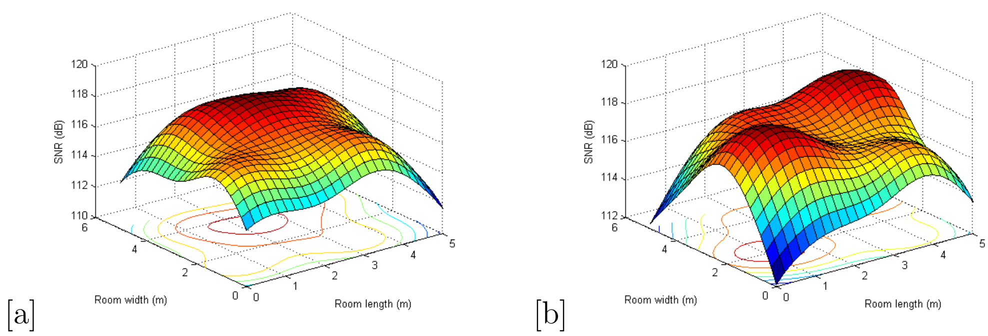


Figure 5.9: Distribution of SNR in the room obtained with LED panels placed at optimal locations using WOA (a) 5 LED panels (b) 6 LED panels.

In this thesis, we proposed the position of LED panels to optimize SNR by selecting communication LEDs in indoor visible light communication. The value of SNR is not optimum if we select random position of LED panels. For better indoor wireless communication it is essential to get optimum SNR for each user. To provide optimum SNR for each user we proposed WOA algorithm for simulation. The simulation results show that the value of SNR is good for indoor visible light communication. Signal to noise ratio is play important role in communication because our main focus is on signal but during transmission it got affected by some random noise or system noise. At the receiving end we want to have the same transmitted signal , to achieve original transmitted signal the noise should be minimized and here SNR plays an important role. High value of SNR show that noise affection is minimum. For wireless communication sytem BER target of $0^{-}6$ requires ThreSINR = 13.6 dB [10]. In our proposed system SNR value between 90 dB to 115 dB, which is very high for indoor wireless communication system and get high speed communication.

In fig.6.7 the distribution of SNR for 1 LED panel and 2 LED panels are shown. The value of SNR obtain by using WOA algorithm for optimum position of LED panels. The value of SNR after optimization is much high and its provide high speed wireless indoor communication. The value of SNR increase by increasing number of LED panels. In fig.6.8 the distribution of SNR for 3 LED and 4 LED panels are shown. The value of SNR before optimization and after optimization 50.52% and 49.51% much higher respectively. The value of SNR for in case of 5 LED and 6 LED panels are also high. Fig.6.10 shown the value of SNR before and after optimization.

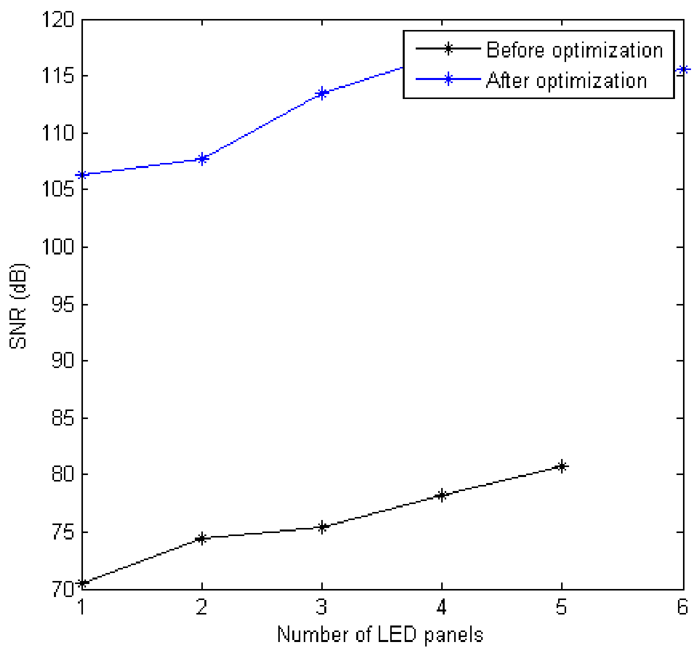


Figure 5.10: Comparison of SNR for different LED panels before and after optimization

Chapter 6

Multi-Objective Whale Optimization Algorithm

6.1 Introduction

Many real world engineering design and decision-making problems needs to simultaneous objectives. In multi-objective optimization problem the main aim is to simultaneously minimize and maximize problems with the same objectives. A trade-off solutionis required when optimize multi-objective problems between the objectives function. Example: while dispatch a new vehicle the company has to consider the minimizeing the cost while fuel consumption is maximizing [30]. The main intention of multi-objective optimization algorithms is highest diversity with accurate approximation of the true pareto optimal solutions [31]. Now a day's various meta-heuristic Multi-objective algorithm are available, which will give the pareto optimal solution of our problem. Paretro optimal solution contain non-dominated solution means any one of the objective function will have better fitness value then other objective. A recently published paper by mirajalili discus the development in multi objective algorithm and their engineering application [32]. Other important articles on applications of multi-objective algorithms includes: such as multi-objective resource allocation [33], wireless sensor network [34], production scheduling [35], energy efficient illumination and communication in indoor VLC [36] and optimal robot mobile path planning [37].

Research on multi-objective algorithm was more and more popular after proposed the Non-dominated sorting Genetic algorithm (NSGA-II) in 2000 proposed by K.Deb group [38]. NSGA-II used a fast non-dominated sorting technique which decrease the aforesaid problems. NSGA-II algorithm sort with randomly generated populations. The fitness function of each parameters is defined based on the non-dominated sorting method. Second population is createdbased on the selection and mutation operator and both population together and make a big populations. The highest priority to be selected a new particular final population and this process is repeated until the same size of initial population cannot be achieved. After some years NSGA-III introduced for parameter less unconstrained and constrained optimization problems [39]-[40]. Another most famous multi-objective optimization is multi-objective particle swarm optimization (MOPSO) [41]. In this optimization technique group of particles, fly in the search zone to find the best solution. The computational complexity of MOPSO is lower than NSGA-II due to use of grid and an archive controller technique.

There are various different type of multi-objective optimization approach in literature over the past a few years. A multi-objective CLONAL for normal and aggressive 3D human models [42], Multi-objective Cat swarm optimization [43], Gravitational search algorithm [44], Multi-objective ant colony optimization [45], multi-objective moth flame optimization [46]is inspired by the special characteristics of a moth during in the dark night to either fly direct againest the moon or fly in a circular path to reach around fabricated light source. Brighter destination will be the optimized solution for MOMFO, multi-objective ant lion optimizer [47] and multi-objective grey-wolf optimization [48].

In 2016, Mirajalili [49] proposed a new meta-heuristic whale optimization algorithm (WOA). It is encourged by special trapping behavior of humpback whales. This trapping process is called bubble net attacking method [50] which is unique method and observed in Humpback whale. In bubble net feeding group of whales goes around 12m-15m deep and then start to create bubble in circular shape acrros the prey and swim towards the surface. In this hunting process Humpback whales introduce three distinct steps: coral loop, lob tail and capture loop to finish the hunting process. Mirajalili tested the algorithm on 29 different unimodal and multimodal benchmark test functions to analyze convergence speed and local optima avoidance and also applied on six different structural engineering problems (example: Design of 25-bar and 52-bar truss, welded beam, tension/compression spring etc.) Were solved. The WOA is applied various applications such as early warning system for air quality measurement in various cities of china [51], minimizing the fuel consumption of vehicle consider various traffic scenarios [52].

6.2 Multi-Objective Whale Optimization Algorithm(MOWOA)

The multi objective whale optimization algorithm (MOWOA) is developed to solve multi-objective issues. To get better solutions, the proposed algorithm includes exploitation mechanism and exploration mechanism which is associate in the original WOA. Whales are the huge mammals in the world. The size of an adult whales can reach around 30m long and 190t weight. There are seven distinct type of category such as killer, minke, sei, humpback, right, finback and blue. Whales are intelligence as compare to human because in whales twice cells are present. MOWOA is encouraged by hunting behave of humpback whales and this behavior is known as bubble net attacking method and can be observe only in humpback whales. to simulate the MOWOA the mathematical model of MOWOA as follows: encircling prey, bubble net attacking and search for prey.

6.2.1 Encircling Prey:

In this technique the position of search zone is not known before, the WOA is assumed the current position is best position and further position can be updated by these given below equations.

$$\vec{D} = |\vec{c} \cdot X^*(t) - \vec{X}(t)| \tag{6.1}$$

$$\vec{X}(t+1) = |\vec{X}^*(t) - \vec{A} \cdot \vec{D}| \tag{6.2}$$

Where t represent the present iteration and X is the current position while X^* represents the best positions obtained so far whereas $\vec{A}$ and $\vec{C}$ represent coefficient vector and calculates as follows

$$\vec{A} = 2\vec{a} \cdot \vec{r} - \vec{a} \tag{6.3}$$

$$\vec{C} = 2 \cdot \vec{r} \tag{6.4}$$

Where $\vec{a}$ is decay from 2 to 0 and r is arbitrary vector [0 1].

6.2.2 Bubble-net Feeding process (exploitation phase):

In this technique two approach is designed as follows: Shrinking encircling mechanism and spiral updating position. The humpback whales swim towards the prey in both mechanism so we assume that there is 50% possibility to choose either the encircling or spiral mechanism when probability is less than 50% use encircling technique otherwise spiral.

$$X(t+1) = \begin{cases} \vec{D}' \cdot e^{bl}. \cos(2\pi l) + \vec{X}^*(t) & \text{if } p \geq 0.5 \\ \\ \vec{X}^*(t) - \vec{A} \cdot \vec{D} & \text{if } p < 0.5 \end{cases} \tag{6.5}$$

Where parameter b is constant and play important role to define the shape of spiral and l is arbitrary value [-1 1]

$$\vec{D}' = |\vec{X}^*(t) - \vec{X}(t)| \tag{6.6}$$

6.2.3 Search for prey (exploration phase):

The location of other whales can recognize the humpback whales and chosen search for prey arbitrary. The fitness function is updated by arbitrary chosen value instead of the best values.

$$\vec{D} = |\vec{C} \cdot \vec{X}_{rand} - \vec{X}| \tag{6.7}$$

$$\vec{X}(t+1) = \vec{X}_{rand} - \vec{A} \cdot \vec{D} \tag{6.8}$$

Where X_{rand} is arbitrary generated position vector. The pseudo code of

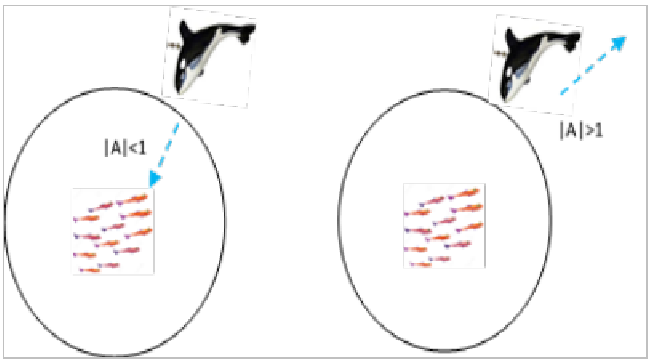


Figure 6.1: Attacking prey versus searching for prey

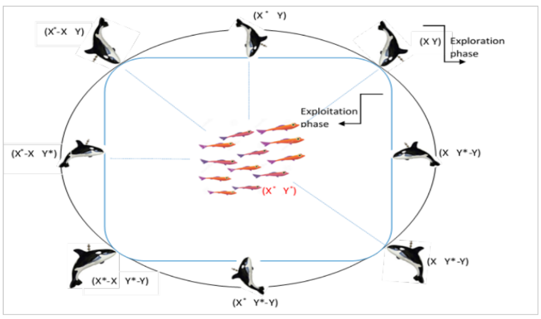


Figure 6.2: Position updating mechanism of search agents and effects of A on it

the MOWOA algorithm for obtaining the best results is described as follows.

ALGORITHM

1. Initialize the random whale's population X_i, $i = 1, 2, ...n$.

2. Evaluate the fitness of population.

3. Find the non-dominated solutions and initialized the archive with them.

4. X^*= the best search agent.

5. For each search agent.

6. Update a, A, c, l and p

7. If $(|A| < 1)$

8. Update the position of current agent by equation (2)

9. Else if $(|A| > 1)$

10. Update the position of current agent by equation (8)

11. End if

12. Else if $p > 0.5$

13. Update the position of current agent by equation (5)

14. End if

15. Evaluate the fitness function of all search agents.

16. Evaluate non-dominated solution.

17. Update the best search agent with respect to the non-dominated solutions.

18. End for

19. Check if search agent goes beyond the search space and amend it.

20. Calculate the fitness function of search agent.

21. Update X^* if there is better solution.

22. $t = t + 1$

23. End while

24. Return archive.

6.3 Test Problems

The performance of the proposed MOWOA is tested on six unconstraint Bi-objective test problems [53]. In all test problems that the objectives is minimized objective function.

Test Function-1: This bench mark unconstrained optimization function consists of two objective and two inequality unconstrained [53]. Mathematically it can be represented as:

$$f_1 = \sqrt[5]{x_1} + \frac{2}{|J_1|} \sum_{j \epsilon J_1} {y_j}^2 \qquad (6.9)$$

$$f_2 = 1 - \sqrt[5]{x_1} + \frac{2}{|J_2|} \sum_{j \epsilon J_2} {y_j}^2 \qquad (6.10)$$

where J_1 = {j|j is odd and 2≤j≤n}, J_2 = {j|j is even and 2≤j≤n}, and

$$y_j = x_j - \sin(6\pi x_1 + \frac{j\pi}{n}), j = 2, ..., n \qquad (6.11)$$

Test Function-2: This bench mark unconstrained optimization function consists of two objective and two inequality unconstrained [53]. Mathematically it can be represented as:

$$f_1 = x_1 + \frac{2}{|J_1|} \sum_{j \epsilon J_1} h(y_j) \tag{6.12}$$

$$f_2 = 1 - x_2 + \frac{2}{|J_2|} \sum_{j \epsilon J_2} h(y_j) \tag{6.13}$$

J_1 and J_2 are same as Test Function1

$$y_j = x_j - \sin(6\pi x_1 + \frac{j\pi}{n}), j = 2, 3...n, h(t) = \frac{|t|}{1 + e^{2|t|}} \tag{6.14}$$

Test Function-3: This bench mark unconstrained optimization function consists of two objective and two inequality unconstrained [53]. Mathematically it can be represented as:

$$f_1 = x_1 + \frac{2}{|J_1|} \sum_{j \epsilon J_1} [x_j - \sin(6\pi x_1 + \frac{j\pi}{n})]^2 \tag{6.15}$$

$$f_2 = 1 - \sqrt{x}_1 + \frac{2}{|J_2|} \sum_{j \epsilon J_2} [x_j - \sin(6\pi x_1 + \frac{j\pi}{n})]^2 \tag{6.16}$$

where J_1 = {j|j is odd and 2≤j≤n} and J_2 = {j|j is even and 2≤j≤n}

Test Function-4: This bench mark unconstrained optimization function consists of two objective and two inequality unconstrained [53]. Mathematically it can be represented as:

$$f_1 = x_1 + \frac{2}{|J_1|}\sum_{j\epsilon J_1} {y_j}^2 \tag{6.17}$$

$$f_2 = 1 - \sqrt{x}_1 + \frac{2}{|J_2|}\sum_{j\epsilon J_2} {y_j}^2 \tag{6.18}$$

where J_1 = {j|j is odd and 2≤j≤n}, J_2 = {j|j is even and 2≤j≤n}, and

$$y_j = \begin{cases} x_j - [0.3{x_1}^2 \cos(24\pi x_1 + \frac{4j\pi}{n}) + 0.6x_1] & \\ \cos(6\pi x_1 + \frac{j\pi}{n}) & j\epsilon J_1 \\ & \\ x_j - [0.3{x_1}^2 \sin(24\pi x_1 + \frac{4j\pi}{n}) + 0.6x_1] & \\ \cos(6\pi x_1 + \frac{j\pi}{n}) & j\epsilon J_2 \end{cases} \tag{6.19}$$

Test Function-5: This bench mark unconstrained optimization function consists of two objective and two inequality unconstrained [53]. Mathematically it can be represented as:

$$f_1 = x_1 + \frac{2}{|J_1|}(4\sum_{j\epsilon J_1} {y_j}^2 - 2\prod_{j\epsilon J_1} \cos(\frac{20y_j\pi}{\sqrt{j}}) + 2) \tag{6.20}$$

$$f_2 = \sqrt{x}_1 + \frac{2}{|J_2|}(4\sum_{j\epsilon J_1} {y_j}^2 - 2\prod_{j\epsilon J_2} \cos(\frac{20y_j\pi}{\sqrt{j}}) + 2) \tag{6.21}$$

J_1 and J_2 are same as Test Function1

$$y_j = x_j - {x_1}^{0.5(1.0+\frac{2}{|j|},j=2,3...n.} \tag{6.22}$$

Test Function-6: This bench mark unconstrained optimization function consists of two objective and two inequality unconstrained [53]. Mathematically it can be represented as:

$$\begin{aligned}
&f_1 = x_1 + \max\{0, 2(\frac{1}{2N} + \epsilon)\sin(2N\pi x_1)\} \\
&+\frac{2}{|J_1|}(4\sum_{j\epsilon J_1} {y_j}^2 - 2\prod_{j\epsilon J_1}\cos(\frac{20y_j\pi}{\sqrt{j}}) + 1)) \\
&f_2 = 1 - x_1 + \max\{0, 2(\frac{1}{2N} + \epsilon)\sin(2N\pi x_1)\} \\
&+\frac{2}{|J_2|}(4\sum_{j\epsilon J_2} {y_j}^2 - 2\prod_{j\epsilon J_2}\cos(\frac{20y_j\pi}{\sqrt{j}}) + 1))
\end{aligned} \tag{6.23}$$

J_1 and J_2 are same as Test Function1,$\epsilon > 0$

$y_j = x_j - \sin(6\pi x_1 + \frac{j\pi}{n})$, $j = 2, 3...n$

6.4 Results and Discussion

The simulation of proposed MOWOA and MOGWO, are carried out on MATLAB 2013a environment. The program is allowed to run in an Intel i3 laptop with 4GB ram and 1.90GHz clock frequency with windows 10, 64-bit operating system. The parameter size of these two algorithm are : the size of population 100, size of repository is 60 and total number of iterations is 1000. The performance between these employed two algorithm are in generational distance (GD), Diversity Metric(Δ). Diversity shows about the advancement of the solution in the optimal, and generational distance shows that the closeness between obtained solution to the true Pareto front.

Generational Distance(GD): Generational distance (GD) which is a performance metric mostly involve in the literatures is investigated. The main aim of this principle is to clarify the capability of the algorithms to find the best approximate solution with having the least distance when compared with the true pareto front. Based on this criteria, it is essential that the obtained approximate solution with the minimum GD has the best convergence to the true pareto front. This decision parameter is describe in mathematical form as follows

$$GD = \frac{(\sum_{i=1}^{n} {d_i}^2)^{1/2}}{n} \tag{6.24}$$

where n is the number of points in the MOWOA solution, and d_i is the Euclidean distance between point i in MOWOA solution and the nearest point in the true pareto front.

Diversity Metric(Δ): We know that the diversity play important role in multi-objective problems to show the optimum solutions. we create two parameters one based on the successive distances among the best non-dominated front in the final population and the other based on the average distance of solutions from the known global Pareto optimal front. The collect set of the first non-dominated solutions are compared with a uniform distribution and the deviation is computed as follows:

$$\Delta = \frac{d_f + d_l + \sum_{j=1}^{N-1} |d_j - d^*|}{d_f + d_l + (N-1)d^*} \tag{6.25}$$

The number of non-dominated solutions obtained by proposed algorithm is denoted as N. The parameters d_f, d_l represent the Euclidean distance between extreme solutions and the boundary solutions of the obtained non-dominated solutions set respectively. The d^* is the average of all distances d_j, j = 1, 2, ..., (N 1). The diversity metric Δ= 0 represents the most widely and uniformly distributed set of non-dominated solutions. Smaller value of diversity metric Δ indicates the better diversity of non-dominated solutions set.

Results obtained for various benchmark multi objective functions by using MOWOA is given in fig (3) and fig (4). Measures used for the performance comparison are generational distance and diversity metric. Data to compare MOWOA with another algorithm is taken from [48]. From the figures, it can be seen that while using MOWOA is converging towards true pareto front better than other algorithms. The results get in the form of best, worst, mean and standard deviation values for the 6 unconstrained benchmark functions are reported in Table 7.1. Which contain results of MOWOA, MOGWO. From the table it can be seen that in almost cases

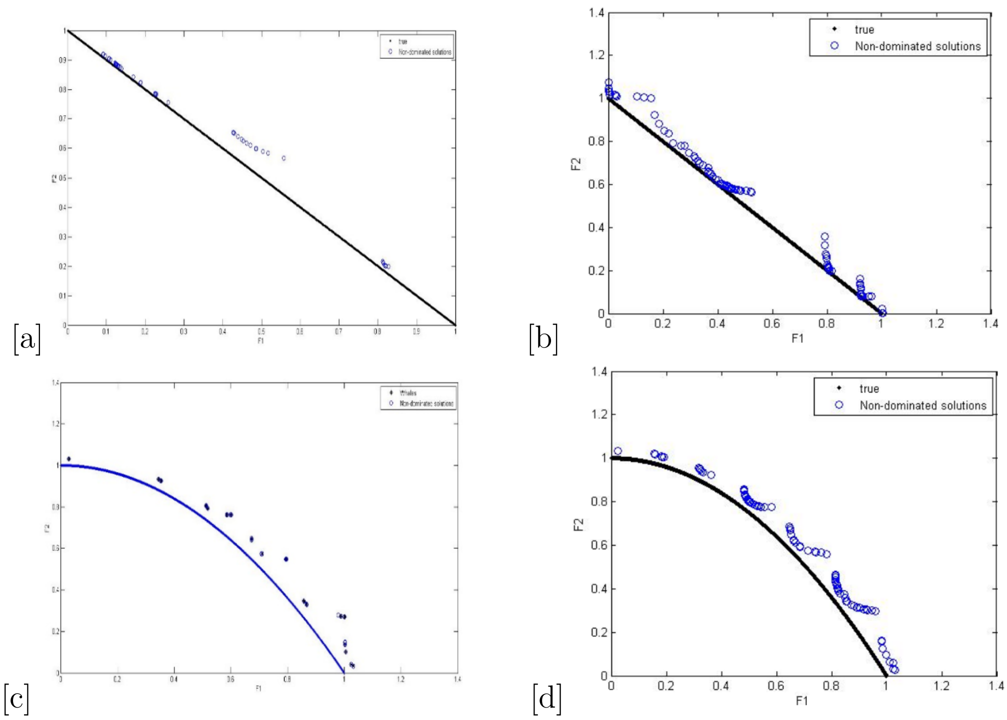


Figure 6.3: True Pareto Fronts obtained for Test functions 1 and 2 : With Test Function 1 (a) True Pareto front with MOWOA (b) True Pareto front with MOGWO; With Test Function 2(c) True Pareto front with MOWOA (d) True Pareto front with MOGWO.

the generational distance and diversity metric for all functions are lowest while applying MOWOA. Which shows the better convergence of MOWOA.

The results shows that sometimes MOGWO algorithm provides better performance in terms of generational distance(GD) and diversity metric Δ, because in MOGWO also leader selection mechanism is there, which update the position by using three non-dominated solution like MOWOA.

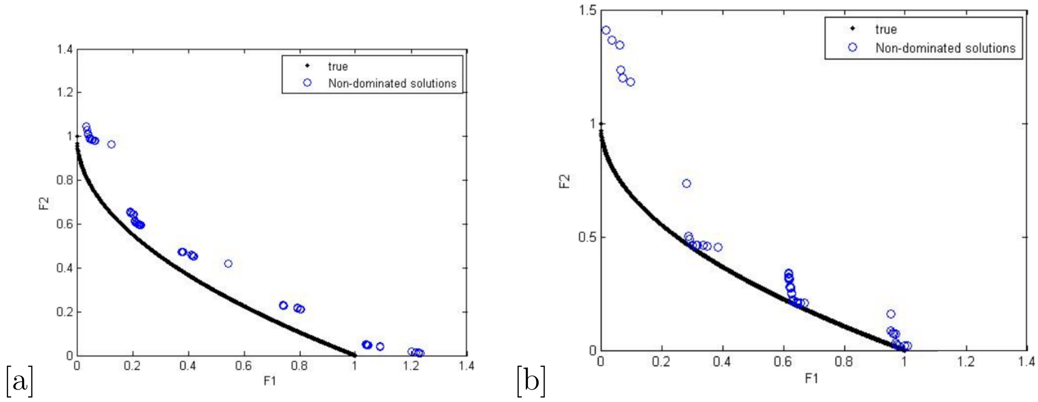


Figure 6.4: True Pareto Fronts obtained for Test functions 3 : (a) True Pareto Fronts with MOWOA (b) True Pareto Fronts with MOGWO.

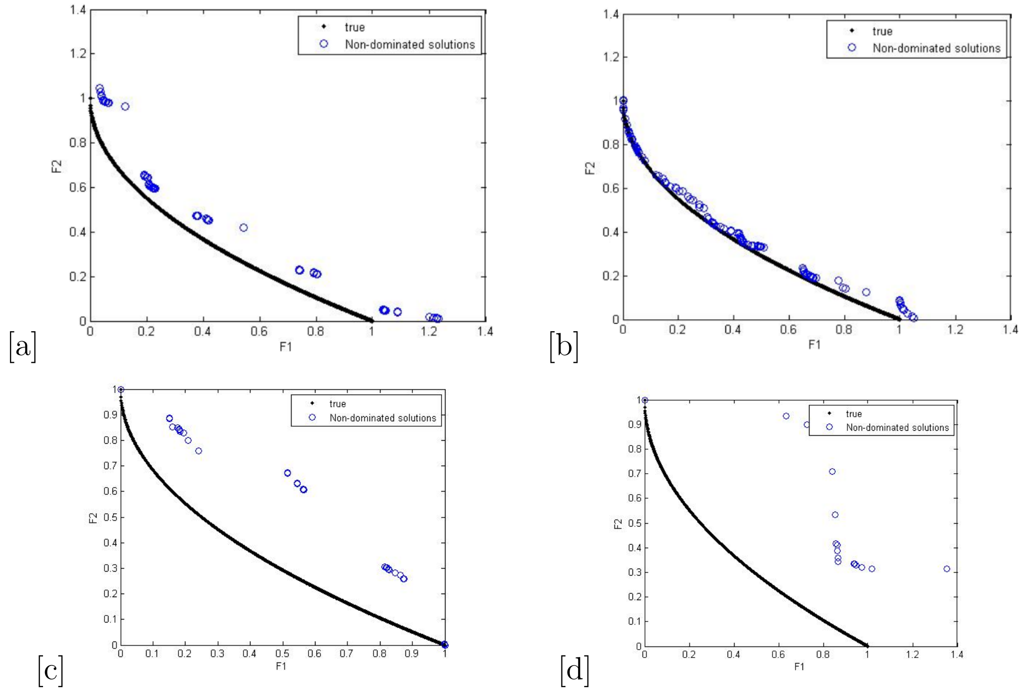
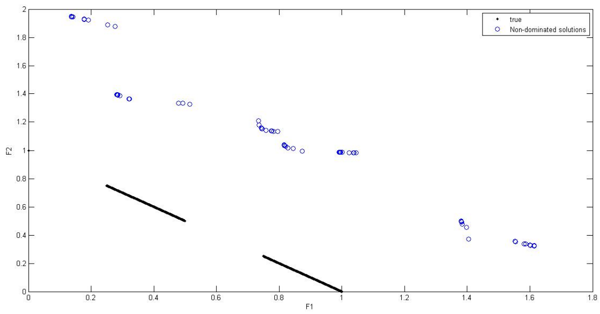
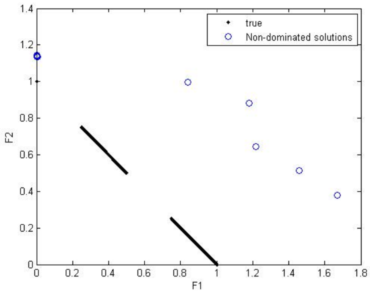


Figure 6.5: True Pareto Fronts obtained for Test functions 4 and 5 : With Test Function 4 (a) True Pareto Fronts with MOWOA (b) True Pareto Fronts MOGWO; With Test Function 5(c) True Pareto Fronts with MOWOA (d)True Pareto Fronts with MOGWO.



[a]



[b]

Figure 6.6: True Pareto Fronts obtained for Test functions 6 : (a) True Pareto Fronts with MOWOA (b) True Pareto Fronts with MOGWO.

Table 6.1: Comparative results of performance of proposed MOWOA with MOGWO

Objective function	Algorithm	GD				Diversity Metric			
		Best	Worst	Mean	Std.	Best	Worst	Mean	Std.
Test Fun 1	MOWOA	0.0592	0.3842	0.0685	0.1304	0.6066	0.6532	0.6245	0.0016
	MOGWO	0.0612	0.3992	0.0701	0.1371	0.6213	0.6741	0.6392	0.0028
Test Fun 2	MOWOA	0.0572	0.0593	0.0579	0.0008	0.6218	0.6721	0.6304	0.0021
	MOGWO	0.0562	0.0573	0.0569	0.0004	0.6132	0.6682	0.6292	0.0018
Test Fun 3	MOWOA	0.0758	0.1474	0.032	0.029	0.6278	0.6359	0.6302	0.0033
	MOGWO	0.0821	0.1652	0.1230	0.0021	0.6329	0.6458	0.6329	0.0040
Test Fun 4	MOWOA	0.0588	0.0798	0.0581	0.0072	0.6051	0.6433	0.6195	0.0149
	MOGWO	0.0542	0.0693	0.0553	0.0069	0.5982	0.6342	0.6092	0.0138
Test Fun 5	MOWOA	0.1321	0.4353	0.2819	0.0201	0.6048	0.6214	0.6126	0.0077
	MOGWO	0.1435	0.4630	0.3020	0.0245	0.6132	0.6481	0.6832	0.0084
Test Fun 6	MOWOA	0.4210	1.8810	1.5210	0.0956	0.6750	0.6879	0.6811	0.0048
	MOGWO	0.2132	1.7625	1.4867	0.8649	0.6621	0.6732	0.6711	0.0051

Chapter 7

Conclusion and Future work

In this thesis, a simulation model is developed for indoor visible light communication using white LED panels. The simulation is done by using Whale optimization algorithm to archive uniform illuminance and better SNR value for indoor VLC system. It is shown that the Whale optimization is good technique for the positioning of LED panels. The (x, y) positions of the LED panels were set in the roof of the room using WOA and PSO algorithms to achieve uniform illuminance and enhancing the data down load speed (by improving the SNR). In chapter 4 VLC system model is proposed for LED panels. In this system LED panels is used for both illuminance and communication device. We consider both thermal and shot noise for LOS link. The relation between SNR and received optical power can be established. In chapter 5 inspiration and mathematical model of whale optimization algorithm is discussed. It is shown that how that the whale optimization is used different method like: encircling and bubble-net feeding method. In chapter 6 results are obtained by using whale optimization algorithm for indoor VLC system model. First we calculate the degree of uniformity for different LED panel's configurations by positioning of the LED panels at the roof. The WOA is used to find the x and y coordinates of the LED panels keeping the distance between transmitter and receiver constant. Results show that the degree of uniformity is not good when we increase the LED panels configurations its depend upon the position of LED panels and results clear that the best degree of uniformity can be achieve in 4 LED panels configurations. SNR is calculated for each LED panels configuration. The results revels that the value of SNR is very good for indoor wireless communication.

In this thesis a newly proposed nature inspired algorithm called as multi-objective whale optimization algorithm. The proposed algorithm was applied on most challenging CEC 2009 benchmarks function and results revels with MOGWO. The proposed algorithm has improved capabilities due to two mechanism such as: Archive mechanism for sorting and recall the best non dominated results so far and another was leader selection mechanism to update the position of whales according to archive. Performance analysis on six benchmark function show better results over MOGWO in terms of diversity and generational distance.

7.1 Future Work

In future all digital network require high speed communication so visible light communication is better option. In our thesis we consider only line of sight (LOS) communication for indoor system. In future the same optimization technique can be used for NLOS system and diffused system. We can also use multi-objective technique for energy efficient communication means power consumption of LED is minimum while as uniformity can be maximize. The effect of dispersion and inter symbol interference can also be include. Different modulation technique can also be used for same work to compare results. The multi-objective optimization can be used in visible light communication for energy efficient communication by minimize power consumption while maximize the uniform illuminance.

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List of Publications

- Ishwar Ram Kumawat*, Satyasai Jagannath Nanda, Ravi Kumar Maddila, "Positioning LED Panel for Uniform Illuminance in Indoor VLC System using Whale Optimization", *In International Conference on Optical Wireless Technologies (OWT-2017)*, March 18-19, 2017.
- Ishwar Ram Kumawat*, Satyasai Jagannath Nanda, Ravi Kumar Maddila, "Multi-objective Whale Optimization", Submitted to IEEE conf. on *System, Man and cybernetics(TENCON)*, Nov. 5-8, 2017