**Sudan University of Science and Technology**

**College of Graduate Studies**

**M.Sc. Program in Telecommunication Engineering**

# Interference management in optical attocells networks by using fractional frequency reuse

# إدارة التداخل في شبكات اتوسيل الضوئية عن طريق إعادة استخدام التردد الجزئي

**A thesis submitted as partial fulfillment of the requirements for the degree of M.Sc (honors) in electronic engineering (Telecommunications engineering).**

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**March 2019**

# الاستهلال

**قال تعالى:**

**{وما أوتيتم من العلم إلا قليلاً}**

**(سورة الاسراء الآية 85)**

# *DEDICATION*

**TO MY FAMILY AND TEACHERS,,,,,,,,**

# ACKNOWLEDGMENT

I take this opportunity to deeply grateful to all those who provided creative analysis and ideas to end this thesis, especially my supervisor Dr. Ibrahim Khider Eltahir who gives full support and advising until completion.

Finally, I would like to thank my parents for they encouragement and all those gives me advising until this project finished.

# *Abstract*

Light fidelity (Li-Fi) is new technology using lights (LEDs) as transceiver to send and receive data. However, when Light fidelity access points (attocells) placing near to each other in the network, they interfere each other with phenomena called co-channel interference which decreasing quality of the signal. In this thesis, fractional frequency reuse introduced as solution to solve this problem. MATLAB simulator showing the impact of fractional frequency reuse to solve problem.

# المستخلص

تعد تقنية الضوء الدقيق من التقنيات الحديثة التي تستخدم الضوء لإرسال واستقبال البيانات. ولكن عند وضع نقاط وصول اتوسيل الضوئية قريبة من بعضها البعض في الشبكة فإنها تعمل على إحداث تشويش في الإشارة، مما يقلل من كفاءة عمل الشبكة. في هذا البحث تم عرض تقنية التردد الجزئي لحل مشكلة التداخل ومن ثم محاكاة المشكلة وعلاجها ببرنامج الماتلاب الذي بين أن هذه الطريقة أدت إلى تحسين جودة الإشارة بشكل ملحوظ.

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# Abbreviations

| | |
|---|---|
| ❖ Li-Fi | Light fidelity |
| ❖ LED | Light emitting diode |
| ❖ CCI | co-channel interference |
| ❖ AP | Access point |
| ❖ VLF | Very low frequency |
| ❖ OFDM | Orthogonal frequency division multiplexing |
| ❖ PD | Photo-diode |
| ❖ OWC | Optical wireless communications |
| ❖ RF | Radio frequency |
| ❖ LD | Laser diodes |
| ❖ OLO | Optical local oscillator |
| ❖ SCM | Single carrier modulation |
| ❖ MCM | Multiple carrier modulation |
| ❖ OOK | On-off keying |
| ❖ PPM | Pulse-position modulation |
| ❖ PAM | Pulse-amplitude modulation |
| ❖ ICI | Inter-cell interference |
| ❖ FFR | Fractional frequency reuse |
| ❖ SINR | Signal to interference noise ratio |
| ❖ FSO | Free space optics |

# Chapter 1:

# Introduction

# 1. Introduction

Telecommunication became one of the most important part of our life. Everyday demand to data increase and upgrade in mobile technology go slowly compared to data demand [1]. Most of radio communication accord in radio band from VLF to EHF, and these bands almost full, so engineer solving this problem by reuse frequency or by using small cells, but still problem exist. Visible band provide solution to this problem. This band is neglect and not used, Professor Harald Haas invent technology called Light fidelity (Li-Fi), Li-Fi use this band for sending and receiving data by using LED in transmitter and photo detector in receiver. The optical access point (AP) in Li-Fi is called attocell. If we equip a room with multiple light and that each light function as a very small radio base station, the result is a network of very small cells that known as optical attocells. Attocells made co-channel interference (CCI) between each other at the edge of the coverage area. In this research, we will study this technology and provide some approach to minimize CCI interference in optical attocells network. By using MATLAB software, we will design complete optical wireless communication system and sending data through optical wireless system by using LEDs. After that, we will apply interference management approaches to the system and compare it before applying approaches.

# 2. Literature Review and related works

Due to the increasing demand for wireless data communication, the available radio spectrum below 10 GHz (cm wave communication) has become insufficient. The wireless communication industry has responded to this challenge by considering the radio spectrum above 10 GHz (mm-wave communication). However, the higher frequencies, f, mean that the path loss, L, increases according to the Friis free space equation ($L \propto f^2$). In addition, blockages and shadowing in terrestrial communication are more difficult to overcome at higher frequencies. Systems must be design to enhance the probability of line-of-sight (LoS), typically by using beamforming techniques and by using small cells [2]. One disadvantage is that the providing a supporting infrastructure forever smaller cells becomes significant. Light-fidelity (Li-Fi) [3], [4] is a continuation of the trend to move to higher frequencies in the electromagnetic spectrum. Specifically, LiFi could be classified as nm-waves communication. Li-Fi uses light emitting diodes (LEDs)for high speed wireless communication, and speeds of over 3 Gb/s from a single micro-light emitting diode (LED) [5] have been demonstrated using optimized direct current optical orthogonal frequency division multiplexing (DCO-OFDM) modulation [6]. Light-Fidelity (Li-Fi) is being seen as one of the key emerging technologies to provide wireless access of data using visible light at high data rates. In Li-Fi, the data is usually intensity modulated to the visible light using light emitting diodes (LED), also called as downlink Li-Fi access points. In cellular systems, downlink communication is defined as the data transmission from an AP to a UE [7]. The modulated intensities travel through an optical channel and are detected by a receiver photodiode (PD) [8]. An optical element is used to concentrate radiation onto a photodiode (PD) which then creates an electrical signal that is further amplified to recover the data. For the uplink IR links are usually preferred, as the wavelength separation between uplink and downlink allows simultaneous (full duplex) bi-directional communication with appropriate optical filtering. In addition, visible sources on the UE (usually a mobile device) are distracting [9]. The light radiation pattern of a visible light source with strong directionality confines most of the radiated optical power within the coverage area of an AP. Thus, CCI can primarily be expected at the cell boundaries, but due to overlapping light cones, CCI can be severe. Therefore, CCI poses major challenges to the downlink in Li-Fi attocell networks with dense spatial reuse [10].

## 3. Problem Statement

In optical attocells network, there are many Li-Fi access point that causes co-channel interference (CCI), and this decrease the efficiency of the system.

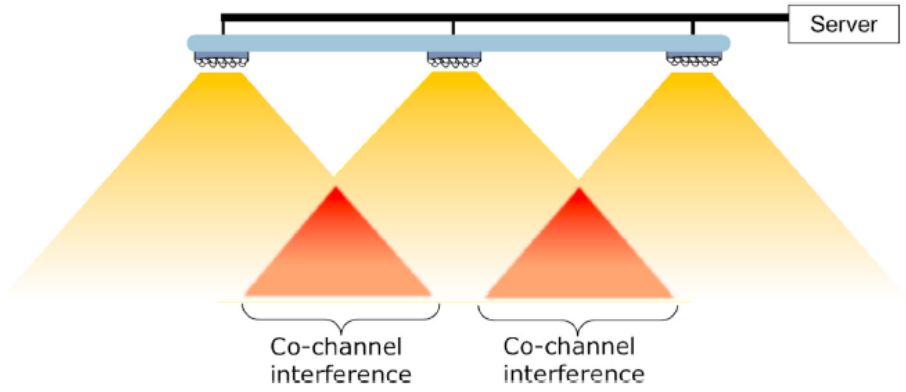

Figure1: Co-channel interference

## 4. Proposed Solution

Using interference management approaches in optical attocells network to minimize co-channel interference in the system. We will do simulation in room (L*W*H = 10*10*3) using 9 LEDs and measuring SINR before applying any approach and measuring SINR after applying approach and compare two results. We will use fractional frequency reuse approach. In this approach, each attocell (LI-FI access point) in same cluster has different set of frequencies at cells edges but they share same frequency at cells center.

## 5. Research aims and objectives

**Aim:**

- To manage interference in optical attocells network

**Objectives:**

- Designing complete optical wireless communication system

- Applying interference management approach to the system and compare it before applying approaches based on SINR.

## 6. Methodology

We used MATLAB software to send data through optical wireless network and compare result after applying interference management approach.

# 7. Time Table Schedule

Time schedule of project summarize in bellow table.

| | **Month 1** | | **Month 2** | | **Month 3** | | | **Month 4** | |
|---|---|---|---|---|---|---|---|---|---|
| | 20 days | 10 days | 15 days | 15 days | 10 days | 10 days | 10 days | 15 days | 15 days |
| **Collecting data** | 🟨 | | | | | | | | |
| **Chapter one** | | 🟨 | | | | | | | |
| **Chapter two: Background** | | | 🟨 | | | | | | |
| **Chapter three: Methodology** | | | | 🟨 | | | | | |
| **Chapter four: Simulation & results** | | | | | 🟨 | 🟨 | 🟨 | | |
| **Chapter five: Conclusion** | | | | | | | | 🟨 | |
| **Finalize work** | | | | | | | | | 🟨 |

# Chapter 2:

# Background

## 2.1 Introduction

We are seeing a growing demand for bandwidth in mobile communication, as the number of users is increasing significantly. The next-generation wireless communication systems therefore should be able to offer higher capacity to support various broadband wireless services. In access networks, the technologies currently in use include the copper and coaxial cables, wireless Internet access, broadband radio frequency (RF)/microwave and optical fiber. These technologies, in particular copper/coaxial cables and RF based, have limitations such as a congested spectrum, a lower data rate, an expensive licensing, security issues and a high cost of installation and accessibility to all. Optical wireless communications (OWC) is an age-long technology that entails the transmission of information-laden optical radiation through the free-space channel. OWC offers a flexible networking solution that delivers the truly broadband services. OWC or better still FSO communication is an age-old technology that entails the transmission of information-laden optical radiation through the air from one point to the other.

A number of light sources and photo-detectors could be used for OWC systems. The most commonly used light sources used are the incoherent sources light emitting diodes (LEDs) and coherent sources—laser diodes (LD) LEDs are mainly used for indoor applications. However, for short link (up to a kilometer) and moderate data rates, it is also possible to use LEDs in place of LDs Lasers, because of their highly directional beam profile, are mostly employed for outdoor applications. For detectors, both the PIN and the APD photo-detectors could readily be used. For optical communication systems, light sources adopted must have the appropriate wavelength, line width, and numerical aperture, high radiance with a small emitting surface area, a long life, a high reliability and a high modulation bandwidth. There are a number of light sources available but the most commonly used source in optical communications are LEDs and LDs, both of which rely on the electronic excitation of semiconductor materials for their operation [11]. The optical radiation of these luminescent devices, LED and LD, excludes any thermal radiation due to the temperature of the material, as is the case in incandescent devices. Both LD and LED light sources offer small size, low forward voltage and drive current, excellent brightness in the visible wavelengths and with the option of emission at a single wavelength or range of wavelengths. Which light source to choose mainly depends on the particular applications and their key features, including optical power versus current characteristics, speed and the beam profile. Both devices supply similar power (about 10–50 mW) [12]. LEDs/LDs can be fabricated to emit light across a wide range of wavelengths (colors) from the visible to the infrared (IR) parts of the electromagnetic spectrum. The visual range of the human eye only extends from 400 nm to 700 nm. All these wavelengths are of great interest in OWC. We will mention here only LEDs because it mainly used in indoor visible light communication.

The LED is a semiconductor p–n junction device that gives off spontaneous optical radiation when subjected to electronic excitation. The electronic excitation is achieved by applying a forward bias voltage across the p–n junction. This excitation energizes electrons within the material into an ‘excited’ state, which is unstable. When the energized electrons return to the stable state, they release energy in the process and this energy is given off in the form of photons. In the working of an LED, the electronic excitation causes electron(s) in the conduction band to spontaneously return to the valence band. This process is often referred to as the radiative recombination. It is so called because the electron returning to the valence band gives off its energy as photon as shown in Figure 2.1. In effect, the energy of the emitted photon is equal to the energy difference between the conduction and the valence bands, that is, the band-gap energy. Non-radiative recombination occurs when the falling electron only gives out phonons (heat) and not photons.

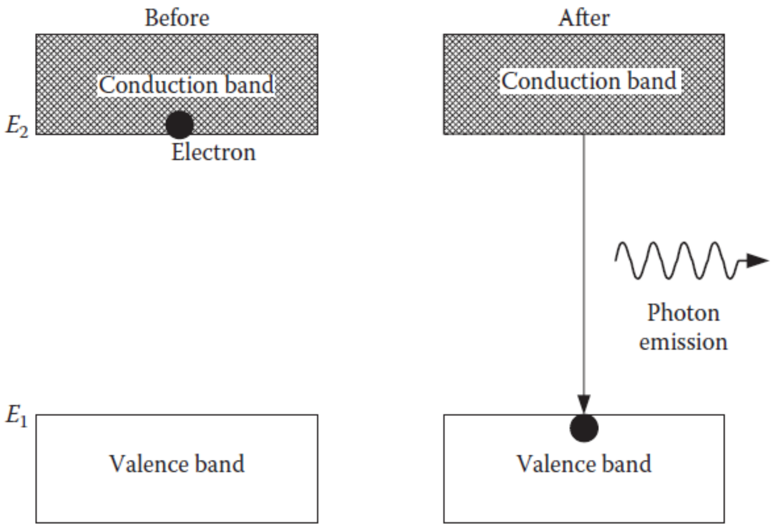

Figure 2.1: Spontaneous emission of photon

The basic structure of an LED is a p–n junction in which the extrinsic material types dictate the radiation wavelength(s). If the structure of the p–n junction is such that the semiconductor materials making up the junction are dissimilar, with different band-gap energies, a hetero-structure device is formed; otherwise, it is a homo-structure. There are various structures of an LED depending on the application and more importantly how the light generated at the p–n junction is radiated out of the device. To illustrate the basic structure of an LED.

The planar LED has the simplest structure and it is fabricated by either liquid- or vapour-phase epitaxial process over the whole surface of a GaAs substrate [13]. The planar LED structure shown in Figure 2.2 emits light from all surfaces and the emission is therefore termed as Lambertian. In Lambertian emission, the optical power radiated from a unit area into a unit solid angle (otherwise called the surface irradiance) is constant.

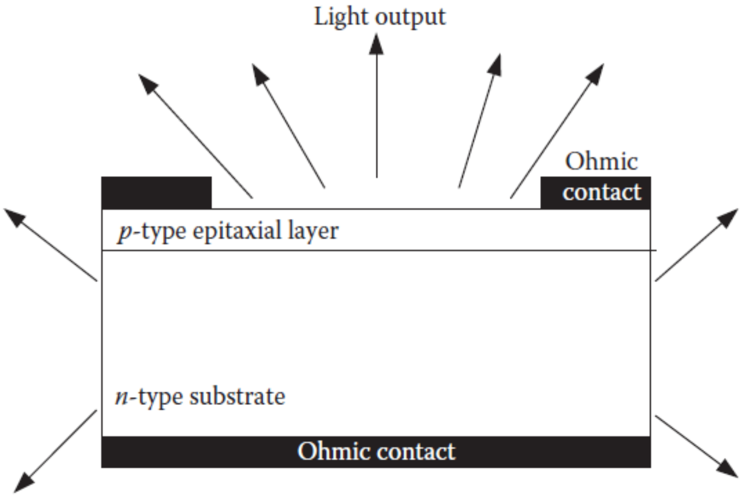

Figure 2.2: Planar LED structure

The structure of a typical dome LED is shown in Figure 2.3. In this structure, a hemisphere of n-type GaAs is formed around a diffused p-type region. The diameter of the dome is chosen to maximize the external quantum efficiency of the device. The geometry of the dome is such that it is much larger than the recombination area; this gives a greater effective emission area and thus reduces the radiance. Because the dome structure does not suffer as much internal reflection as the planar LED, it therefore has a higher external quantum efficiency [14].

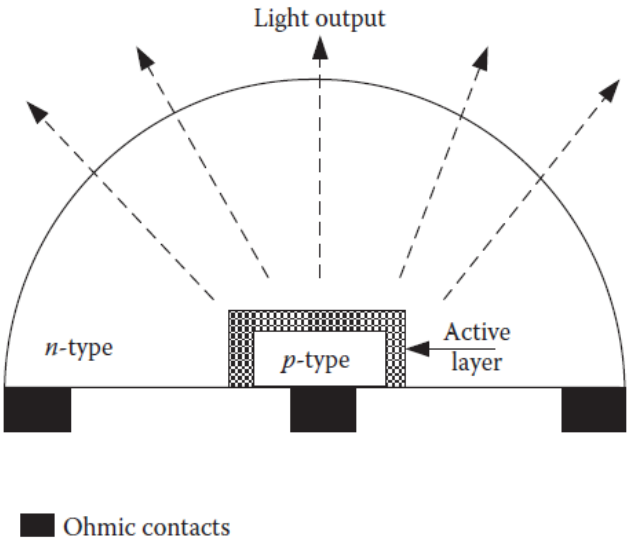

Figure 2.3: Dome LED structure

### Edge-emitting LED

As discussed above, the planar structure of an LED emits light in all directions but there are very many instances in optical communications when this is not desirable and the light will be preferred confined. The edge-emitting LED does just this by confining the light in a thin (50–100 µm) narrow stripe in the plane of the p–n junction [15]. This is illustrated in the figure of a double hetero-structure AlGaAs edge emitting LED depicted in Figure 2.4.

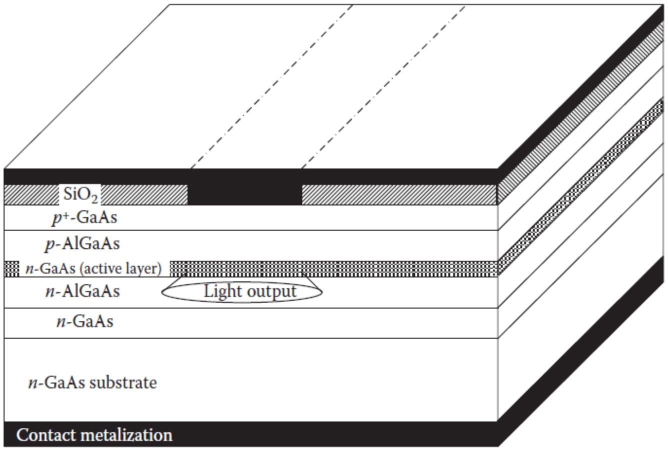

Figure 2.4: edge emitting LED structure

### Photo detector

The photo detector is a square-law optoelectronic transducer that generates an electrical signal, which is proportional to the square of the instantaneous optical field impinging on its surface. Thus, the signal generated by a photo-detector is always proportional to the instantaneous (received) optical power. Since the optical signal is generally weak, having travelled through the communication channel, the photo-detector must therefore meet stringent performance requirements such as high sensitivity within its operational range of wavelengths, a low noise level and an adequate bandwidth to accommodate the desired data rate.

The PIN photo-detector consists of p- and n-type semiconductor materials separated by a very lightly n doped intrinsic region. In normal operating conditions, a sufficiently large reverse bias voltage is applied across the device as. The reverse bias ensures that the intrinsic region is depleted of any charge carriers. For the device to convert an incident photon into an electron/electric current, the energy of the incoming photon must not be less than the band-gap energy of the semiconductor material. The incident photon uses its energy to excite an electron from the valence band to the conduction band, thereby generating a free electron– hole pair in the process. Normally, the incident light is concentrated on the depleted intrinsic region. The high electric field present in this depleted region causes the generated charge carriers to separate and be collected across the reverse biased junction. This gives rise to a current flow in an external circuit as shown in Figure 2.5, there is one electron flowing for every carrier pair generated.

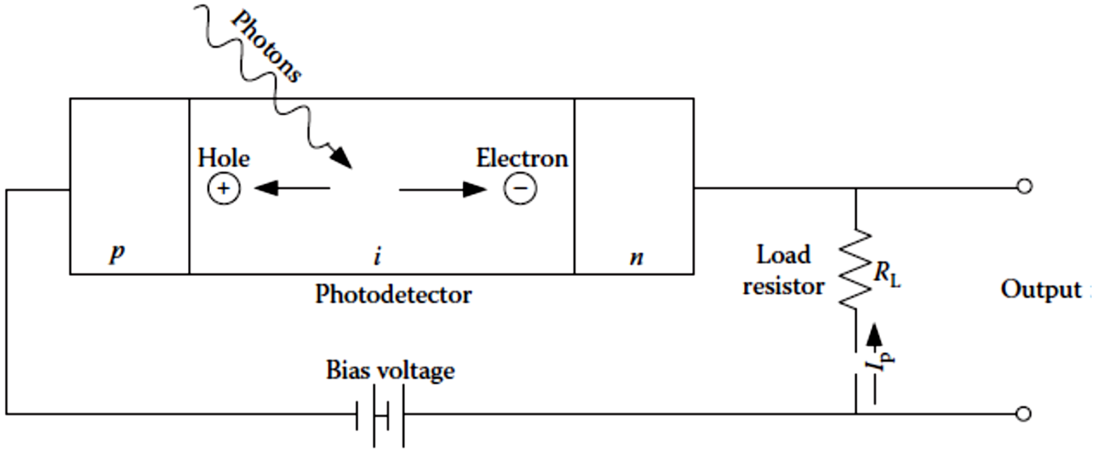

Figure 2.5: PIN photo-detector

Photo detection is the process of converting information-bearing optical radiation into its equivalent electrical signal with the aim of recovering the transmitted information. At the transmitter, the information can be encoded on the frequency, phase or the intensity of the radiation from an optical source. This encoded radiation is then transmitted to the receiver via the free-space channel or the optical fiber. The receiver front-end devices (telescope and optical filter) focus the filtered radiation onto the photo-detecting surface in the focal plane. There are two possible detection schemes widely adopted in optical communications: IM-DD and coherent schemes IM-DD is the simplest and widely used Coherent detection schemes offer the potential of restoring full information on optical carriers.

- **Direct Detection**

In intensity-modulation direct detection, only one degree of freedom, the intensity of the light emitted from an LD or an LED, is employed to convey the information. In direct detection scheme, a local oscillator is not used in the detection process and for this type of receiver to recover the encoded information, it is essential that the transmitted information be associated with the intensity variation of the transmitted field [16]. The block diagram of the direct detection receiver is illustrated in Figure 2.6.

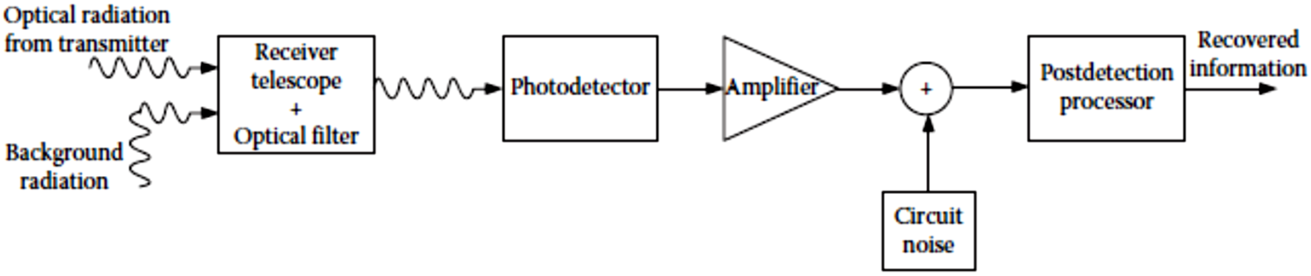

Figure 2.6: Block diagram of a direct detection optical receiver

- **Coherent Detection**

In coherent optical communications, the optical signal is modulated by the information using amplitude, phase and frequency of the light wave. At the receiving end, an optical local oscillator (OLO) is used and by combining the OLO with the received signal [17]. The frequency of the local oscillator does not have to be the same as that of the incoming information-bearing radiation.

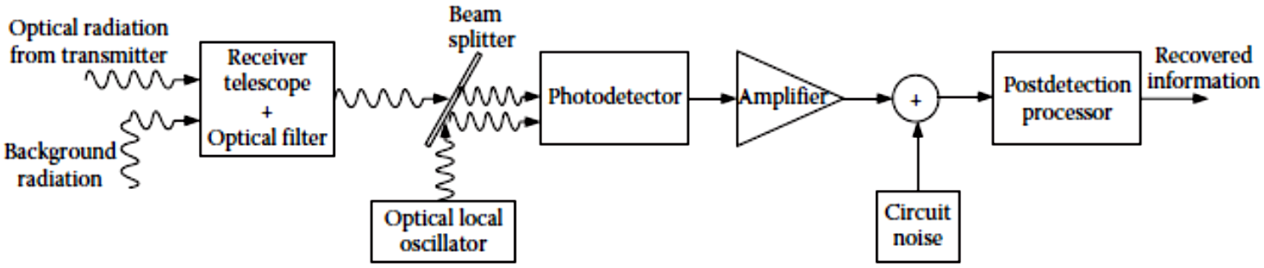

Figure 2.7: Block diagram of a coherent detection optical receiver

## 2.2 Li-Fi Attocell Networks

Due to the increasing demand for wireless data communication, the available radio spectrum below 10 GHz (cm wave communication) has become insufficient. The wireless communication industry has responded to this challenge by considering the radio spectrum above 10 GHz (mm-wave communication). However, the higher frequencies, f, mean that the path loss, L, increases according to the Friis free space equation (L ∝ f2 ). In addition, blockages and shadowing in terrestrial communication are more difficult to overcome at higher frequencies. As a consequence, systems must be designed to enhance the probability of line-of-sight (LoS), typically by using beamforming techniques and by using very small cells (about 50 m in radius). The need for small cells is not an issue from a system capacity perspective. This is because reducing cell sizes has without doubt been the major contributor for enhanced system performance in current cellular communications. This means, contrary to the general understanding, using higher frequencies for terrestrial communication has become a practical option. However, one disadvantage is that the challenge for providing a supporting infrastructure forever, smaller cells becomes significant. One such example is the provision of a sophisticated backhaul infrastructure. Light-fidelity (LiFi) [18], [19] is a continuation of the trend to move to higher frequencies in the electromagnetic spectrum. Specifically, LiFi could be classified as nm-wave communication. LiFi uses light emitting diodes (LEDs) for high-speed wireless communication. Given that there is a widespread deployment of LED lighting in homes, offices and streetlights because of the energy-efficiency of LEDs, there is an added benefit for LiFi cellular deployment in that it can build on existing lighting infrastructures. Moreover, the cell sizes can be reduced further compared with mm-wave communication leading to the concept of LiFi attocells [20]. The optical access point (AP) in Li-Fi is called attocell. LiFi attocells are an additional network layer within the existing heterogeneous wireless networks, and they have zero interference from, and add zero interference to, the radio frequency (RF) counterparts such as femtocell networks. A LiFi attocell network uses the lighting system to provide fully networked wireless connectivity.

### 2.2.1 Concept of work

LiFi technology consist of LED Lamp as the media transmission and photo detector as a receiver of transmitted data. Lamp driver is needed to make LED working properly. While amplification and processing are responsible to manage the signal that comes from the photo detector as shown in figure 10.

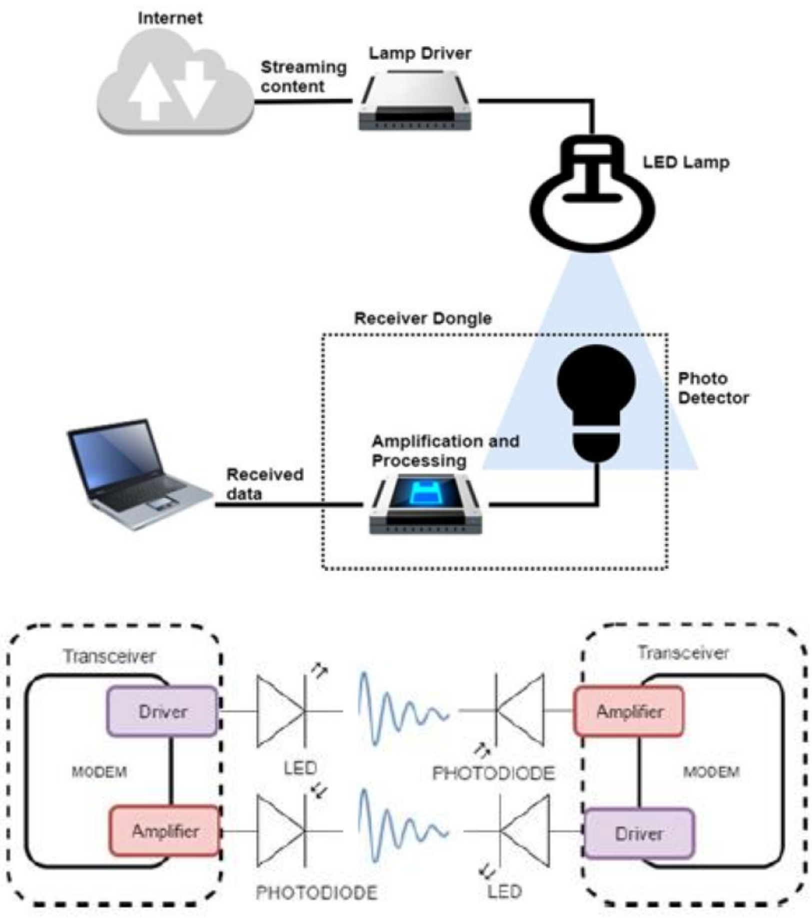

Figure 2.8: Basic Concept Diagram LiFi

Basic concept for working principle in LiFi Technology are pointing into transceiver and Light as a media transmission. Figure 2.8 is a basic concept block diagram for LiFi. This basic concept indicates as a duplex communication. Transceiver is a block that act as a transmitter and receiver at the same time. This transceiver consists of LED to transmit the light and photodiode to receive the light. Amplifier is embedded to strength the power of light received from the photodiode. The modem is used to modulate and demodulate the signal. The signal that comes from the photodiode is analog and it converts into digital in the modem. While the signal that ready to transmit, the digital signal convert into analog signal in the modem and sent by LED. The driver before the LED operates to drive the current of the LED in order to get the flickering. The flickering is functioning the LED for data transmission, if LED is ON then it transmits digital ‘1’ and if OFF, it transmits digital ‘0’[21][22].

### 2.2.2 Propagation model

**LiFi propagation model summarized in figure 2.9.**

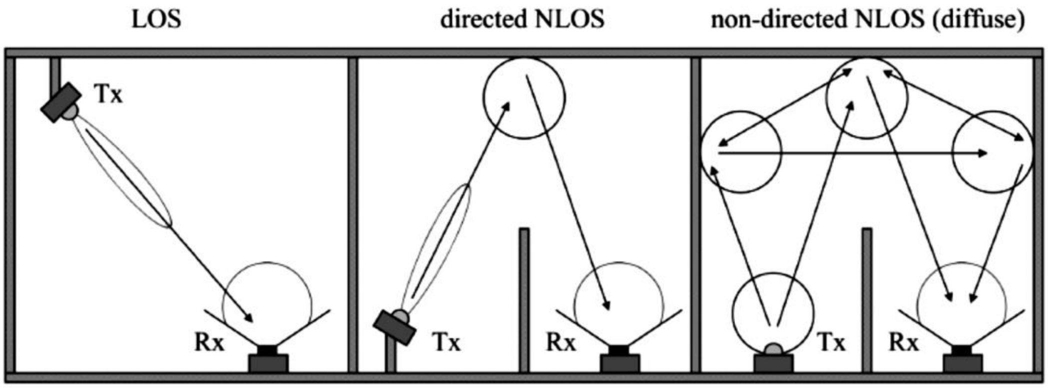

Figure 2.9: LiFi propagation mode

### 2.2.3 Advantages of LiFi:

<u>Advantages of Li-Fi technology include:</u>

- ✓ **<u>Efficiency</u>**: Energy consumption can be minimized with the use of LED illumination, which are already available in the home, offices and Mall etc. for lighting purpose. Hence the transmission of data requiring negligible additional power, which makes it very efficient in terms of costs as well as energy.
- ✓ **<u>High speed</u>**: Combination of low interference, high bandwidths and high-intensity output, help Li-Fi provide high data rates i.e. 1 Gbps or even beyond.
- ✓ **<u>Availability</u>**: Availability is not an issue as light sources are present everywhere.

Wherever there is a light source, there can be Internet. Light bulbs are present everywhere – in homes, offices, shops, malls and even planes, which can be used as a medium for the data transmission.

- ✓ **<u>Cheaper</u>**: Li-Fi not only requires fewer components for its working, but also uses only a negligible additional power for the data transmission.
- ✓ **<u>Security</u>**: One main advantage of Li-Fi is security. Since light cannot pass through opaque structures, Li-Fi internet is available only to the users within a confined area and cannot be intercepted and misused, outside the area under operation as shown in figure 2.10.

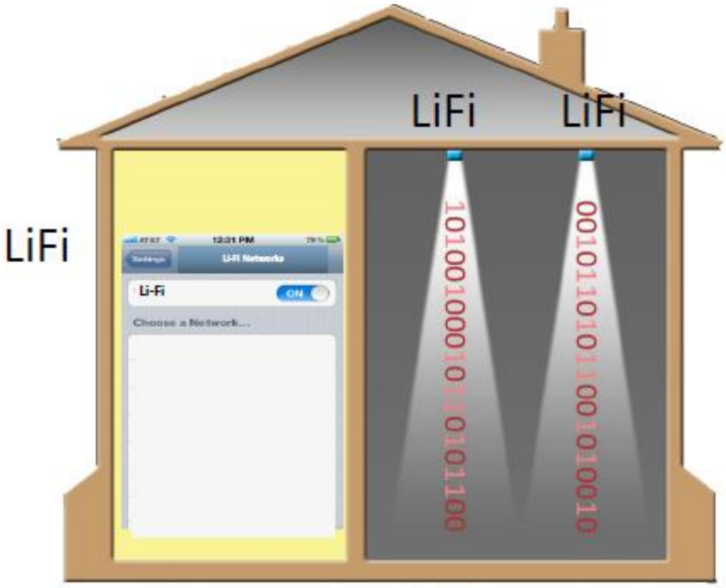

Figure 2.10: LiFi security

- ✓ **<u>Li-Fi technology has a great scope in future</u>**: The extensive growth in the use of LEDs for illumination indeed provides the opportunity to integrate the technology into a plethora of environments and applications.

### 2.2.4 Application of Li-Fi:

There are numerous applications of Li-Fi technology, from public Internet access through existing lighting (LED) to auto-piloted cars that communicate through their headlights (LED based). Applications of Li-Fi can extend in areas where the Wi-Fi technology lacks its presence like aircrafts and hospitals (operation theatres), power plants and various other areas, where electromagnetic (Radio) interference is of great concern for safety and security of equipment and people. Since Li-Fi uses just the light, it can be used safely in such locations or areas. In future with the Li-Fi enhancement all the street lamps can be transformed to Li-Fi connecting points to transfer data. As a result of it, it will be possible to access internet at any public place and street.

**Some of the future applications of Li-Fi could be as follows:**

- ✓ ***Education systems:*** Li-Fi is the latest technology that can provide fastest speed for Internet access. Therefore, it can augment/replace Wi-Fi at educational institutions and at companies so that the people there can make use of Li-Fi with the high speed.
- ✓ ***Medical Applications:*** Operation theatres (OTs) do not allow Wi-Fi due to radiation concerns. Usage of Wi-Fi at hospitals interferes/blocks the signals for monitoring equipment. Therefore, it may have hazardous effect to the patient's health, due to improper working of medical apparatus. To overcome this and to make OT tech savvy Li-Fi can be used to access internet and to control medical equipment. This will be beneficial for conducting robotic surgeries and other automated procedures.
- ✓ ***Cheaper Internet in Aircrafts:*** The passengers travelling in aircrafts get access to low speed Internet that too at a very high price. In addition, Wi-Fi is not used because it may interfere with the navigational systems of the pilots. In aircrafts, Li-Fi can be used for data transmission. Li-Fi can easily provide high speed Internet via every light source such as overhead reading bulb, etc. present inside the airplane.
- ✓ ***Underwater applications:*** Underwater ROVs (Remotely Operated Vehicles) operate from large cables that supply their power and allow them to receive signals from their pilots above. But the tether used in ROVs is not long enough to allow them to explore larger areas. If their wires were replaced with light — say from a submerged, high powered lamp then they would be much freer to explore. They could also use their headlamps to communicate with each other, processing data autonomously and sending their findings periodically back to the surface.

Li-Fi can even work underwater where Wi-Fi fails completely, thereby throwing open endless opportunities for military underwater operations.

- ✓ ***Disaster management**:* Li-Fi can be used as a powerful means of communication in times of disaster such as earthquake or hurricanes. The average people may not know the protocols during such disasters. Subway stations and tunnels, common dead zones for most emergency communications, pose no obstruction for Li-Fi.
- ✓ ***Applications in sensitive areas**:* Power plants need fast, inter-connected data systems so that demand, grid integrity and core temperature (in case of nuclear power plants) can be monitored. The Radio communication interference is considered to be bad for such sensitive areas surrounding these power plants. Li-Fi can offer safe, abundant connectivity for all areas of these sensitive locations. Also, the pressure on a power plant 's own reserves (power consumption for Radio communications deployments) will be lessened.
- ✓ ***Traffic management**:* In traffic signals Li-Fi can be used to communicate with passing vehicles (through the LED lights of the cars etc) which can help in managing the traffic in a better manner resulting into smooth flow of traffic and reduction in accident numbers. Also, LED car lights can alert drivers when other vehicles are too close.
- ✓ ***Mobile Connectivity**:* Mobiles, laptops, tablets, and other smart phones can easily connect with each other. The short-range network of Li-Fi can yield exceptionally high data rates and higher security.
- ✓ ***Replacement for other technologies**:* Li-Fi doesn't work using radio waves. So, it can be easily used in the places where Bluetooth, infrared, Wi-Fi, etc. are banned.

# Chapter 3:

# Methodology

## 3.1 Interference mitigation

In an optical attocell network, inter-cell interference (ICI) is inevitable since APs are placed close to each other. This can significantly compromise the system performance. In order to mitigate ICI, Fractional frequency reuse (FFR) used in this study.

### 3.1.1 Fractional frequency reuse (FFR)

The fractional frequency reuse (FFR) technique is a cost effective approach to achieve interference mitigation in a cellular system. It maintains the balance between the average spectral efficiency and cell edge user performance with low system complexity [24]. Over the past few years, the FFR technique has been studied for applications in RF cellular networks. In FFR, all cell centers in the system employ a frequency reuse of one, the cell-edges in a cluster still employ classical frequency reuse as shown in Figure 3.1. The available spectrum is divided into two sub-bands: the first one is permanently used in cell-center zones, while the second sub-band is used according to frequency reuse-N model in the cell-edge zones. SINR for cell edge UEs is improved [25], since they operate on different spectrum. One disadvantage of FFR is that a portion of the available spectrum is permanently unused in each cell. We can used an optical AP using two LED sources with different beam-width to achieve this scenario.

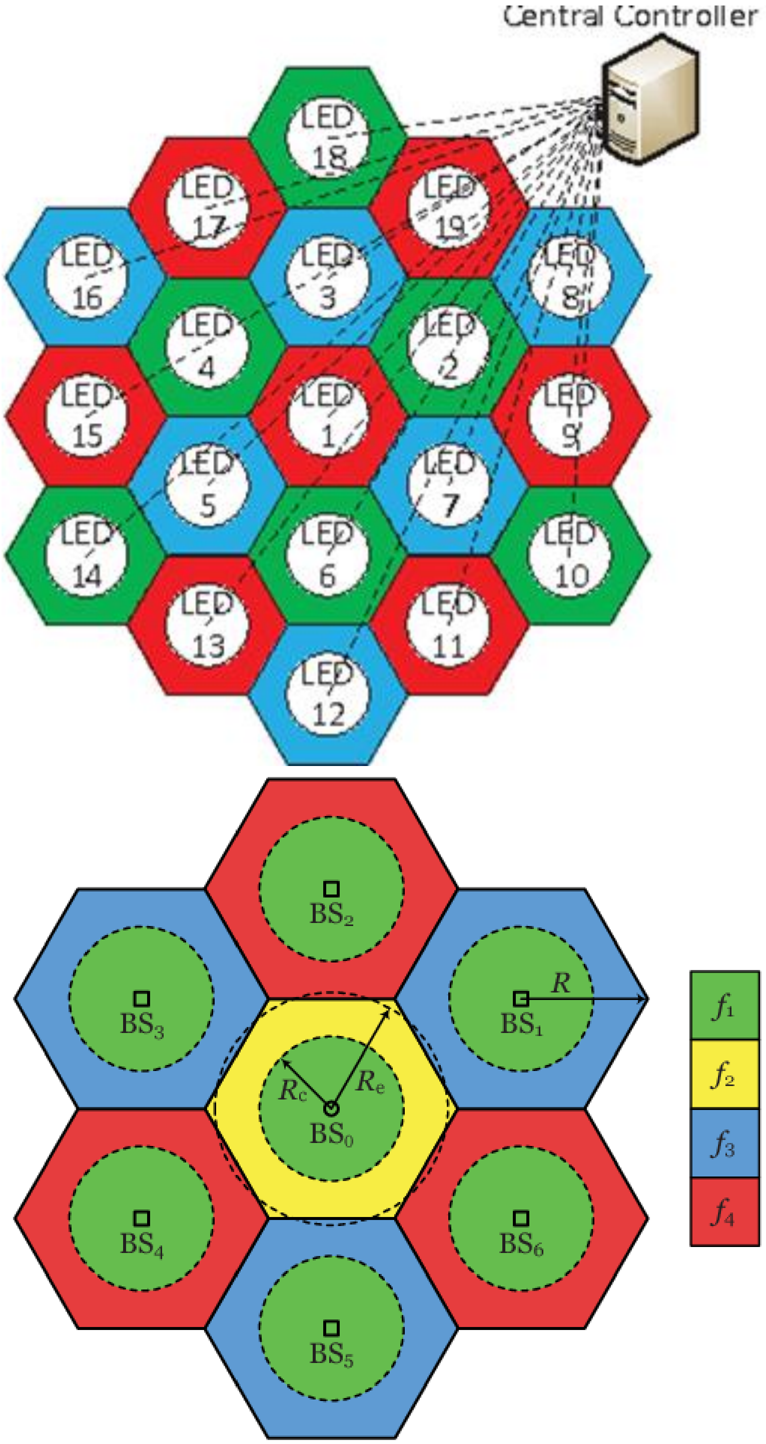

Figure 3.1: Deployment of fractional frequency reuse in an optical system

There are two typical FFR schemes: ii) strict fractional frequency reuse (sFFR) and ii) soft frequency reuse (SFR) [26]. sFFR divides the whole frequency band into multiple protected sub-bands and one common sub-band. Cell center users in each cell experience minor interference from nearby BS, so the common sub-band is assigned to them. Since cell edge users receive higher interference power, protected sub-bands are assigned to the cell edge users, and the sub-bands are arranged such that there is a minimum spatial reuse distance between them. The SFR applies an even shorter reuse distance compared to the sFFR scheme. In addition to the use of a different sub-band for cell edge users in each adjacent cell, the SFR scheme allows the center users to take the sub-bands that are assigned to cell edge users in adjacent cells. To protect the cell edge users, the transmission power for cell edge users is typically higher than that for the cell center users.

## 3.2 System model

It is assumed that all the optical AP transmit with an equal power P in one room. The mobile user is served one closest AP. The path loss exponent is given by (α), and the noise power is given by ($\boldsymbol{\sigma}^2$). We assume that the small-scale fading between any interfering AP and the typical mobile in consideration, denoted by gz, The set of interfering AP is Z, where AP that use the same sub-band as user y. We denote the distance between the interfering AP and the mobile node by $Rz$.

The associated Signal to Interference plus Noise Ratio (SINR) is given in equation 3.1

$$\mathrm{SINR} = \frac{\mathrm{P g_y r^{-\alpha}}}{\sigma^2 + \mathrm{PI_r}} \tag{3.1}$$

where for an interfering AP set Z is given as equation 3.2

$$\mathrm{I_r} = \sum_{z \in Z} g_z R_z a^{-\alpha} \tag{3.2}$$

In the above expression, we have assumed that the nearest AP to the mobile is at a distance r, which is a random variable.

Where,

* $g$z is statistical distribution and is fading value or value for fading, shadowing and any other desired random effect with mean (1/μ). When g is also exponential then simpler expression will result.

* $r$ is distance from mobile to its base station.

* $R$ is distance from the mobile to other AP on same reuse assignment.

* $\alpha$ is path loss coefficient.

* σ2 is noise power.

After the SINR estimation, we proceed with the throughput calculation. The spectral efficiency in bps/Hz of users (SE) can be calculated by the Shannon's formula:

$$SE = \ log_2(1 + SINR\,) \tag{3.3}$$

Moreover, the throughput in bps of the users expressed as follows:

$$T \ = \sum_{n} \Delta f \ .SE_n \tag{3.4}$$

Where:

$\Delta f$ is the available bandwidth for each subcarrier

The system simulated in MATLAB and mathematical expression basis is reference. The environment assumed is static, inside room, Hexagonal geometry with symmetric alignment of APs. This makes the simulation a bit simpler. Here in this thesis we are doing comparative analysis thus, this assumption also makes good sense for analysis though we are not assuming real time scenario.

In addition, we can calculate bit error rate (BER) after converting SINR from decibel to power value.

$$\mathbf{SINR_{dB} = 10log_{10} (SINR)} \qquad \mathbf{(3.5)}$$

$$\mathbf{BER= 1/(2*SINR)} \qquad \mathbf{(3.6)}$$

***Parameters used:***

Parameters used in this study summarize in table 1:

| Parameter | Value |
|---|---|
| AP power | 40 dBm |
| Path loss exponent (α) | 1.6 (in building LOS) |
| Room Size | 10*10 $m^2$ |

Table 3.1 : Simulation parameters

Cell radius of 5m is taken during observation. The environment considered is totally static. Simulation is carried out for number of times to calculate SINR and rate for user equipment and its mean value is taken during final plot so that best result is obtained.

# Chapter 4:

# Results and Discussion

## 4.1 Simulation

This chapter discusses the results of the simulation after executing the system model which described in the previous chapter with an interactive Graphical User Interface (GUI) to manipulate them. Also, analysis and comment on these results have been described.

## 4.2 Map of system model

Figure 4.1 shows overall system design (LEDs potions, users' distribution and way of applying fraction frequency reuse method).

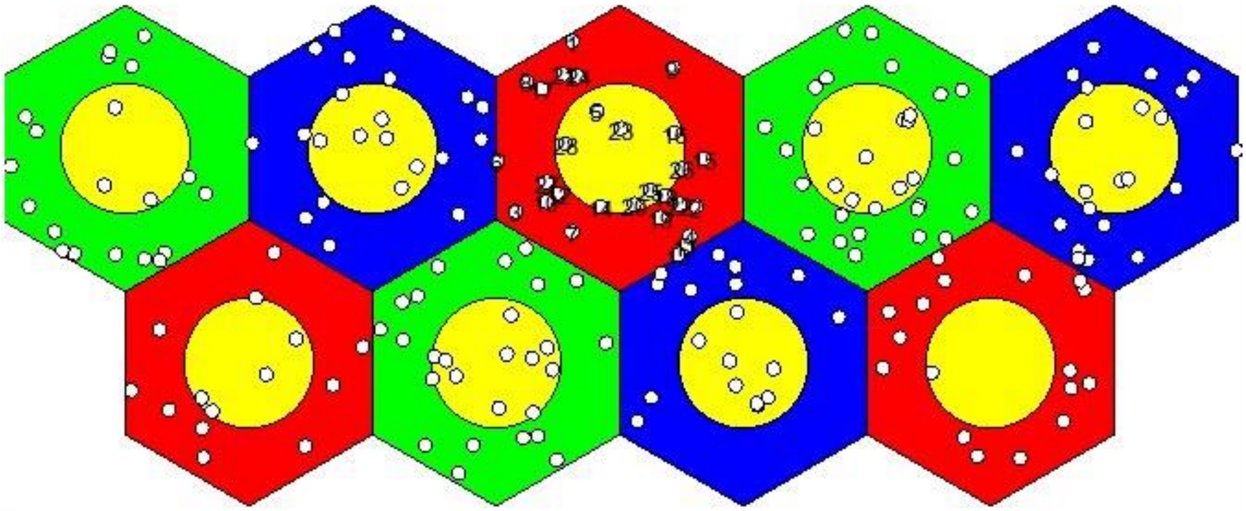

Figure 4.1: System design

Where

f1= 🟨 f2= 🟥 f3= 🟩 f4= 🟦

All cells shared same frequency at the center of cell (f1), and frequency reuse method apply only at cells edges by using rest of frequencies (f2, f3 and f4).

In FFR system, the serving AP needs to know whether the user is in the cell center or is in the cell edge. This can be simply realized by determining the average signal strength of the downlink signal. If the signal power is higher than a threshold, this particular user is categorized as a cell center user. Otherwise, the user is categorized as a cell edge user. It is assumed there is no movement of users within the period between two adjacent pilot signal transmissions.

## 4.3 Signal to Interference Noise Ratio (SINR)

Fractional frequency reuse (FFR) method used as solution to solve ICI problem in attocells network.

Simulation done before and after applying method based on parameters shown on table 3.1.

Figure 4.2 shows SINR before applying FFR method. As figure shows, SINR is -13 dB.

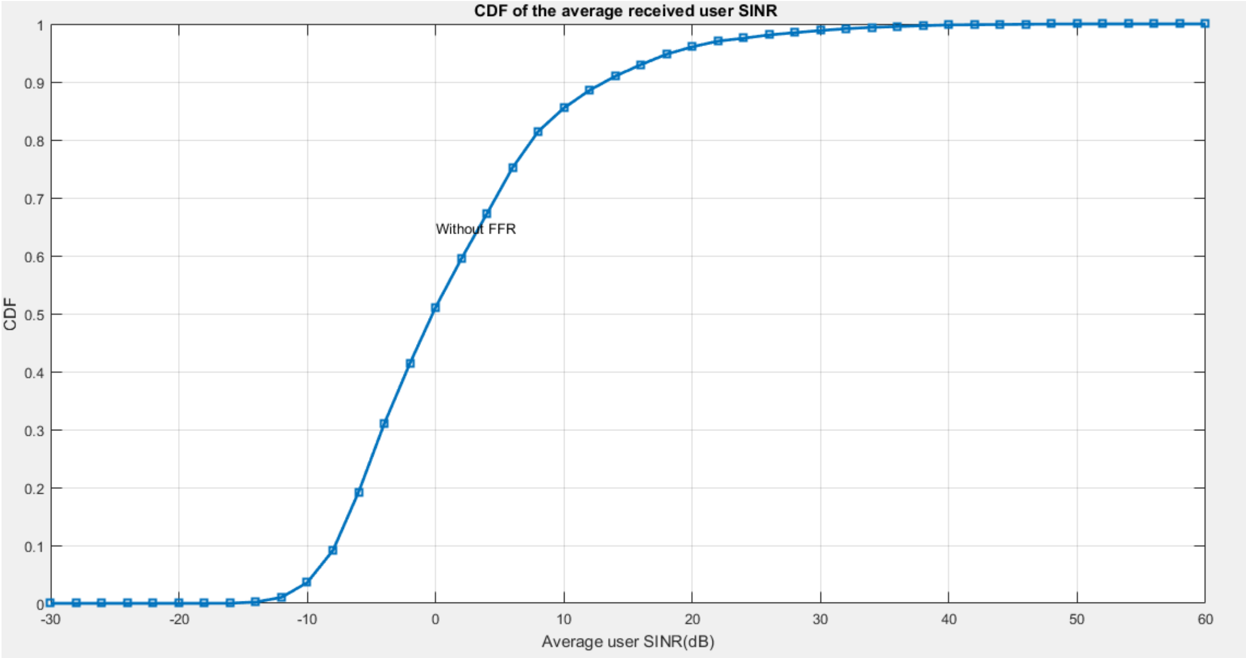

Figure 4.2: SINR results before applying FFR

By applying FFR method SINR increase from -13 dB to 3 dB as shown in figure 4.3, SINR enhanced by almost 8 dB.

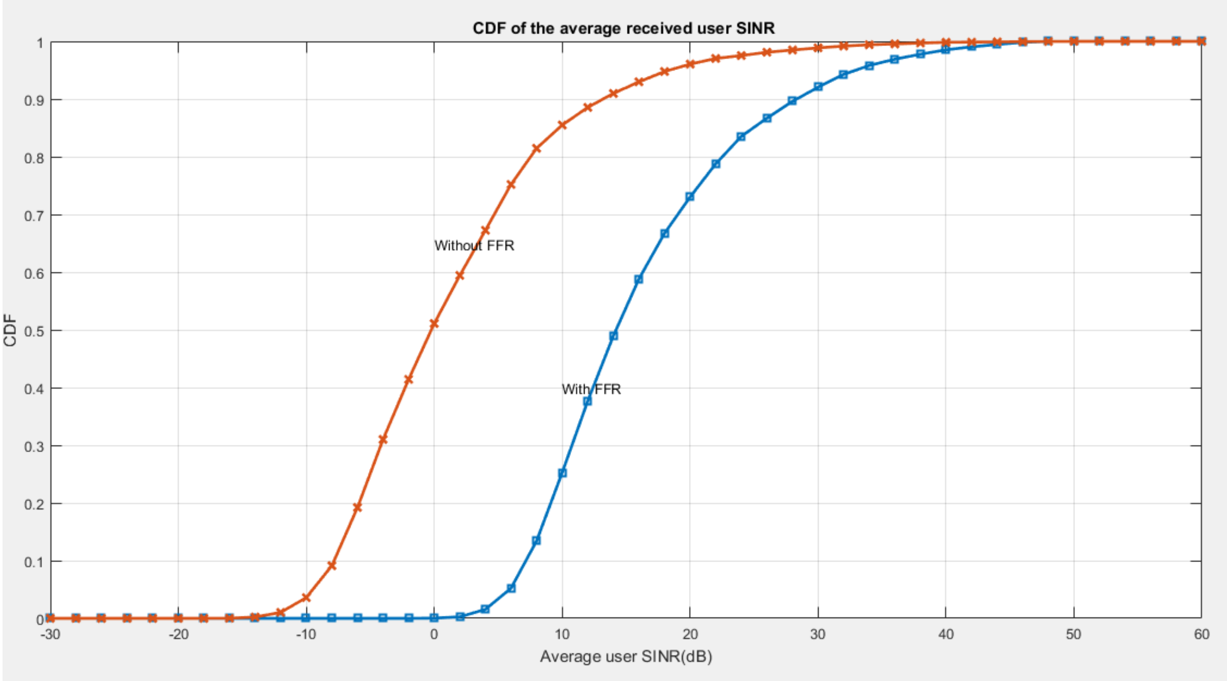

Figure 4.3: SINR results after applying FFR

FFR method gives better SINR to the users and reduce ICI problem

## 4.4 Throughput and distance

Based on table 3.1, equation 3.3 & 3.4, we could found relation between user's throughput and distance.

### 4.4.1 User moving away from center of cell

When user go far away from AP, throughput decreasing. Figure 4.4 shows relation between throughput and distance, when distance increase throughput decrese.

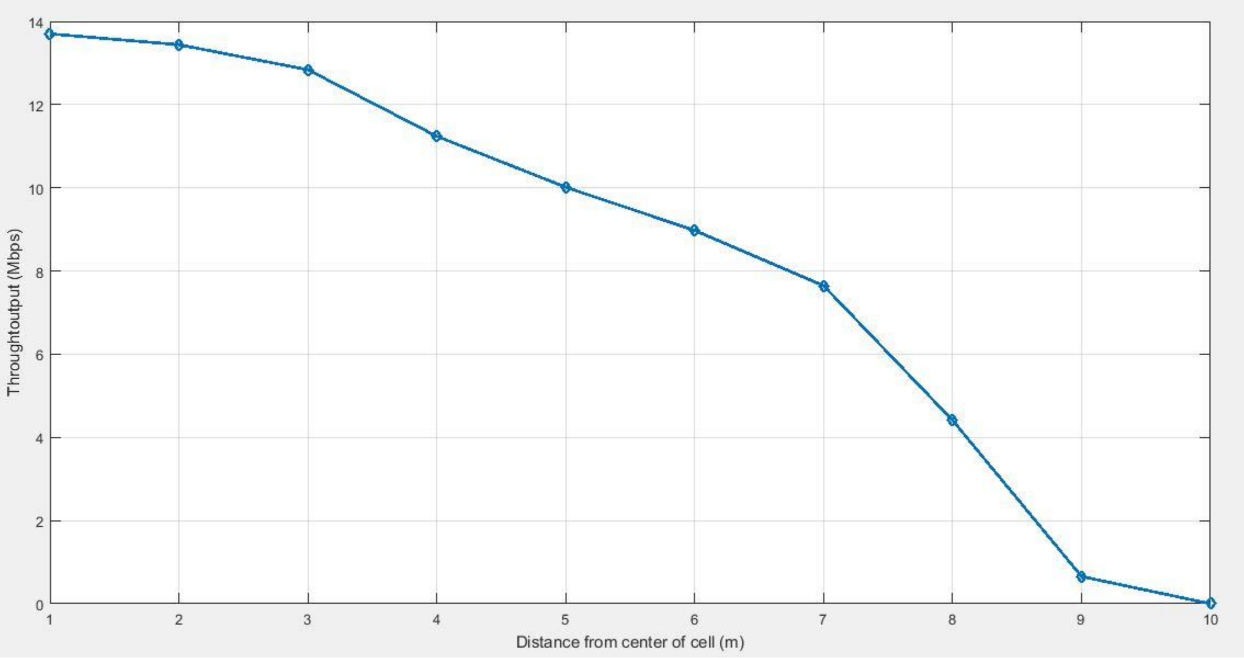

Figure 4.4: Throughput vs distance

Table 4.1 show values of throughput when user go away from AP.

| Distance(m) | Throughput (Mbps) |
|---|---|
| **1** | 13.9 |
| **2** | 13.5 |
| **3** | 12.5 |

| | |
|---|---|
| **4** | 11.5 |
| **5** | 10.2 |
| **6** | 8.8 |
| **7** | 7.5 |
| **8** | 4.2 |
| **9** | 0.7 |
| **10** | 0 |

Table 4.1: Throughput vs distance

### 4.4.2 User moving away from edge of cell toward cell’s center

When user go far away from cell’s edge toward cell’s center, throughput increasing. Figure 4.5 shows relation between throughput and distance, when distance increase throughput increase because user go toward AP.

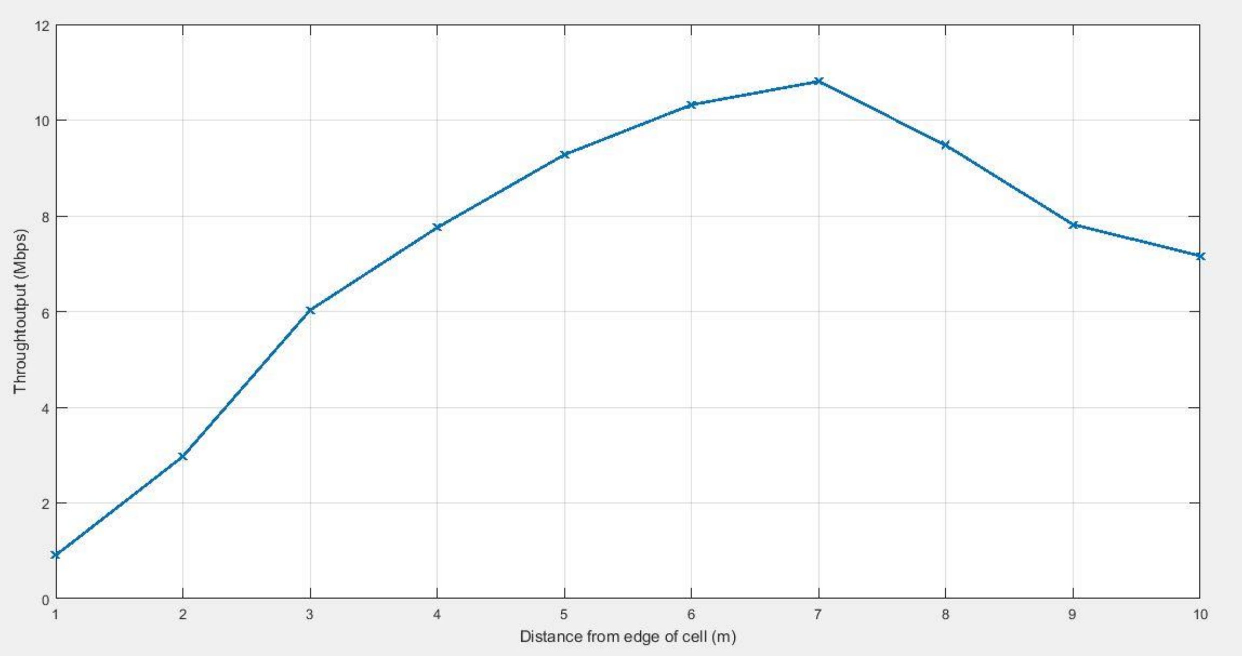

Figure 4.5: Throughput vs distance

Table 4.2 show values of throughput when user go away from cell’s edge.

| Distance(m) | Throughput (Mbps) |
|---|---|
| **1** | 0.7 |
| **2** | 3.4 |
| **3** | 5.8 |
| **4** | 7.8 |
| **5** | 8.9 |

| | |
|---|---|
| **6** | 10.3 |
| **7** | 10.8 |
| **8** | 9.5 |
| **9** | 7.4 |
| **10** | 7 |

### 4.4.3 Total throughput

we could calculate total throughput at each distance using following equation:

$$\text{Total throughput} = \sum_x^{10} \text{throughput at center of cell} + \sum_x^{10} \text{throughput at edge of cell}$$

Figure 4.6 shows total throughput at each distance

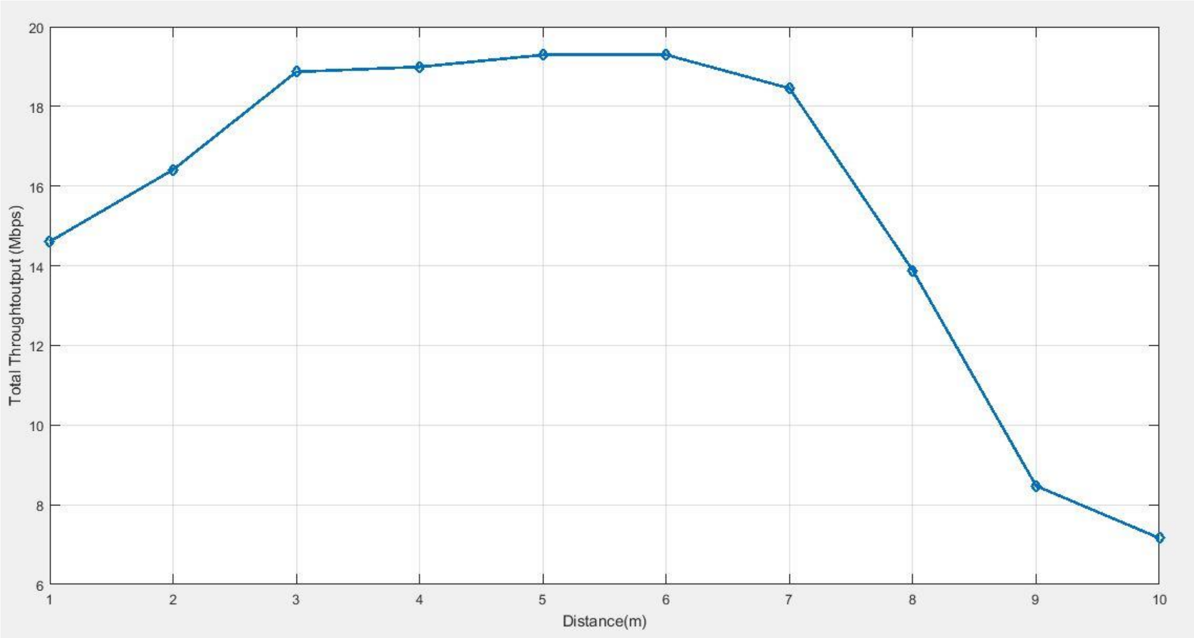

Figure 4.6: Total throughput

Table 4.3 show values of total throughput at each distance.

| Distance(m) | Throughput (Mbps) |
|---|---|
| **1** | 14.6 |
| **2** | 16.9 |
| **3** | 18.3 |
| **4** | 19.3 |
| **5** | 19.1 |
| **6** | 19.1 |
| **7** | 18.3 |
| **8** | 13.7 |
| **9** | 8.1 |
| **10** | 7 |

### 4.4.4 Average throughput

We could calculate average throughput by dividing total throughput to number of users, if we assume that we have 8 users in room, so average throughput =

Total throughput / 8 users.

Figure 4.7 shows average throughput.

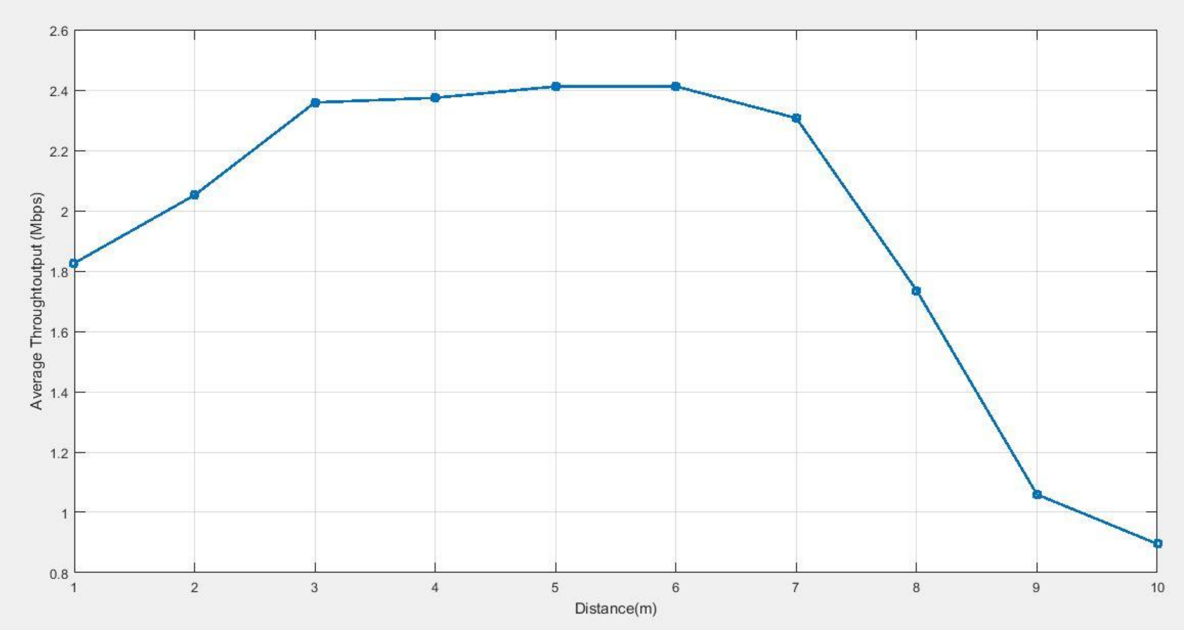

Figure 4.7: Average throughput

Table 4.4 show values of average throughput at each distance.

| Distance(m) | Throughput (Mbps) |
|---|---|
| **1** | 1.84 |
| **2** | 2.06 |
| **3** | 2.27 |
| **4** | 2.39 |
| **5** | 2.43 |
| **6** | 2.42 |
| **7** | 2.27 |

| | |
|---|---|
| **8** | 1.69 |
| **9** | 1.09 |
| **10** | 0.9 |

## 4.5 Bit error rate (BER)

By using equation 3.5 & 3.6 we can calculate BER. Figure 4.8 shows BER results. We can notice that BER of system decrease from 1 to 0.0001 errors.

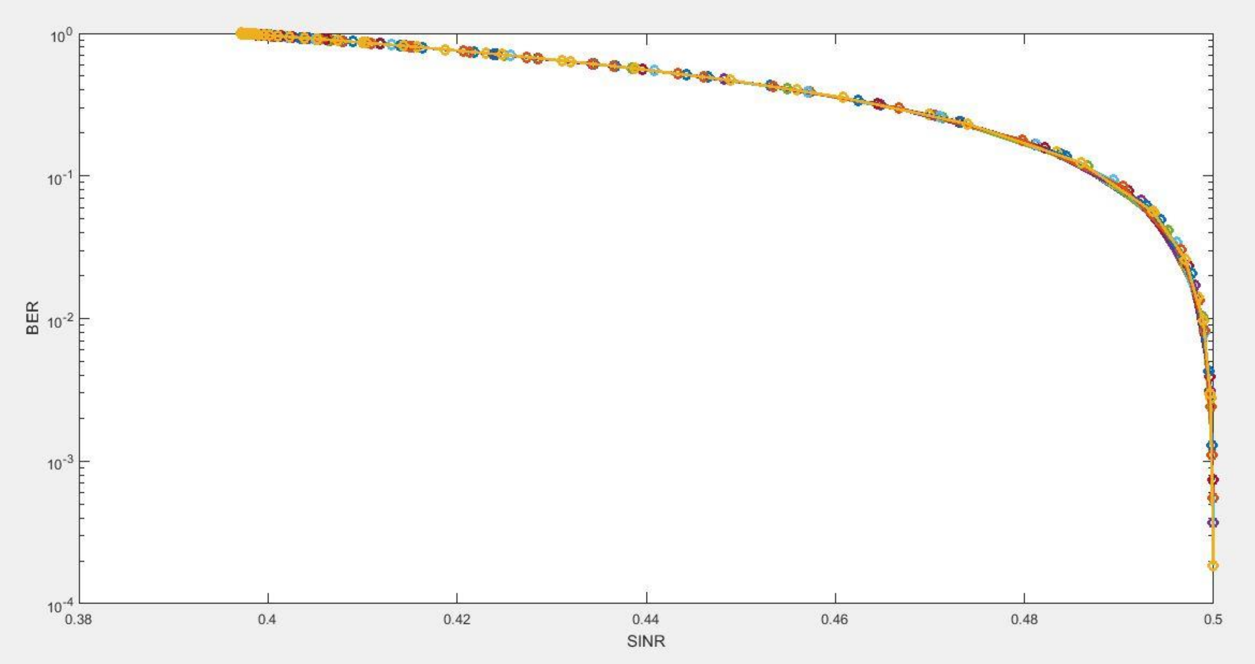

Figure 4.8: BER vs SINR

# Chapter 5:

## Conclusions and Recommendations

## 5.1 Conclusions

This study give brief review about Li-Fi technology, its application and ICI problem. FFR method introduced as a solution to solve ICI problem.

By applying this method on MATLAB, SINR increase and give better performance to the users and decrease ICI.

## 5.2 Recommendations

Recommendations could be summarize in the following points:

- ✓ Prompting researchers to do deep research in Li-Fi technology.
- ✓ Prompting researchers to do deep research in Li-Fi security and privacy.
- ✓ Searching to find method or enhance existing method that solve ICI problem.
- ✓ Using Li-Fi as a key to IoT.

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# Appendix

## MATLAB code for SINR and throughput vs distance

```
clear;
distance_now=0;
distance_end=10;
throughtoutput=0;
systemband=20;%MHz
bs_power=40;%dBm
ru_num=27;
slot_num=20;
subcarrier=48;
r_cell=0.01;%km
sigma=1.6;
unaccess_num=0;
centerratio=0.1;
centerratio2=0.1;
powerratio=0.1;
yy=zeros(46,10);
ber=zeros(46,10);
capa=zeros(46,10);
m=1;
mm=1;
mm1=1;
while centerratio<=1
    distance_now=0;
    total_output=0;
    center_output=0;
    edge_output=0;

    while distance_now<distance_end
        i=1;
        ru_center=0;
        ru_edge=0;
        while i<=ru_num*slot_num

        r_user =sqrt(rand(1,1));
        user_angle = rand(1,1)*2*pi/3+pi/6;
        userposi = [r_user*cos(user_angle),r_user*sin(user_angle)];
        if r_user < (35/1000)
            continue;
        end
        if user_angle>=pi/6 && user_angle<pi/3 && r_user >
sqrt(3)/(2*cos(user_angle - pi/6))
            continue;
        elseif user_angle>=pi/3 && user_angle<2*pi/3 && r_user >
sqrt(3)/(2*cos(user_angle - pi/2))
            continue;
        elseif user_angle>=2*pi/3 && user_angle<5*pi/6 && r_user >
sqrt(3)/(2*cos(user_angle - 5*pi/6))
            continue;
        end
            if r_user<centerratio
                ru_center=ru_center+1;
            else
```

```
                ru_edge=ru_edge+1;
            end
            [baseinfo] = basest;
            bstranspower = bs_power -30-10*log10(27); %µ¥خ»db
            bstranspower_w=10^(bstranspower/10);

power_center_w=bstranspower_w*powerratio/(1/3+2/3*powerratio);
            power_edge_w=bstranspower_w/(1/3+2/3*powerratio);
            power_center=10*log10(power_center_w);
            power_edge=10*log10(power_edge_w);

            interference=zeros(1,19);%db
            sigle_interference=0;%w
            total_interference=0;%w
            A = 13;
            noise = 9 - 174 + 10*log10(systemband/27*10^3)-30;%db
            noise = 10^(noise/10);%w

center_interfer_bspower=[power_center,power_center,power_edge,power_cente
r,power_edge,power_center,power_edge,power_center,power_edge,power_center
,power_center,power_center,power_edge,power_center,power_center,power_cen
ter,power_edge,power_center,power_center];

edge_interfer_bspower=[power_edge,power_center,power_center,power_center,
power_center,power_center,power_center,power_center,power_edge,power_cent
er,power_edge,power_center,power_edge,power_center,power_edge,power_cente
r,power_edge,power_center,power_edge];
            for cell=1:19
                userposi_to_allbase=userposi-baseinfo(cell,:);
                pl = dist(userposi_to_allbase(1),userposi_to_allbase(2));
                if r_user<centerratio
                    interference(cell)=center_interfer_bspower(cell)+A-
pl-shadow(sigma);
                else
                    interference(cell)=edge_interfer_bspower(cell)+A-pl-
shadow(sigma);
                end
                if cell==1
                    continue;
                end
                sigle_interference=10^(interference(cell)/10);
                total_interference=total_interference+sigle_interference;
            end%end for
             l=0;
            SINR=interference(1)-10*log10(noise+total_interference);
            if SINR <-3.14
                rb_output=0;
                unaccess_num=unaccess_num+1;
            elseif SINR>=-3.14 &&SINR<-0.73
                rb_output=48*2*(1/12)/5;   %qpsk 1/12  kbps
            elseif SINR>=-0.73 &&SINR<2.09
                rb_output=48*2*(1/6)/5;   %qpsk 1/6  kbps
            elseif SINR>=2.09 &&SINR<4.75
                rb_output=48*2*(1/3)/5;   %qpsk 1/3  kbps
            elseif SINR>=4.75 &&SINR<7.86
                rb_output=48*2*(1/2)/5;   %qpsk 1/2  kbps
            elseif SINR>=7.86 &&SINR<9.94
```

```
                rb_output=48*2*(2/3)/5;    %qpsk 2/3  kbps
            elseif SINR>=9.94 &&SINR<13.45
                rb_output=48*4*(1/2)/5;    %16qam 1/2  kbps
            elseif SINR>=13.45 &&SINR<18.6
                rb_output=48*4*(2/3)/5;    %16qam 2/3  kbps
            elseif SINR>=18.6 && SINR<24.58
                rb_output=48*6*(2/3)/5;    %64qam 2/3 kbps
            elseif SINR>=24.58
                rb_output=48*6*(5/6)/5;    %64qam 5/6  kbps
            end
             total_output=total_output+rb_output*3/1000;
            if r_user<centerratio %&& l==0
                if ru_center<=(2/3*ru_num*slot_num)

center_output=center_output+rb_output*3/1000;%thoughtoutput,
                else
                    center_output=center_output+0;
                end
            else
                if ru_edge<=(1/3*ru_num*slot_num)
                edge_output=edge_output+rb_output*3/1000;
                else
                    edge_output=edge_output+0;
                end
            end
            ma = 0;
            for x= -30:2:60
                ma=ma+1;
                if SINR<=x
                    yy(ma,m)  = yy(ma,m)+1;
                end
                count(ma)=x;
            end
            i=i+1;
        end%end while
        distance_now=distance_now+1;
    end%end while
    ru_center
    throughtoutput_center(m)=center_output/distance_end;
    throughtoutput_edge(m)=edge_output/distance_end;

total_throughtoutput(m)=throughtoutput_center(m)+throughtoutput_edge(m);
    for ma=1:46
        yy(ma,m)=yy(ma,m)/(ru_num*slot_num*distance_end);
    end
    centerratio=centerratio+0.1;
    m=m+1;
end%end while centerratio
sinpow=db2pow(yy);
for x=1:10
    for bb=1:46
        ber(bb,mm)=1/(2*sinpow(bb,mm));
    end
mm=mm+1;
end
for x1=1:10
    for bb1=1:46
```

```
        cap(bb1,mm1)=systemband*log2(1+sinpow(bb1,mm1));
    end
mm1=mm1+1;
end
w=(total_throughtoutput/8)
figure (11);
l0=plot(count,yy(:,9),'-square');
 hold on ;
 set(l0,'LineWidth',2);
grid on;
xlabel('Average user SINR(dB)');
ylabel('CDF');
title('CDF of the average received user SINR ');
text(0,0.65,'Without FFR');
hold on;
figure (1);
l1=plot(count,yy(:,1),'-square');
 hold on ;
 set(l1,'LineWidth',2);
l2=plot(count,yy(:,9),'-X');
set(l2,'LineWidth',2);
grid on;
xlabel('Average user SINR(dB)');
ylabel('CDF');
title('CDF of the average received user SINR ');
text(0,0.65,'Without FFR');
text(10,0.4,'With FFR');
hold on;
figure (2)
l3=plot(throughtoutput_edge,'-diamond');
set(l3,'LineWidth',2);
grid on;
ylabel('Throughtoutput (Mbps)');
xlabel('Distance from center of cell (m)');
figure (3)
l4=plot(throughtoutput_center,'-X');
set(l4,'LineWidth',2);
grid on;
ylabel('Throughtoutput (Mbps)');
xlabel('Distance from edge of cell (m)');
figure (4)
l5=plot(total_throughtoutput,'-diamond');
set(l5,'LineWidth',2);
grid on;
ylabel('Total Throughtoutput (Mbps)');
xlabel('Distance(m)');
figure (5)
l6=plot(w,'-square');
set(l6,'LineWidth',2);
grid on;
ylabel('Average Throughtoutput (Mbps)');
xlabel('Distance(m)');
figure (6)
l7=semilogy(ber,yy,'-o');
set(l7,'LineWidth',2);
ylabel('BER');
xlabel('SINR');
```