REPUBLIC OF TURKEY
FIRAT UNIVERSITY
THE INSTITUTE OF NATURAL AND APPLIED SCIENCES

OPTIMIZATION FOR NEXT GENERATION WIRELESS SYSTEM USING RADIO OVER FIBER IN TERMS OF TOPOLOGY

Master's Thesis

Shwan Asaad Othman
(151137120)

Department: Software Engineering
Supervisor: Prof. Dr. İbrahim TÜRKOĞLU

August - 2017

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Thesis Supervisor : **Prof. Dr. İbrahim Türkoğlu (Firat Univ.)** ……………………
Other Jury Members : **Prof. Dr. Abdulkadir Şengür (Firat Univ.)** ……………………
Doç. Dr. Cihan Varol (Sam Houston State Univ.) ……………………

August - 2017

DECLARATION

I declare that this thesis with title “Optimization for Next Generation Wireless System Using Radio over Fiber in Terms of Topology” is prepared by myself as a partial fulfillment of the requirements for the degree of Master of Science in Software Engineering.

Shwan Asaad Othman

Elazığ/TURKEY - 2017

DEDICATION

This work is dedicated to my beloved parents who have supported me through the course of this degree and my sincere supervisor Prof. Dr. İbrahim TÜRKOĞLU for their endless and unconditional support.

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In the name of Allah, all praise is due to him for granting me the ability to finish this thesis that will be the first step to go through the master. firstly I would like to thank the staff members of Firat University for offering me the opportunity to study my master degree. My special thanks for Prof. Dr. Asaf Varol the chair of software engineering. My special thanks for Prof. Dr. Ibrahim Türkoğlu for support in preparing my thesis. With warmest regards and best wishes to my family and my friends who assisted me. Dedicated to my family.

LIST OF CONTENTS

ABSTRACT

OPTIMIZATION FOR NEXT GENERATION WIRELESS SYSTEM USING RADIO OVER FIBER IN TERMS OF TOPOLOGY

This dynamic execution of Radio over Fiber (RoF) joins utilizing minimal effort optoelectronic parts are evaluated for dispersed receiving wire applications in cutting edge remote frameworks. Vital configuration issues are examined and an illustrated the outline is exhibited for a remote framework requiring the transmission of four radio channels for every connection course. Each of these channels has 100 MHz transmission capacity, balance many-sided quality of 256-QAM and 2048 OFDM subcarriers. The clamor presented by the RoF joins has been tested and it is demonstrated that no significant effect is presented for remote range, given the remote framework has an uplink power control. Design and execution expense has been considered for RoF connection with option join sorts. This application utilized radio transmission and demonstrated that RoF is an ideal decision from a cost point of view.

Keywords: Next Generation, New Radio Access Network (RAN), Radio over Fiber (RoF), Mesh Topology, Dispersion of Fiber Optic.

ÖZET

TOPOLOJİ K AÇIDAN FİBER ÜZERİ RADYO KULLANARAK GELECEK KUŞAK KABLOSUZ SİSTEMİN OPTİMİZASYONU

Minimum çaba gösteren optoelektronik parçaları kullanarak Fiber birleşimleri üzerinden gerçekleştirilen bu dinamik Radyo yürütmesi, dağınık alıcı kablo uygulamalarının uzaktaki keskin kenarlı çerçevelerce değerlendirilmesidir. Oldukça büyük bir önem arzeden bu konfigürasyona dair sonuçlar denendi ve taslak çizimleri yapılarak her bir ileti için dört radyo kanalına gereksinim duyan uzak çerçeveler için sergilendi. Bu kanalların her biri 100 MHz transmisyon kapasitesine sahip olup, 256-QAM ve 2048 OFDM alt taşıyıcılarının çok yönlü kalitesini dengeleyin. RoF eklaentileri üzerinden gelen gürültüler test edilmiş ve uzak menzil için bir etkisi olmadığı belirlenmiştir ayrıca güç kontrolü oluşturmuştur. Tasarım ve uygulama masrafları RoF bağlantı ve eklenti çeşitleri için düşünülmüştür. Bu uygulama radyo transmisyonunu kullanmıştır ve RoF'nin bu bağlamda gayet ideal olduğunu göstermiştir.

Anahtar Kelimeler: Gelecek kuşak, Yeni radyo erişim ağı (RAN), Fibeer üzeri radyo, Ağ topoloji, Fiber optik dağılımı.

LIST OF TABLES

Page No

LIST OF FIGURE

Page No

LIST OF ABBREVIATIONS

3GPP : 3rd Generation Partnership Project
ACI : Adjacent Channel Interference
AUC : Authentication Center
BER : Bit Error Rate
BISDN : Broadband-Integrated Services Digital Network
BSC : Base Station Controller
BSs : Base Stations
BSS : Base System Subsystem
BTS : Base Transceiver Station
CBS : Central Base Station
CCI : Co-Channel Interference
CDMA : Code Division Multiple Access
CS : Control Station
DFB : Distributed Feedback
DR : Data Rate
E/O : Electrical to Optical
EIR : Equipment Identity Register
FBG : Fiber Bragg Grating
GPRS : General Packet Radio Service
GSM : Global System for Mobile Communications
HLR : Home Location Register
HSPA : High-Speed Packet Access
IF : Intermediate Frequency
IMT : International Mobile Telecommunications
IMT : Multipoint Video Distribution Services
ISI : Inter Symbol Interference
ITU : International Telecommunication Union
LED : Light Emitting Diode
LO : Local Oscillator
LOS : Line Of Sight
LTE : Long Term Evolution

MBS : Mobile Broadband System
ME : Mobile Equipment
MMF : Multi-Mode Fiber
MS : Mobile Station
MSC : Mobile Switching Station
MVDS : Multichannel Video Distribution System
NA : Numerical Aperture
NSS : Network Switching Subsystem
O/E : Optical to Electrical
OADM : Optical Add-Drop Multiplexer
OFDM : Radio over Fiber
OSS : Operation and Support Subsystem
QAM : Quadrature Amplitude Modulation
RAN : Radio Access Network
RAU : Radio Access Unit
RF : Radio Frequency
RNC : Radio Network Controller
RoF : Radio over Fiber
SIM : Subscriber Identity Module
SMF : Single-Mode Fibers
SNR : Signal to Noise Ratio
SSGN : Spanish Speaking Growth Network
UHF : Ultra High Frequency
UMTS : Universal Mobile Telecommunications System
VCSEL : Vertical Cavity Surface Emitting Laser
VHF : Very High Frequency
VLR : Visitor Location Register
WDM : Wavelength Division Multiplexing
WiMAX : Worldwide Interoperability for Microwave Access
WLAN : Wireless Local Area Network

1. INTRODUCTION

1.1. Introduction

The next-generation mobile system includes the concept that the next-generation of wireless mobile communications system will be a major move toward prevalent wireless communications systems and constant high-quality wireless services [1].

Fourth generation system is the fourth generation of wireless mobile technology, which came after the 3G system. A 4G system provides more abilities defined by ITU in IMT-Advanced. Current applications of the 4G system are include amended mobile web access, high-definition (HD) mobile TV, IP telephony, video conferencing, gaming services and 3D television [2].

In 2009 a 4G system was used in Oslo, Stockholm, and Sweden known as Long Term Evolution (LTE) standard which used as the first release and used commercially. However, LTE has been debated whether first-release versions should be considered 4G [3].

The 4^{th} generation wireless system provides high bandwidth for multimedia applications. Next-generation mobile systems are well prepared to head the technology journey. The new technology faces the challenge of providing flexible, have architectures can reconfigure and have the capability of catering the dynamics of the network and provide low-cost solutions for service providers [4].

Five generation systems are proposed as next generation mobile system standards after the current 4G/IMT-advanced standards. The first chip was designed in October 2016 by Qualcomm. The operations in the 28 GHz band was supported by Snapdragon X-50 5G modem, which also known as mmW (millimeter wave) spectrum. The download peak speed of more than 35.46 is achieved by 800 MHz bandwidth support. 5^{th} generation system aims a higher capacity than current 4G, which allows supporting device-to-device, more useful for mobile broadband, ultra reliable, and huge machine communications [5].

Optical communication is a form of communication that uses light as the transmission medium [6]. RoF used to transmit modulated Radio Frequency (RF) signals. It transmits the radio frequency signal from CS to word BS and vice versa. The duplex operation ideal length, require few mm-wave parts in the BS's and also require only a little best performance of optical components, are requirements of RoF link architecture (e.g. downlink-uplink) [7].

Radio over fiber RoF systems is used for improving cellular coverage inside the buildings. It has low-cost aim because it boosts the high-cost radio equipment which is located at central stations and simplifying the remote antenna sites. The radio signal frequency is distributed by RoF systems which cover more area (often in the GHz zone) and lay on the applications nature [8], stages of thesis study work as shown in figure 1.1.

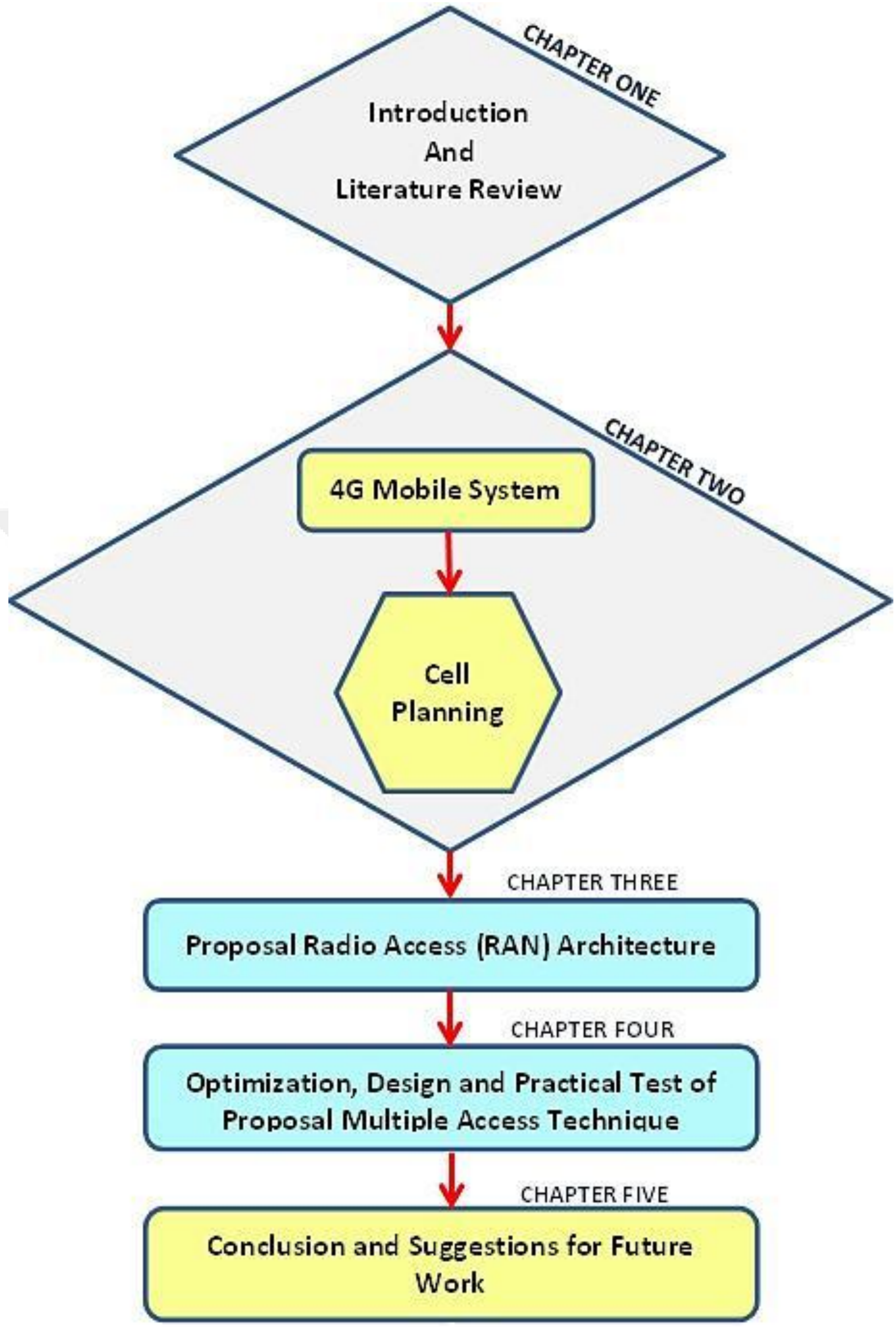


Figure 1.1: Stages of Thesis Study Work.

1.2. A Brief Summary of Previous Research

S. Singh *et. al.* 2007 proposed a simulation by using optisystem software of data transmission in full duplex manner in the RoF system. They transmit four signals (1.25 Gb/s, 9.1 and 9.4 GHz) data on long dragging single mode fiber for down-link transmission. Those data signals are uplinked, for BS's. Less error rate is obtained for transmission of the up-link and down-link [9].

V. Reddy and L. Jolly *et. al.* 2016, integer microwave and optical networks. A compare between (Intermediate Frequency IF over fiber optic and radio over fiber optic RoF) has been analyzing the quality factor and (BER) in a Radio over Fiber RoF system. The Intermediate Frequency IF over fiber optic display good performance than Rof in terms of a (BER) and Quality factor [10].

A. Kim *et. al.* 2004, shows a broadband RoF communication system which transmitted wireless signals at the mm-wave bands. It engaged (25-km) of an optical IF supplier. OFDM (60-GHz) signal transmission at (155 Mbps) with a BER > 10 - 6 was obtained in the system cell with 2.6 m radius [11].

Affida *et. al.* characterize the distribution of WLAN service using RoF technique in GPON (Gigabit Passive Optical Network) network architecture by means of simulation which was done in commercial OptiSystem software. The bidirectional transmission was used with fiber length varied from 2-20 km. The simulation results show that the system scheme exhibits the performance standards [12].

J. Johny and S. Shashidharan *et. al.* 2012, use optisystem version 10 to develop simulation model. They integrate systems for both optical fiber and RF wireless in which the RoF network model composes of a CS, an optical fiber link model and a remote access unit, which uses the available parameters [13].

A. Mohan and Anish A. *et. al.* 2015, use full-duplex transmission of RoF by means of WDM and OADM, where WDM enables transmission of various signals via a single-mode fiber optic over large way and OADM permits transmission of both up-link and down-link data via the single mode fiber optic (same one). In addition, the performance analysis of RoF system employing various line coding techniques has also been done [14].

F. Yunazar *et. al.* 2009, modulated broad-band m-wave data signals over an optical carrier at a CS and then transported to remote sites or BS using optical fiber. The BS Base Station then transmits the RF over small areas using m-wave antennas [15].

R. Karthikeyan and S. Praksam *et. al.* 2013, use orthogonal frequency division multiplexing (OFDM) to improve the signal by using RoF for a wireless system. They innovate a new modeling up-converter (10 Gb/s). The OFDM signal on 7.5 GHz carrier frequency over (60 km) SMF is utilized for modulating signal such as QAM. The result of Radio Frequency RF signal bandwidth is increasing for the wireless done by Optisystem software simulation [16].

A. Mohan and Anish A. P. *et. al.* 2013, do Performance Comparison of Radio over Fiber System Using WDM and OADM with Various Digital Modulation Formats. The performance analysis of RoF system employing various line coding techniques and digital modulation formats has also been done. The simulation and performance comparison of RoF was done using Optisystem [17].

1.3. The Purpose of This Work

4G mobile system expected challenges will be the interference effects (CCI and ACI) because of higher number of base stations, channel allocation for the system, carrier frequencies assignment, the base stations connection topology for further interference reduction, secondly, high data rate transmission because the 4th Generation minimum target speed reach up to 100 Mbps for indoor and 1Gbps for outdoor communications, this needs a technique for increasing the transmission speed of data, also, the capacity for a unit area for the system in compression to 3rd Generation cellular systems must be at least 10 times higher, in this case, the cost of it must be decreased and people can use it with no more cost [13], with increasing of transmission speed, the signal level will increase as required, this needs better area coverage with different speed transmission, therefore, there must be cell planning for the system RAN. [5]

Because 4G will be the integration of the other wireless systems, handover also will be another challenge must be controlled; in this case, using higher frequency band radio entrance links are used to transmit broadband signals. rain attenuate bands with high-frequency band, so the transmitted signal range will decrease to less than some Km, in this case, the radio repeaters will be necessary for base stations far from the radio network controllers (RNC), for solving this problem, there will then need a new model of RAN for the system [9].

1.4. Methodology

1. Radio over fiber (RoF) instated of the microwave has been used which used in fiber optic system for connecting a group of BTS, then all BTS connected to BSc and finally Connected to the internet. The fiber optic parameter for the length of our systems (Four Generation and above) which have a small area of coverage (about 2 km). We optimize the fiber optic parameter for maximum 2 km by using Matlab software for best case (Dispersion, Attenuation, and Numerical aperture) and changing in the delta of fiber optic parameter to show how they affect on length or quality of the signal.
2. In this proposal has been used a new design RAN topology in form of mesh for next generation (4 Generation and above), which all BTS is connected to BSc after a better optimization by Matlab software for all parameters, then as a project by using optisystem software; the optisystem give us all parameters such as (Attenuation, Maximum length, power output, WDM output) and this project will be as simulation, then this simulation converted hardware in the lab.
3. After making the project by optisystem software, the project has been used run in the lab with hardware, that output results achieved by hardware are the same to optisystem software.

1.5. Thesis Layout

This thesis consists of six chapters. First chapter brief introduction about next generation, radio over fiber (RoF), mobile evolution four generation and five generation, then the aim of our work and methodology. The second chapter in this chapter discusses the problem of microwave, radio access network (RAN) and radio over fiber (RoF). The third chapter in this chapter, we design radio access network (RAN) which have a topology in form of mesh, then step by step all parameters well done and run the project to achieve the results. The fourth chapter the result achieved in chapter three by MATLAB software and optimization and by using hardware and they are compared. Fife chapter all the results obtained, problem and treatment are discussed in this chapter.

2. NEXT GENERATION MOBILE SYSTEMS AND RADIO OVER FIBER

2.1. Introduction

Change in the nature of the service, new frequency bands and non-backwards compatible transmission technology is generally called the next generation. New generations have risen again in every 10 years from 1981, analog 1st G to analog 2nd G network, then the 3rd G multimedia support followed the two previous generations [18]. And finally, the 4th G comes, in last years a great growth in the industry of wireless, both subscribers and mobile technology [19]. A dramatic change from fixed to mobile cellular telephony [20]. Together, the vendors and mobile network operators have important role of effective networks with the equally effective design. This development leads to optimization related services and Network Planning coming into focus. The 5th G is multi Technology Core as given in Table 2.1. The assemblage of new technologies such as Nano-technology, Cognitive Radio, Cloud Compute, and based on all IP Platform form a core [21]. Table 2.1 is the mobile generation evolution from 1G to 5G.

Table 2.1: Evolution of Mobile Radio Standards (1G to 5G) [21].

Technology	1G	2G	3G	4G	5G
Year	**1970**	**1980**	**1990**	**2000**	**2012**
Standards	**AMPS, NMT, HICAP, CDPD, TACS, ETACS**	**GSM, I-DEN, D-AMPS**	**CDMA 2000, WCDMA**	**Signal Standard LTE, Advance**	**Single Unified Standard**
Data Bandwidth	**1.9 Kbps**	**14.4 Kbps**	**2 Mbps**	**200 Mbps**	**1 Gbps & Higher**
Core Network	**PSTN**	**PSTN**	**Packet Network**	**INTERNET**	**INTERNET**
Multiplexing	**FDMA**	**CDMA, TDMA**	**CDMA**	**OFDMA**	**CDMA, BDMA**
Service	**Analog Voice**	**Digital Voice**	**Higher capacity, Broadband Data**	**Broadband Data With High Speed**	**Dynamic Information Access**

RoF systems use optical fiber, which has minimum lack and wide band width transmission area that allow the spreading of broadband data or high frequency signals into many BS's easy [24].

Techniques are realizing best performance integrated networks are RoF. The increase of wireless communications and mobile that enhance the increasing requiring services for multimedia with a high kind of service. The actualization is required for access networks and broadband spreading. Via this frame, RoF architecture is placed for actualizing seamless wireless networks that permit the easy distribution of millimeter waves and microwaves over long mileage over optical fibers. Applications of RoF technology contain cellular networks, satellite communications, Multipoint Video Distribution Services (MVDS), the Mobile Broadband System (MBS), wireless LANs over optical networks [25].

The benefits of Radio over Fiber technology makes it an important for the future of wireless communication and makes the companies race to know that technology and implement it to obtain a system that more efficient and has better performance. The technology of Fiber optic gives technical works advantage over commercial coaxial feeds almost indefinite bandwidth and far, RoF systems are the clear choice for present and future generation electronic signals. Low noise and best communications security encase low frequency to very high frequency RF spectrum of RoF links. Fiber optic systems can carry RF signals for kilometers with less loss and can be designed for special RF links. Low Noise Amplifiers can be placed to elevate the RF signal more than the post RF and laser noise, amplifiers can be utilized to add signal gain at the far end receive site and to overcome any optical link loss [26].

2.2. The Next Generation Mobile from LTE-Advanced and 5G

Continues of expanding of Mobile broadband industry, converting lives and businesses together. 20 years ago, computing by hand and wireless data communications were in focus technologies, utilized mainly in industries. now, the connected devices number is very large than the number of people of the USA. The manufactory would be enjoyable although if it had reached to an endpoint, it is at a beginning of growth, that has no end in the scene for the possible improvement [27].

For example, at the last 5 years, the rate of LTE is increased from 10Mb/sec. to >100 Mb/sec. accelerating, engineers to reach tenfold in productivity as 5G developed. Employing new spectrum in ever-higher-frequency bands, and growing network intensity, the manufacturing will increase network ability by 2 to 3 times of magnitude by the coming 10 years [28]. in spite that radio communications do not reach the capacity of fiber optic cable, the abilities of mobile broadband are had become powerful in which an increasing percentage of users will no longer require wireline broadband connections. neither only is a wireless technology the way by which humans are combined with one another and their work, and how also we will at the end connect self-driving cars, so many numbers of machines, health monitors, or many numbers of devices for which software have that not even been conceived [29].

5G, with its large abilities the cellular manufactory has met on 3GPP, LTE, contain LTE proceeding, as the air interface. A manufactory that was at last time divided within multiple air interfaces worldwide System for Mobile Communication GSM, UMTS/HSPA, and CDMA 2000 led to large economies of the line for manufactory and person who use this equipment [22].

5G will convert to the communications platform. In regional area networks, Wi-Fi has also achieved noticeable success. With continuous developments to more strongly integrate Wi-Fi using with LTE, in addition, the growing LTE operation into none official licensed bands, the industry is to rec=ognize the sight of one global, harmonized network [23].

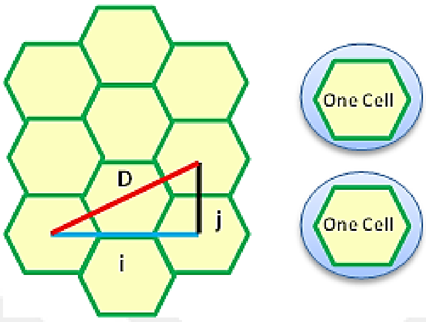
2.2.1. Cell planning

Therefore, (RAN) in the mobile system Next generation contains a group of (BTS) that all of them are designed next together. Each (BTS) contains a (Cell) that called six dimensions or squib. Also, each cell contains three Antennas.

When we want to send the frequency for all of the (BTS) we have to make them as a group because it is easier to send the frequency for each group. So, (BTS) groups are arranging like (3, 7, 9, 12, 13, 19, and 27) and they called (Cluster Size). However, it has a special rule to make them as a group as shown in figure 2.2. Cluster Size rule is (i, j) to finding (N) it can be use this rule (N= i2 + ij + j2) as given in Table 2.2 [30].

For distance of the (i, j) rule and w=it can be used $D = \sqrt{3N}$, in the picture below will illustrate how we classify (BTS) over the groups as shown in figure 2.1.

Where is i= blue line, j= black line, D= red line, i= vertical, j= horizontal, D= distance between two cell.



$$\mathbf{N = i^2 + ij + j^2} \quad \mathbf{(2.1)}$$

$$\mathbf{D = \sqrt{3N}} \quad \mathbf{(2.2)}$$

Figure 2.1: Cell Planning in Cluster Size

Table 2.2 is the cluster size calculation for the cell planning procedure.

Table 2.2: Cell Planning in Cluster Size [30]

I	j	$N = i^2 + ij + j^2$	$D = \sqrt{3\,N}$	Radius Cells
0	0	0	$D = \sqrt{3*0}$	0
0	1	1	$D = \sqrt{3*1}$	1.73 ≅ 2
1	0	1	$D = \sqrt{3*1}$	1.73 ≅ 2
1	1	3	$D = \sqrt{3*3}$	3
0	2	4	$D = \sqrt{3*4}$	3.46
2	0	4	$D = \sqrt{3*4}$	3.46
1	2	7	$D = \sqrt{3*7}$	4.58
2	1	7	$D = \sqrt{3*7}$	4.58
2	2	12	$D = \sqrt{3*12}$	6
0	3	9	$D = \sqrt{3*9}$	5.19
3	0	9	$D = \sqrt{3*9}$	5.19
3	1	13	$D = \sqrt{3*13}$	6.24
1	3	13	$D = \sqrt{3*13}$	6.24
3	2	19	$D = \sqrt{3*19}$	7.54
2	3	19	$D = \sqrt{3*19}$	7.54
3	3	27	$D = \sqrt{3*27}$	9

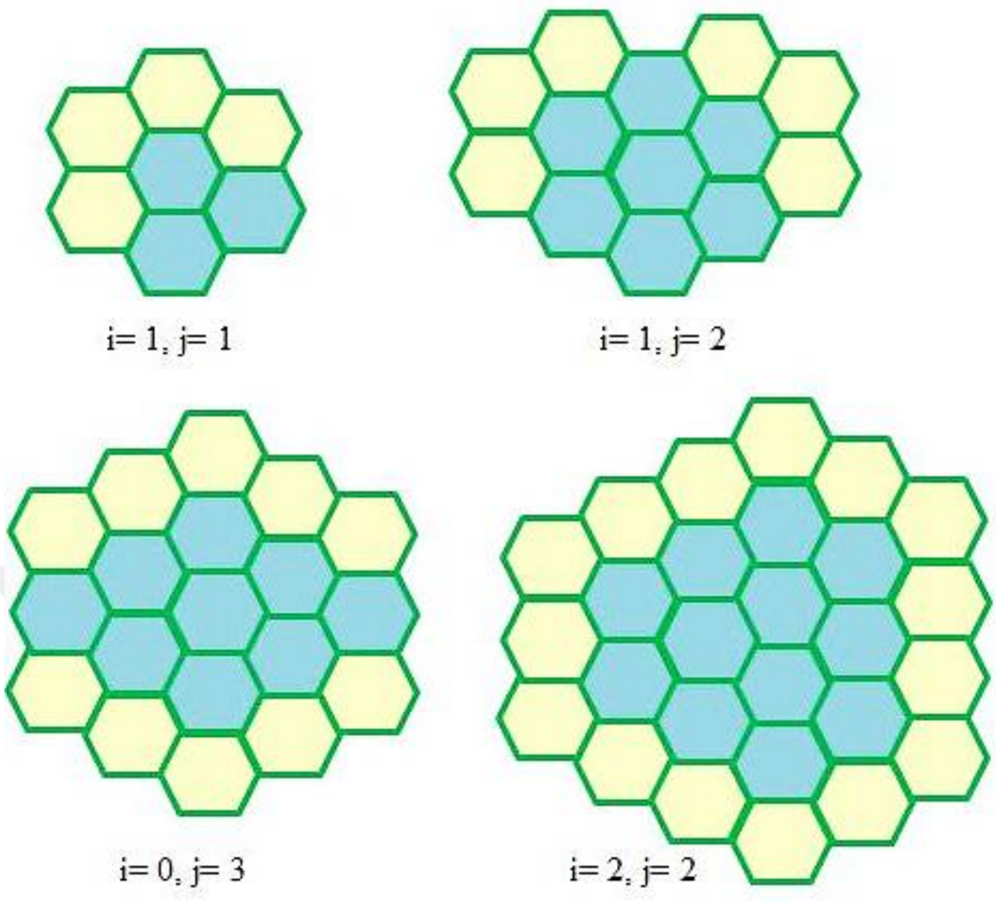


Figure 2.2: (N) Group in Cluster Size.

2.3. Optical Communication System

In general, Optical Communication System can be described that RoF is a part of it.

Moreover, block diagram contains some parts, firstly it starts with Source, then Volt and Current (V&I) comes from a source that connected with Light Source (L.S). So, (L.S) is divided into two parts (LED & Laser). Regarding Light Source (LS), it produces lights and goes through Optical Fiber cable, this process will continue until lights go through Light Director and then connected to the destination, as shown in figure 2.3. Fiber optic cable has been included two parts step index and graded index. As shown in figure (2.4, 2.5).

Also, RoF in the area of (LS) becomes an Electrical-to-Optical (E/O) [31, 32].

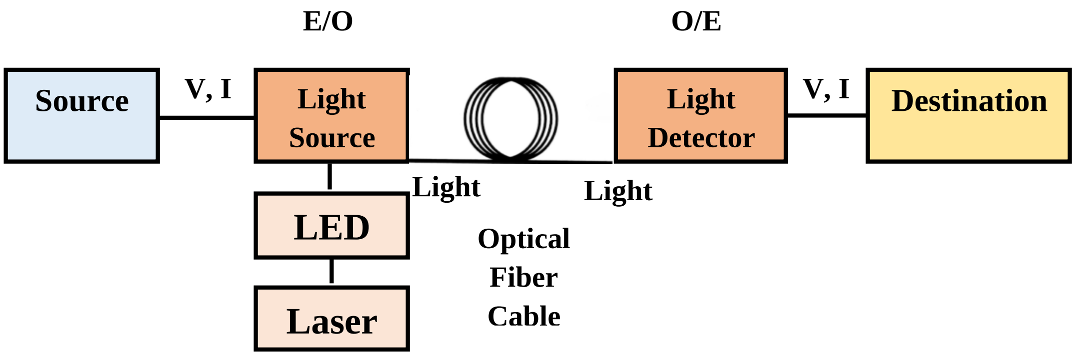


Figure 2.3: Block Diagram of Optical Communication System.

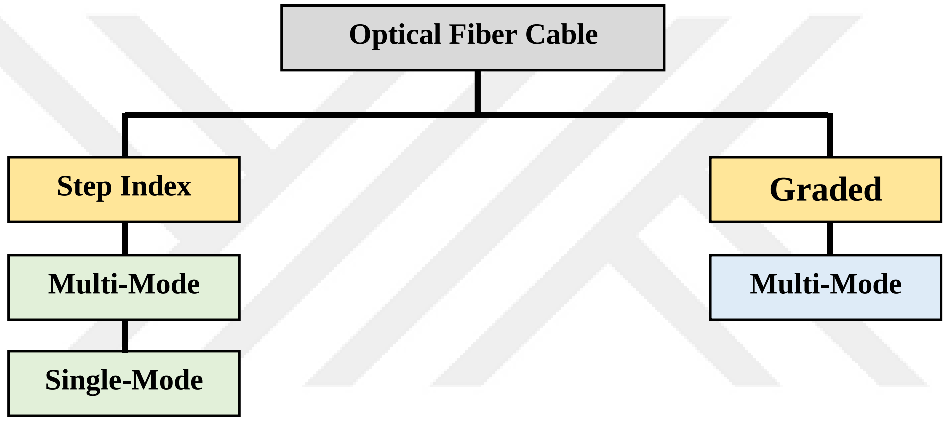


Figure 2.4: Type of Fiber Optic Cable.

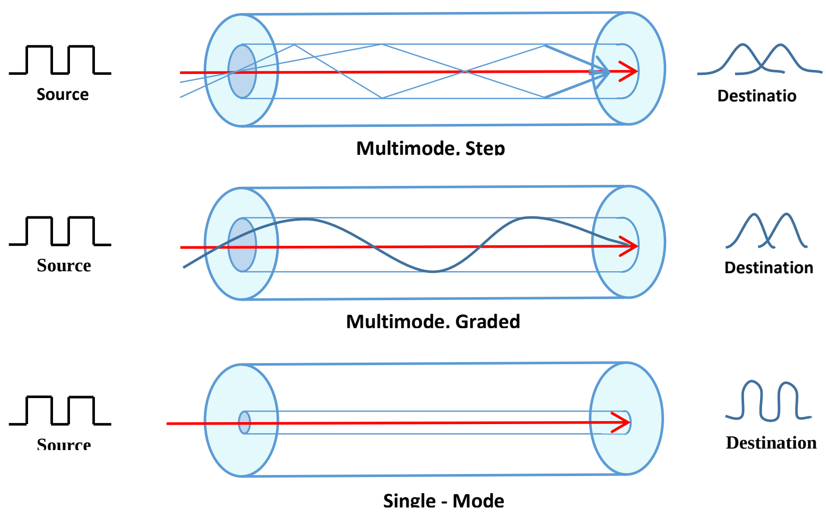


Figure 2.5: Optical Fiber Types.

Generally, Index in Fiber is called (n)

$$\text{Relative Index (n)} = \frac{\text{Velocity of Light in Vacuum}}{\text{Velocity of Light in Medium}} \qquad (2.3)$$

Vacuum is light speed in the space = 10^8*3

Medium is a light speed in a specific area such as (Water, Air, and Fiber Glass).

Normally, Fiber Optic it can be divided into three significant parts such as (Jacket, Cladding, and Core), Jacket is the strong part and it is responsible to protect the Cladding and Core. So, information is only going through Core. Therefore, during this process, it is not eligible that Light goes through Cladding if it goes through Cladding in the process of transforming the information it makes Loss [33].

Refractive Index Core = n1

Refractive Index Cladding = n2

When the light crosses the core, it makes a corner that is called Phi (Φ), also (Refractive) (Φ) it must bigger than Phi (Φc) because if (Φ) is smaller than corner in that light is crossing among the core and reaches the Cladding wall.

When we send lights to cross among the core, it would be a corner that is not affected the surface of the Cladding; it means that just the corner should cross the middle of the process. When we send a light to cross among the big corner, this corner would be the top parts of the core. Which is the center of the Core and Cladding that called (Φ) critical (Φc).

If (Φc) is not solving our problem, we have to use more corners more than the corner of (Φc), then cross the light among the core without any problem. This process is called (Total Internal Reflection) Φ > Φc. As shown in figure 2.6 [34].

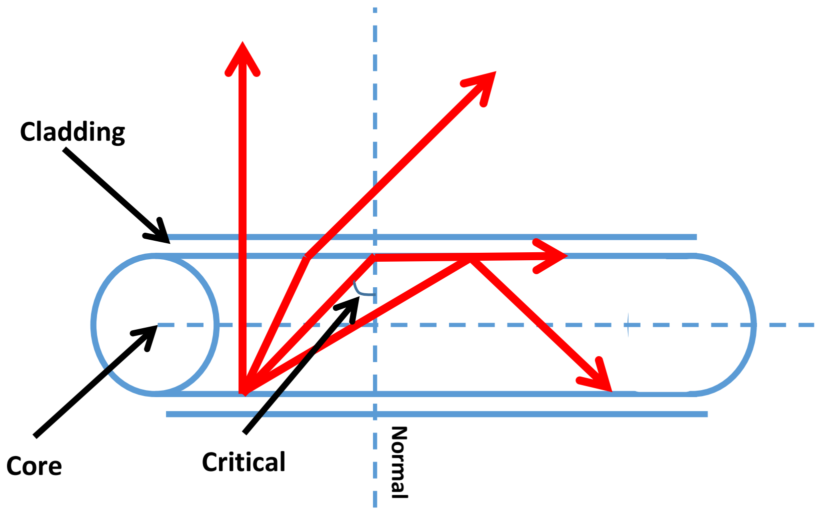


Figure 2.6: Critical Angle of Optical Fiber.

Additionally, when we want to control a corner inside the core, we have to create a new corner outside the core that called (θa) to rearrange the (Φc) inside the core. As shown in figure 2.7.

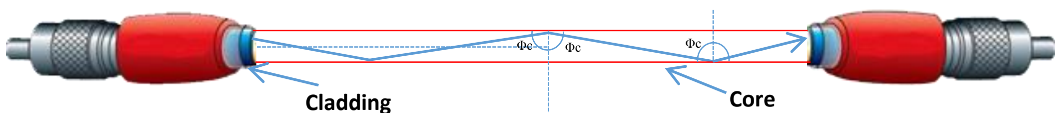


Figure 2.7: New Corner Outside for the Core in optical Fiber.

If we use Acceptance Angle (θa) outside the core, we have to cross it in a small corner inside the core; the result of this it produces a big corner in (Φc) [35]. As shown in figure 2.8.

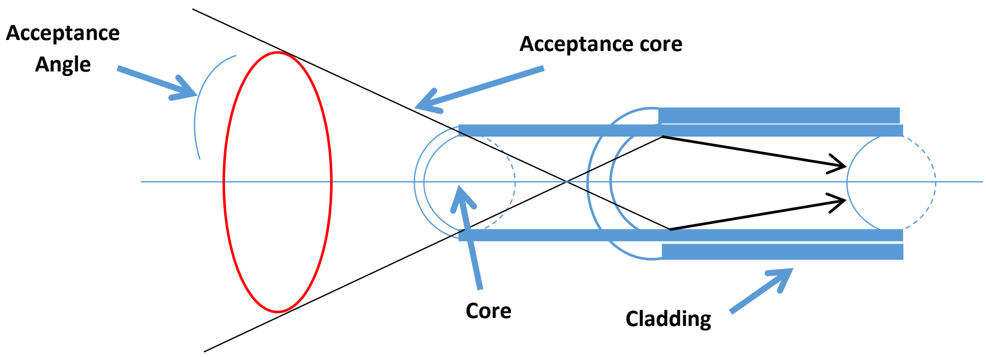


Figure 2.8: Acceptance Angle for Optical Fiber.

Then, we have another partner it called Numerical Aperture (NA), (NA) is a new shape of using and crossing lights among core also it calls Conical.

If we look at the process it looks like a triangle, but in fact, it is in the shape of Conical, also it touches the core by (θa) corner [36].

$$\mathrm{NA} = \sqrt{\mathrm{n}_1^2 - \mathrm{n}_2^2} \tag{2.4}$$

Where n1= core refractive of Index, n2= cladding refractive of Index, n1>n2, N.A. = Numerical Aperture directly with acceptance, θa = $\sin^{-1}$, Φc critical angle directly relative with the n1 and n2.

a = radius of the optical fiber.

λ= Wavelength of the light.

$$\theta_a = sin^{-1} \sqrt{\mathrm{n}_1^2 - \mathrm{n}_2^2} \tag{2.5}$$

Where n1= core refractive of Index, n2= cladding refractive of Index, n1>n2,

θa = $\sin^{-1}$, a= radius of the fiber optic.

$$\Phi_c = \sin^{-1} \frac{\mathrm{n}_2}{\mathrm{n}_1} \tag{2.6}$$

Where n1= core refractive of Index, n2= cladding refractive of Index, n1>n2, Φc critical angle directly relative with the n1 and n2.

$$\Delta = \frac{\mathrm{n}_1^2 - \mathrm{n}_2^2}{2\mathrm{n}_1^2} = \frac{\mathrm{n}_1 - \mathrm{n}_2}{\mathrm{n}_1} \tag{2.7}$$

Where Δ= relative refractive index difference, relative with (NA) Numerical Aperture n1 and n2.

2.3.1. Optical Impairments

Generally, explained of disadvantage and challenges of fiber optic has been included:

- **The Attenuation**

The loss of light energy as the light pulse propagates from one end of the cable to the other is called attenuation. It is also called as fiber loss or signal loss as shown in figure 2.9 [37].

$$A = 10\log 10\ \frac{p_i}{p_o}\ [\text{In}\frac{\text{db}}{\text{km}}] \tag{2.8}$$

Where Pi = Power input, Po = Power output, A = attenuation constant.

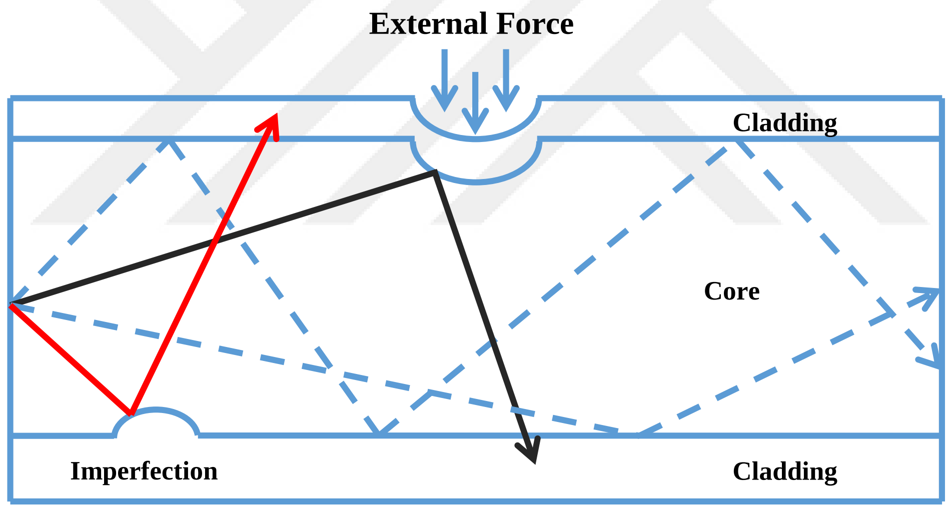


Figure 2.9: Attenuation is the Loss of the Optical Fiber.

- **Absorption**

Light energy absorption is because of heating of not pure iron which leads to a dimming of light at the end of the fiber [38].

Two types:

1. Intrinsic Absorption
2. Extrinsic Absorption

- **The Linear Scattering**

1. Rayleigh Scattering Losses:

These losses are because of tiny differences in the material that fiber made of. Different distribution of atomic densities or molecular densities leads to Rayleigh scattering losses [39].

$$\gamma_R = \frac{8\pi^3}{3\lambda^4} n^8 p^2 \beta_c \, KT_F \tag{2.9}$$

Where γ_R = Rayleigh scattering coefficient, λ = optical wavelength, p = average photo elastic coefficient, n = refractive index of the medium, K is Boltzmann's constant, β_c = isothermal compressibility at a fictive temperature T_F.

2. The Mie Scattering Losses:

The defects created during fiber making and structural in homogeneities and compositional fluctuations leads to losses which cause the light to scatter outside the fiber [39].

- **Non-linear Scattering**

1. Brillouin Scattering:

It can be defined as light modulation via hot molecular vibrations through the fiber optic [40].

$$P_B = 4.4 \times 10^{-3} d^2 \lambda^2 a_{dB} \, V \text{ watts} \tag{2.10}$$

Where (λ and d) are the operating wavelength and the fiber core diameter, α_{dB} = fiber attenuation in decibels per km, ν = bandwidth source.

2. Raman Scattering:

Likely to Brillouin scattering with exception of high-frequency optical phonon rather than acoustic phonon is created in processes of scattering [40].

$$P_R = 5.9 \times 10^{-2} d^2 \lambda a_{dB} \text{ watts} \tag{2.11}$$

Where (λ and *d)* are the operating wavelength and the fiber core diameter, α_{dB} = fiber attenuation in decibels per km.

- **The Bending Losses**

When optical fiber exposed to bending is called bending losses.

There are two types of bending [41].

$$a_r = c_1 \exp(-c_2 R) \tag{2.12}$$

Where (*c*1, *c*2) are constants, *R* = radius of curvature of the fiber bend

1. The Microscopic bending

Whole fiber is bending which leads to particular modes not to be reflected and therefore causes loss to the cladding.

2. The Macroscopic bending

Cladding or the core undergoes little bends at the surface. It leads the light to be reflected at angles when there is no more reflection as shown in figure 2.10.

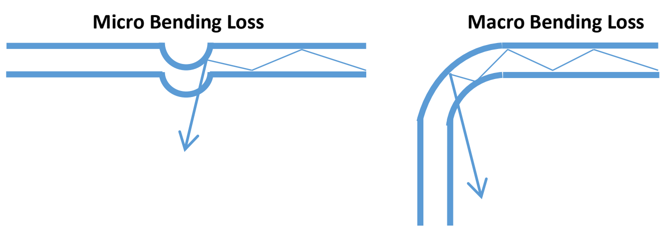


Figure 2.10: Microscopic Bending and Macroscopic Bending Losses.

2.3.2. Radio over Fiber (RoF) Concept

RoF indicates to a technology that using light to tone radio signal and transfer it over an optical fiber connected to divide radio signals of a centric place to remote stations as shown in

Figure 2.11. The radio signals frequencies are divided into RoF systems cover a great range (often in the GHz region), which rely on the kind of the apps. The electrical signal may be baseband the current modulated RF signal, modulated IF, or data to be distributed. RoF conveyance systems are divided into 2 general categories (RF Fiber; IF-over-Fiber) rely on the range of frequency of the radio signal to be transmitted In RF-over-Fiber design, a data (usually more than 10 GHz) is imposed on a light signal wave prior to transported over the optical link [42].

In IF-over-Fiber architecture, an IF (Intermediate Frequency) radio signal together with less frequency

(Less than 10 GHz) is utilized for tone light before being transported over the optical link.

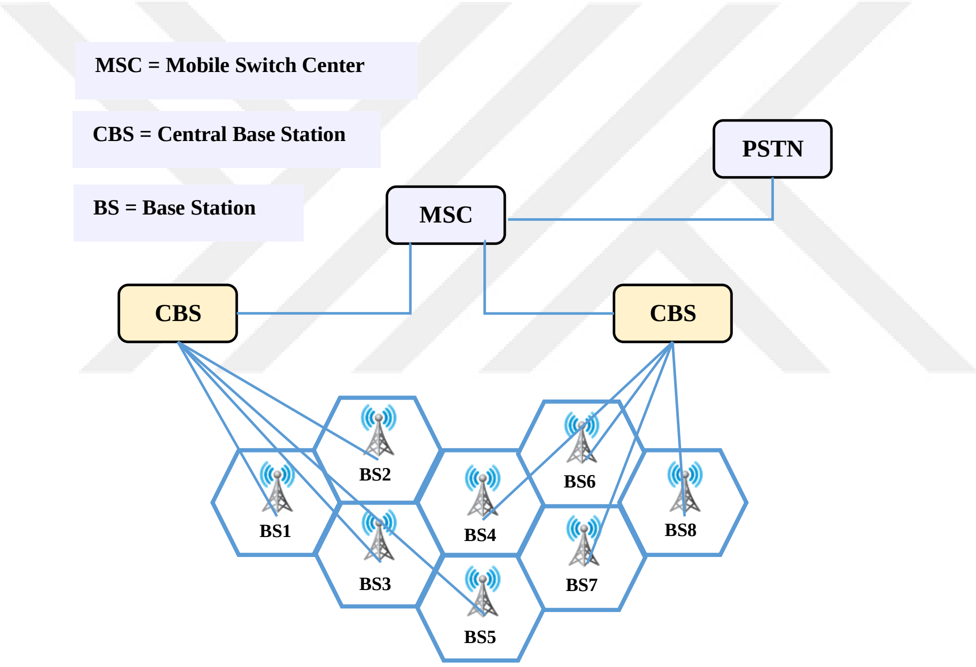


Figure 2.11: Remote Network Antenna for Micro-Cell for RoF System.

2.3.2.1. Radio over Fiber System

RoF, is composed of a CS with an RS joined by an optical fiber network or link as shown in Figure 2.12.

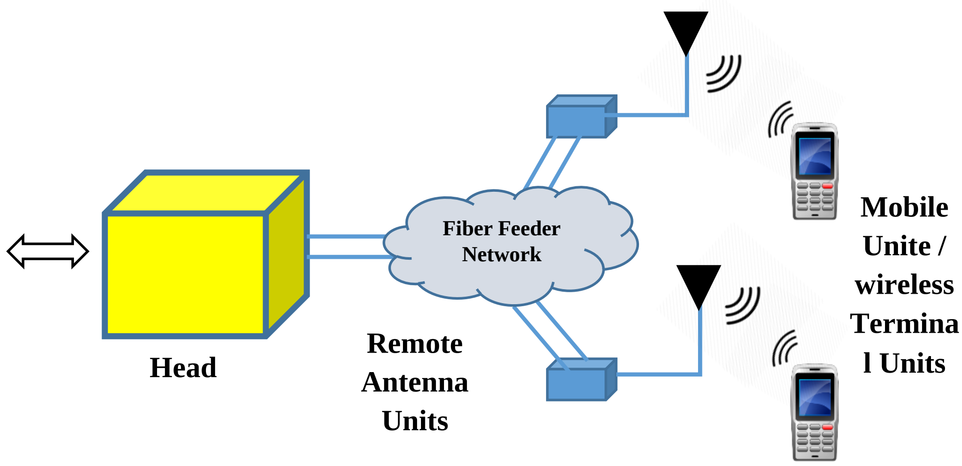


Figure 2.12: The Radio over Fiber System Concept.

The transmitting of peak frequency signals is more affronts due to the requirement of peak frequency part and bigger bandwidth link. This refers to larger frequency signals are more sensitive to the transmission, transmitter and receiver link signal failure [45].

Transmitting of the constant frequency of RF signal, it is not important. For example, an LO signal, if present, may be utilized to down-convert the uplink holder to an IF in the RAU. Performing it would permit the use of low-frequency components for the up-link way in the RAU – directing to a system for reducing cost. By putting a different LO in the RAU, it can transmit from the head end to the RAU by the RoF system. As it available at the RAU, the LO can be used to tone down conversion of the uplink signals [43].

The important benefit of RoF systems is the power to focus on most of the signal treatment task like frequency transformation, multiplexing, and carrier toning, is performed at the BS or the Radio Access Point, and instantly enters into the antenna. RoF made it easy to localize the RF signal transformation task into one participated place (head-end) [43].

2.3.2.2. Benefits of Radio over Fiber Technology

RoF technology advantages are compared with electronic signal distribution are mentioned as follow;

1. Low Attenuation Loss:

Microwave with High frequency signals electrically distribution can be in two ways in empty space and/or within transmission lines is intricate and costly. Losses because of reflection and absorption rise with frequency in free space. In lines transmission, resistance increases with frequency also, directing it to huge losses. So, radio with high-frequency is distributing signals electrically for big distances needs costive new material [44].

2. Large Bandwidth:

A Large amount of bandwidth is given by Optical fibers. There are 3 general transmissions, which give minimum attenuation descending, the 1550nm, 1310nm, and 850nm wavelengths. Three windows linked bandwidth with an overload of 50 THz. Now the case of the art traditional systems utilizes single part of this fullness. Developments are utilized optical capacity/single fiber stays in use until now [44].

3. Radio Frequency Interference Immunity:

Preventing the interference of electromagnetic type is an appealing attribute of communications by optical fiber, particularly for the transmission of the microwave. This due to that signals is transferred in shape of light via fiber. Because of the fiber cables of immunity are the best choice although for small links at millimeter waves [44].

4. Reduced Power Consumption:

Minimizing power usages are a result of owning easy RAUs with **less** equipment. Many of the complicated material is preserve it at the centric head-end. Few apps, its runes in negative mode. For example, few 5 GHz FR systems use picocells role in the RAUs running in negative mode. Minimize power usage with RAU is great to understand RAUs are occasionally put in far places not supplied by the power net [44].

2.3.3. Applications Radio over Fiber

RoF technology applications comprise Multipoint Video Distribution Services, satellite communications, broadband access radio, mobile radio communications, wireless LANs upon optical networks and Mobile [46].

1. **Cellular Networks:**

The remarkable application placed for RoF technology is Mobile networks. The growth in a number of subscribers linked mobile and broadband services preserved continuous mobile network pressure led to getting increasing the capacity [46].

2. **Communications Satellite:**

The early practical application of communications Satellite is RoF. From the various apps does comprise the remote antennas to a good place at earth stations for satellite. At this situation, small size optical fiber links of fewer from 1km and used at freq. ranged from 1 and 15 GHz are used [46].

3. **Video Distribution Systems:**

Main application area of RoF systems is the distribution of video. An example for this is the MVDS. This is a cellular earthly transmission system for TV broadcasting. It was in fact meant to be transmitting lonely service but now, few feedback channels have been coupled to the service reactive. So it used to serve areas like a small town [46].

4. **Broadband Services of Mobile:**

Is prepared to expand the services obtainable in constant BISDN to mobile users of all kinds. [46].

5. **WLANs:**

Broadband wireless LANs for next generation is being ready to give more than 54 Mbps/carrier and they demand frequencies in the 5 GHz band [46].

2.3.4. Radio over Fiber (RoF) Technology

2.3.4.1. Radio over Fiber (RoF) Architectures and Deployments

The architectural arrangement of RoF. The CS is responsible for managing, generating and distributing the RF or millimeter wave (mm-wave) signals to several BSs via optical fibers. In turn, the BSs convert the signal back to electrical and transmit it to the end users. The reverse operation entails the conversion of the electrical signal into optical and transmission to the CS via the optical fiber. A typical link between the CS and one BS.

The principal infrastructure of a BS involves mainly optical to electrical conversion and vice versa along with amplification and antenna equipment. That is, the BS configuration is kept as simple as possible. This arrangement is also called RF-over-Fiber since the RF or mm-wave signal is distributed by the CS. Although this configuration is very cost effective, it is prone to fiber dispersion and phase noise. Alternatively, there are two more possible configurations namely, IF-over-Fiber and baseband (BB)-over-Fiber. In the former case, the CS transmits the signal in an intermediate frequency (IF) and RoF architectural configurations: The CS distributes the mm-wave signal using either RF-over-Fiber or IF-over-Fiber or BB-over-Fiber and possibly employing SCM. Conversion is done at the BS [47].

In the latter one, the CS transmits the baseband signal and the final up-conversions are performed at the BS. These configurations alleviate the drawbacks of RFover-Fiber in the expense of increased BS costs. The centralized RoF architecture is beneficial and flexible since it offers the ability to achieve micro/pico-cellular coverage, thus offering the benefits of mobile communications plus the high bandwidth of the optical fiber. Additionally, it takes advantage of the high-frequency propagation phenomena and is capable of realizing efficient frequency reuse and allocation plans. This is significant since future high-speed networks are tailored to push mm-wave carrier frequencies beyond 60GHz. Overall, the merits of RoF, to name a few, are best in coverage and increased range, centralized renewing, adaptation and dynamic configuration of radio resources, less repairing costs, more reliability for future broadband applications, and commercially access to mobile-broadband communications [47].

2.3.4.2. Radio over Fiber (RoF) Optical Components

The main optical components employed in RoF technology are the laser transmitter, the photodetectors, and the optical fiber. The types of laser transmitters are the FP laser, the DFB laser, and VCSEL laser.

Among them, currently, the proper light sources are the DFB lasers for analog transmission, operating both at 1300 and 1550 nm carrier frequencies, due to their spectral purity, enabling thus low relative intensity noise (RIN) values. The most important deterioration factor of the DFB laser is the actual non-linear interaction between photons and carriers, which dramatically raise the symmetrical or inter-modulation distortion as the toning frequency reach the laser's resonance frequency. Commercially available DFB lasers achieve a resonance frequency in the order of 10GHz although research efforts have reported prototypes of up to 40GHz [48].

A typical bandwidth of a photo detector is in the order of 25 GHz or even greater. The role of the optical fiber is critical for the effective deployment of RoF links, where both single mode (SMF) and multimode fibers are employed.

2.4. Microwave System and Its Disadvantages

A radio - microwave connection is an indicate point correspondence interface utilizing the movement of electromagnetically waves via the free space. Exceptionally & ultra-high frequencies (VHF, UHF) are utilized as often as possible for short wave correspondences among settled points. The proliferation of LOS is not home because of the obstruction of structures, trees, and numerous different items.

The propagation is nonhomogeneous at troposphere at 20 km heights for the microwave. Since a little portion of energy is propagated to the high transmitting power, accepting radio wire, low receiver noise and high reception apparatus are required for good execution. Much longer separations should be possible by utilizing ionosphere reflection. Layers of the ionospheres are situated at around 100 km heights [49, 50].

2.4.1. Disadvantage of Microwave System:

The disadvantage of microwave transmission is that microwave towers can trade information just in the event that they have a clear line of sight between them without any deterrents, for example, mountain, hills, rain, storm, or trees in the way:

- Difficult to evaluate electronic circuits
- Classical parts (inductors, resistors, and capacitors) can't be utilized at microwave frequencies.
- Physical impediments in making resounding circuits at microwave frequencies.
- Classical semiconductor part does not work legitimately at microwave frequencies.
- Because of the short wavelength, the Microwave signs are effectively reflected and occupied.

- Rain, haze can weakling and assimilate the microwave flag particularly at 20 GHz.

2.4.2. Optical fiber and microwave system comparison

An overall comparison between the optical fiber system and microwave system shown in Table 2.3, it is shown that optical fiber has more advantages, therefore, in this work optical fiber system and then radio over fiber (RoF) has been used [51].

Table 2.3 Comparison between optical fiber and microwave system

Table 2.3: Optical Fiber versus Microwave System [51].

Parameters	Fiber Optic System	Microwave System
Attenuation	Costs	Higher
Data Rate	Higher	Lower
Interference	Less affected by interference	Higher affected by interference specially C-band
Network	Flexible (nodes are expandable)	Complex (line of sight)
Maintenance	Lower	Higher
Costs	Running cost is very low	Running cost is high

3. PROPOSED RADIO ACCESS NETWORK WITH RADIO OVER FIBER FOR NEXT GENERATION MOBILE SYSTEM IN TERM OF TOPOLOGY

3.1. Introduction

It can be said that (RAN) is using for all types of mobile system, each of this RAN have a different Topology such as (Star Topology, Circle Topology, and Tree Topology). On the other hand, to creating and using a new (RAN) is better to use (Mesh Topology) which is suitable for the new system.

In the same way, in the field of using new RAN, (Topology) can be applied as a (Mesh), which includes (Radio over Fiber (RoF). It also uses (Next Generation Mobile System) for the new system, instead of using (Microwave) it can use (Fiber Optic) that is why (Microwave) are ignored, instead of using this it can be used (Fiber Optic), which is useful and uses for (4G) and similar system that affects (Next Generation Mobile System) [52].

3.2. Proposed Radio Access Network in Term of Topology

All of the systems is switched to Central Office, and then all BTs are joined together by using Radio over Fiber (RoF). After that some of the BTS are linked to the BSc, the new design will be used for our system that Topology is Mesh as shown in figure 3.1.

In addition, that is why we use Mesh Topology because it is very significant for the Next Generation Mobile System and also it is proper for (4G). On the other hand, if there is any disconnection between those BTs and BSs that mentioned before, they can use (Cell) to keep on the signal. Therefore, in the below picture are indicates that how BTs and BSc are joined [53].

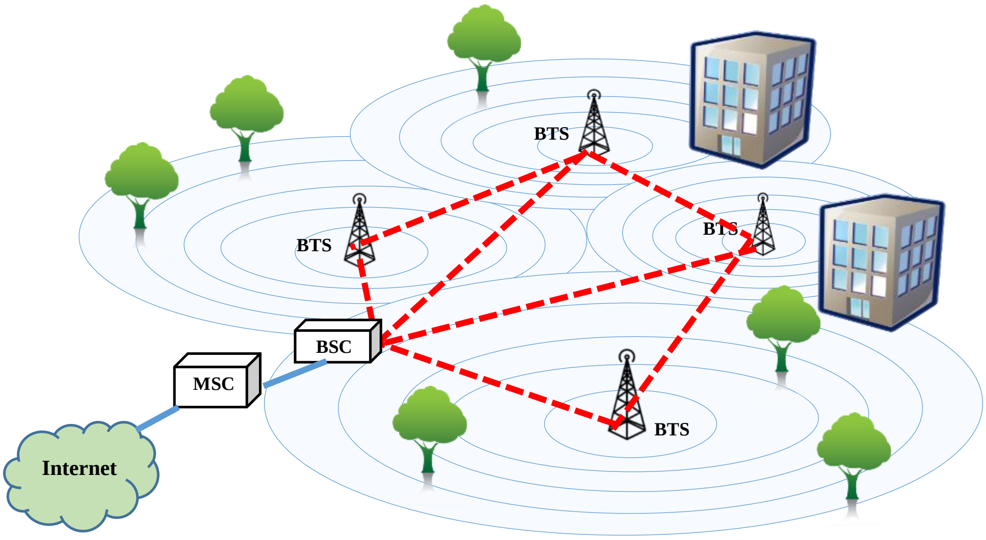


Figure 3.1: Design Radio Access Network by Using RoF.

In relation to the type of communication in GSM, it contains four different types while MS connected to another MS it goes throughout three block diagrams:

- Mobile Station (MS) consists of (ME - SIM).
- Base-System Subsystem (BSS) consists of (BTS - BSC).
- Network and Switching Subsystem (NSS) consists of (MSC - HLR - VLR - EIR - AUC).
- Operation and Support Subsystem (OSS) consists of (ME - BSS - NSS).

Generally, GSM in the systems are known as a (Digital), it called End User and (Mobile Station (MS).

Mobile Station is divided into two parts: Mobile Equipment (ME) and Subscriber Identity Module (SIM), they are creating (MS). So, when the (MS) is connecting and making signals for making coverage inside (BSS) diagram, it directly connects the (MS) to the (BTS), furthermore (BTS) can hold 200 to 300 users at the same time to using channels in terms of calling [54].

When (MS) signaled to the (BTS) number one, it means that this (BTS) signaled to (BSC) in the same block diagram. Then, (BSC) send a signal to (MSC) which is inside the block diagram of (NSS). Subsequently, the block diagram of (NSS) is contains (MSC, HLR, VLR, EIR, and AUC). When (MSC) send announce signal to Home Location Register (HLR).

Regarding (HLR) is a data base for identifying those communications that come through (MSC) or to recognizing those communications comes from (SIM) itself or another SIM. It can be said that HLR is just using for recognizing SIM.

Moreover, if the (SIM) is the same network of the (HLR), the signal is returned to the (MSC). Then, it also returns the signal to (BSC) and (BTS), it means that the (HLR) tells the (MSC) that the calling is in our coverage. But, if the (SIM) is not in our network, the (HLR) send a signal to the (MSC) it announces that this is not in our network.

(VLR) is using when to announce signally comes from (MSC) this is for announce that it is not in our network and it comes from another network. Also, it is responsible to give information and clarify that any connection between two networks which is called (Rooming). If the second network is enabling and there is rooming between two networks, then directly the signal can be sent from our (MSC) and otherwise. But, if there is no room between two networks (VLR) send signals to our (MSC) and announce it that there is no roaming.

Additionally, this time (MSC) send an announcement signal to the Equipment Identity Register (EIR). But sometimes it depends on the users' device, it means that if user's device is installed there is no problem to sending signals. So, in this way (EIR) send signals to (MSC) also to identify that the users' device is installed or not. But, if there is no installation the communication will be disconnected.

This time the (MSC) will send announcement signal to Authentication Centre (AUC). Consequently, it can be said that (AUC) is responsible for balance, and connect to calls or disconnect when (MSC) signals the (BSC). In addition, for those who have a balance (AUC) send another signal for all (BSC) and do the communication successfully.

(OSS) the software is using among three diagram (ME, BSS and NSS). Also, this software is responsible to arrange these three diagrams in terms of communications. (BSS) is using for the 2G system but for 3G it can be used (RNC) instead of (BSS). As shown in figure 3.2.

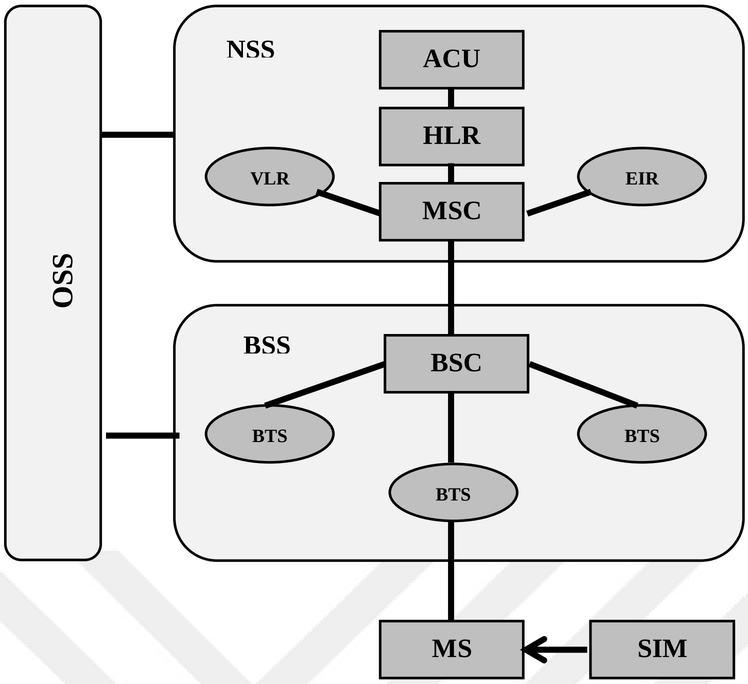


Figure 3.2: Simplified Architecture Diagram of GSM Network.

After the process of calling between Mobile Station (MS) and Base Transmission System (BTS), the calling process is normal if there is no problem between both sides of basic Microwave and Base Transmission System send signals to (Central Base Station).

But, if the signal is lost during sending between Base Transmission System (BTS) and Central Base Station (CBS), there is so many reasons for disconnect the signals this for example: near to airport or large buildings. On the other hand, it affects by some other reason such as raining, snowing, and storm. Those effects are the reason to increase the signal or disconnecting calls between (BTS) and (BSC) [55].

So, to reduce and increase all of the problems that mentioned above and to solve the disconnection between (BTS) and (BSC), it is better to use (Fiber Optic) instead of using (Microwave), because by using (Fiber Optic) in the case of calling those problems are increased.

3.3. Methodology of the Proposed Radio Access Network

3.3.1. Design and Optimization for the New Radio Access Network by using Matlab Code.

Generally, it can be said that we are writing about Dispersion and contains different parts, and each one have a different role. As shown in Figure 3.3.

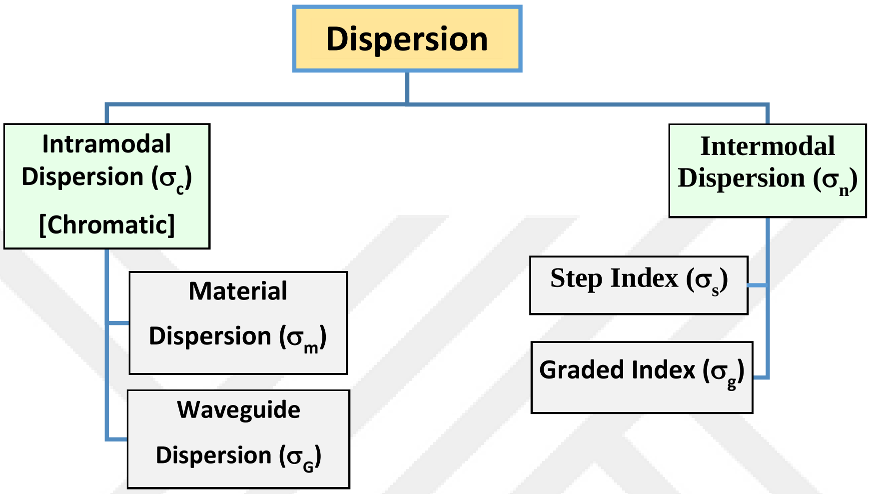


Figure 3.3: Design and Optimization for the Challenges of Optical Fiber.

Dispersion is divided into two main parts (Intermodal and Intermodal dispersion) and (Intermodal). Also (Intermodal) is divided into two parts (Step) and (Graded index); all of the parts will make the Total Dispersion (σ_T). In general, the Dispersion is known by this symbol (σ_T) [56].

Dispersion have another name which called "Chromatic" (σ_c) and divided into two parts (σ_m) and (σ_G), but if (σ_G) approximately near to zero it means ($\sigma_m = \sigma_c$).

So, Intermodal is also divided into two parts (step and graded index), if we use (Step index) we use this symbol (σs), on the other hand, if we use (graded index) we use this symbol (σg).

Step Index has two different types: (single-mode and multi-mode), but in (Graded Index) just we have (multi-mode).

First dispersion, material dispersion (σ_m) in intramodal dispersion (σ_c), also (σ_m) = (σ_c) because waveguide dispersion (σ_G) near of zero therefor (σ_m) = (σ_c) [56].

$$\sigma_{m} = \frac{\sigma_{\lambda} L}{c} \left| \lambda \frac{d^2 n_1}{d\lambda^2} \right| \tag{3.1}$$

Where σ_m= material dispersion, σ_λ = constant, c = 2.998*10^8 constant, L = length of the fiber optic, n1=constant, λ= wavelength of the light.

Second dispersion, waveguide dispersion (σ_G) in intramodal dispersion (σ_c), waveguide dispersion equal to zero therefor (σ_m) = (σ_c) in intramodal dispersion.

Third dispersion, step index (σ_s) in intermodal dispersion (σ_n), has been explained dispersion by Δ or NA. [57]

$$\sigma_s = \frac{L n_1 \Delta}{2\sqrt{3}c} = \frac{L(NA)^2}{4\sqrt{3 n_1} c} \tag{3.2}$$

Where σ_s = step index, L = length of the fiber optic, n1 = constant, Δ= relative refractive index difference, relative with (NA) Numerical Aperture n1 and n2, c = constant.

Forth dispersion, graded dispersion (σ_g) in intermodal dispersion (σ_n), graded dispersion within other dispersion because of length and Δ divided by twenty.

If the user number is few the dispersion is reduced or occur in less rate, so graded dispersion σg is best than other one, the following are the equation of it:

$$\sigma_g = \frac{L n_1 \Delta^2}{20\sqrt{3}c} \tag{3.3}$$

Where σ_g = graded index, L = length of the fiber optic, n1 = constant, Δ= relative refractive index difference, c= constant [58].

Total dispersion (σ_T) is the result of intramodal and intramodal dispersion, by finding the total dispersion we can calculate the Data bit rate by dividing total dispersion by (0.2). [59]

$$\sigma_T = \sqrt{\sigma_c^2 + \sigma_n^2} \tag{3.4}$$

Where σ_T = Total dispersion, σ_c = intramodal dispersion, σ_n = intermodal dispersion.

What is dispersion and how it occurs?

When pulse or signal are sent via Fiber cable, the signal are dissertated by the internal wall of Fiber cable (Root-mean-square), so the distance between the pulses are increasing then in output the pulse are mixed, and it’s called intersymbol interference (ISI).

This increasing in distance for the pulses called Dispersion, as shown in figure 3.4.

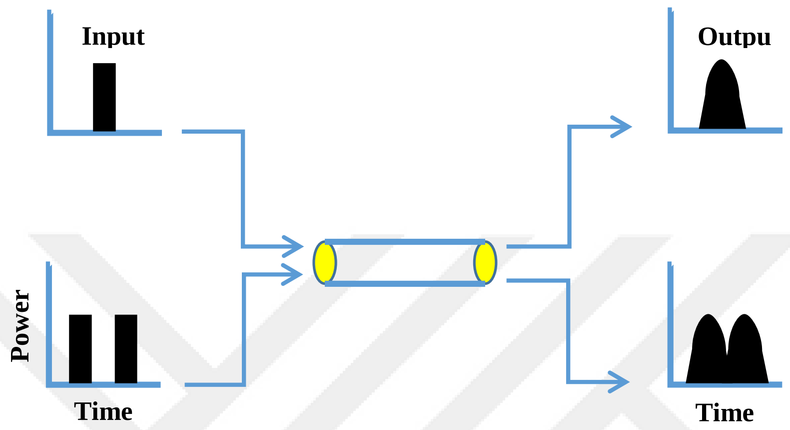


Figure 3.4: This Increasing in Distance for the Pulses Called Dispersion.

The Total Dispersion (σ_T) has been measured, because of the find out Data rate by this equation as follow:

$$BT_{Max} = \text{maximum bit rate} = \frac{0.2}{\sigma_T} \tag{3.5}$$

As σ_T increased the data rate will decrease, by Matlab software we do an optimization for σ_T, we find that best σ_T are that one who have maximum data rate [59].

The data rate for 4G is 1 Gb/sec, for 5G is more than 1 Gb/sec.

3.4. Optisystem Software has been Designing to Design Topology.

Furthermore, in terms of creating new design for (Next Generation Mobile System) that Topology is a Mesh, after we create Matlab code by using Optimization, then using the process of (Optisystem) for creating new design in the shape of (Software), then we use (1 km) or (2 km) Fiber Optic Cable for this system, so some information is collecting before using the system. As shown in figure 3.5 [60].

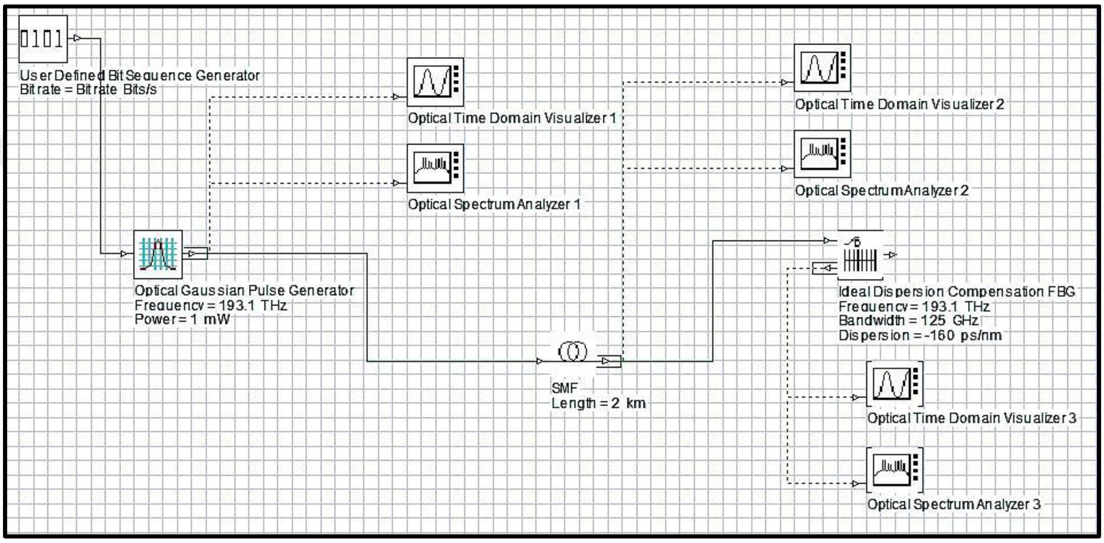


Figure 3.5: Compensation of Dispersion Ideal Dispersion Compensation.

At the beginning of the new design usually it is better to use (User Defined Bit Sequence Generator) however, it works like an (Information) for the system, it means that, it uses instead of using (Mobile Station, User, Video, and Image), and next, we change the signal to Electrical [61].

Subsequently, this Electrical enters the second part of the process (Optical Gaussian Pulse Generator), this part using to remove (Noise) also electrical make it to (Optical), furthermore, inside this part we have (Light Source) if:

(Frequency = 193.1 THZ) and (Power= 1 mW).

It can be said that, we practice two different types of (P input to the fiber), the first one is (Optical Time Domain Visualizer 1) and the second one is (Optical Spectrum Analyzer1), regarding to the first one (Output) is become a (Time with Power), on the other hand, in relation to the second one the (Output) becomes a (λ with Power).

After again giving data for P output from the fiber, first Optical Time Domain Visualizer 1 and second Optical Spectrum Analyzer 1, after for the part Optical Time Domain Visualizer 1 the output result: (Time with Power), also an another part Optical Spectrum Analyzer 1 output result: (λ with Power)

Then, we collect data from (Output) the first time from (Optical Time Domain Visualizer) and then from (Optical Spectrum Analyzer 1).

After using the (Fiber optic cable) it can be noticed that (Dispersion) is built for signals, for reduce or remove this (Dispersion) we are using (Dispersion Compensation FBG). Clarify, how the (FBG) classifies the pulse and arrange them. As shown in figure 3.6 [62].

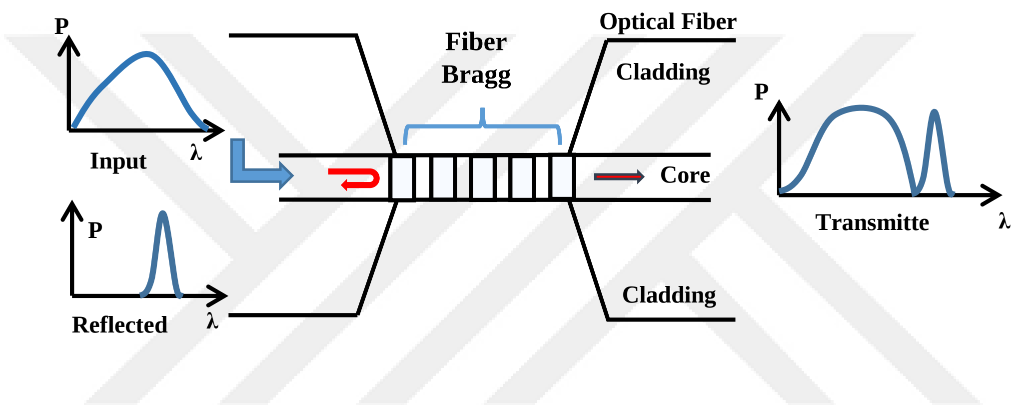


Figure 3.6: The (FBG) are Classify the Pulse and Arrange.

Consequently, after using (Fiber optic cable) it uses (FBG) Fiber Bragg Gratings. After we receiving the signals, we notify that how pulses are combined together, (FBG) are rearrange the signal pulse before they enter to the (Fiber optic cable) [63].

When it have (Dispersion = -160 ps/nm), (Bandwidth = 125 GHz) and (Frequency = 193.1 THz).

After again giving data for P output from the fiber, after using Fiber Bragg Gratings FBG, the first Optical Time Domain Visualizer 1 and the second Optical Spectrum Analyzer 1, after for the part Optical Time Domain Visualizer 1 the output result: (Time with Power), also a another part Optical Spectrum Analyzer 1 output result: (λ with Power). All results in this section explained in chapter four [64].

3.4.1. Hardware Implementation Using Optical Components.

After the simulation of the proposed design with optisystem software, which is a new RAN design for the system, it is topology well be in a mesh topology, for next generation mobile system of 4th generation or above. Later next step is will be the practically shown in figure 4.3.

The aim from this topic is to design a new RAN to solving this problem by removing of Microwave Link between two BTS in place of it, using Fiber optic between All BTS as shown in figure 3.7.

Figure 3.7: Link between Two BTS by Microwave Link.

After, the practical work included a few instrument connected in sequence as (RF Generator, Attenuator, RoF Transmitter, Fiber Optic Cable, RoF Receiver, Spectrum Analyzer, Optical Spectrum Analyzer), presented in figure 3.8.

Figure 3.8: Spectrum Analyzer and Optical Spectrum Analyzer.

The mentioned instruments practically have been connected to gain the results which came to those achieved by optisystem simulation, shown in figure 3.9.

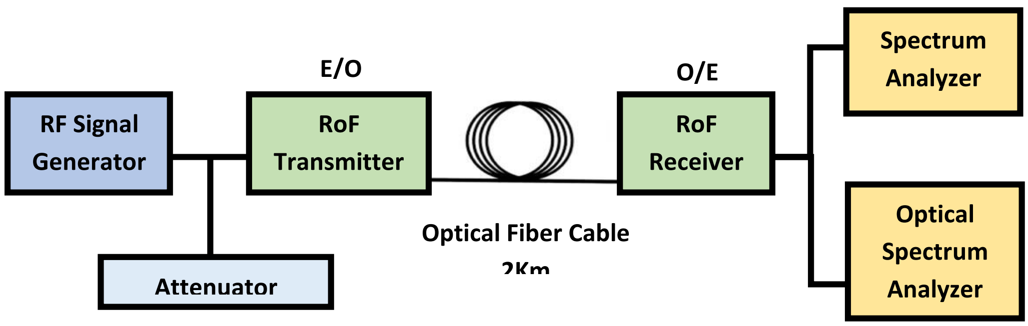


Figure 3.9: Connected Between all Parts.

First, RF signal Generator has been used as a laser source, then connecting to attenuator part, that used the increasing and decreasing of power during reading the results.

After the connection to RoF transmitter part, which is composed of (E/O and light source), and 2 Km fiber optic cable has been connected, after that the RoF receiver connected as comprised in (O/E and detector) as shown in figure 3.10, finally connected to the both parts of spectrum analyzer and optical spectrum analyzer, and the results through them given in chapter four. Spectrum analyzer read the results by frequency versus power, but optical spectrum analyzer read the result by lambda (λ) versus power.

The distance between two BTS is needed to 2 Km fiber optic cable because of the next generation mobile system for a 4th generation or above near 2 Km.

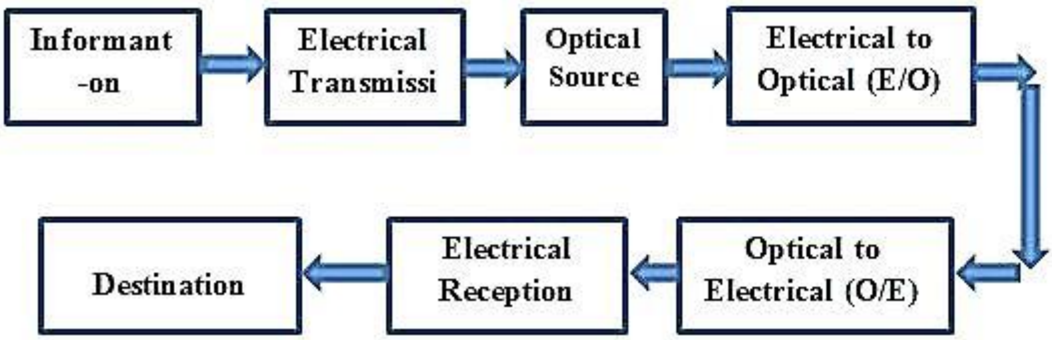


Figure 3.10: Flow Chart in This my Work.

4. DESIGN OF THE PROPOSED RADIO ACCESS NETWORK FOR 4G MOBILE SYSTEMS BY MESH TOPOLOGY

4.1. Introduction

In this study, after the proposed channel allocation and cell distributions, the clustering of the cells, and the carrier frequencies assignment were completed, work was begun for the design of the proposed Radio Access Network (RAN).

The proposed RAN architecture employs grouping the overall coverage base stations into a number equal to the cluster size. For example, for cluster size N = 0 there will be zero group, cluster size N = 1 there will be one group, cluster size N = 3, there will be three groups, four groups when N = 4, seven groups when N = 7, twelve groups when N = 12, thirteen groups N= 13, nineteen groups when N = 19, twenty-seven groups when N = 27 etc. The contribution of this work is that the 4G mobile system will have central base stations (CBSs) for each group connected to these central base stations, unlike the GSM system which has many base transceivers (BTS). In the GSM system, each group of these BTSs is connected to a base switching control (BSC), and these BSCs are connected to the mobile switching center (MSC), with all of these connections between BTSs, BSCs, and the MSC made via a microwave link.

Furthermore, in 3G mobile systems, there are base stations named Node-B, and each group of this Node-BS is connected to radio network controllers (RNC), also through microwave links like the GSM system, and then these RNCs are connected to the core network.

In this work, each group of base stations will be connected directly to CBSs through the use of the radio over fiber (RoF) technique, using a fiber optic channel instead of a microwave link. Figure 4.1 shows the connection of one group of base stations to their central base station (the black nodes represent base stations and the red lines are fiber optic links using RoF technique). A practical view for the proposed RAN is shown in figure 4.2.

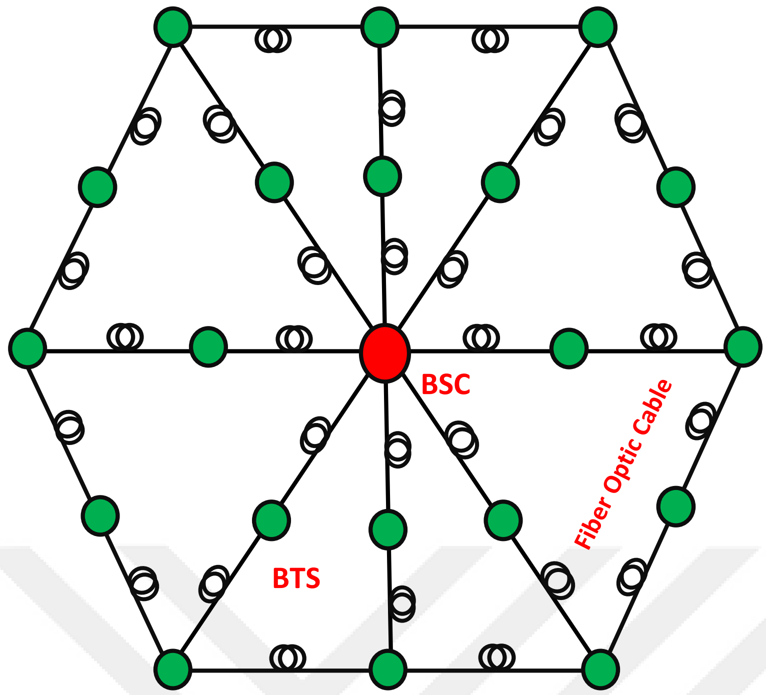


Figure 4.1: Proposed Base Station by Mesh Topology Nodes

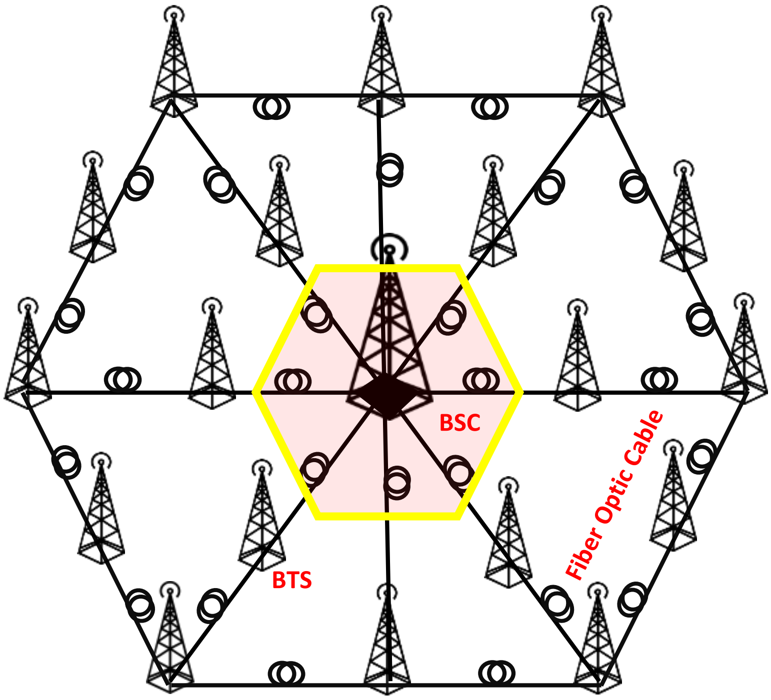


Figure 4.2: Proposed Practical View Mesh Topology

Optical fiber link is an underground link, unlike microwave link, which has many disadvantages such as atmosphere effects, and interference with other signals, especially C-band satellite signals, because the C-band is (4-8) GHz. Thus if microwave linkage were used for a 4G mobile system which has the frequency band (2-8) GHz, the interference with C-band signals would be a problem, but using fiber optics, this problem is solved.

The length of the fiber optic cable between two adjacent base stations BS must be greater than twice the reuse distance D of each base station for cluster size N = group of cells, therefore, the length of the fiber for different cluster sizes can be obtained as given in Table 4.1

Table 4.1: The Group of Cells and Radius Cells.

i	J	Group of cells	Radius Cells
0	0	0	0
0	1	1	1.73 ≅ 2
1	0	1	1.73 ≅ 2
1	1	3	3
0	2	4	3.46
2	0	4	3.46
1	2	7	4.58
2	1	7	4.58
2	2	12	6
0	3	9	5.19
3	0	9	5.19
3	1	13	6.24
1	3	13	6.24
3	2	19	7.54
2	3	19	7.54
3	3	27	9

Where is;

N = Cluster size = Group of cells ⇒ N = Group of cells, Radius of cells = Fiber optic length.

The area of the hexagonal cell can be calculated as:

For the proposed RAN, for each group of base stations and additional central base station, the first tier base station number = 6, second tier = 12, third tier = 18, i.e. 6 base stations will be added for each subsequent tier. Now the total number of base stations needed for a certain coverage area and cluster size can be obtained, after calculation for each group as shown in Table 4.2.

$$\textbf{Coverage Area} = [\,\mathbf{2.6} \times (\boldsymbol{R})^{\mathbf{2}}\,] \times \textbf{BTS}$$

Table 4.2: (L) Fiber Length and Coverage's Area

No. of Groups	No. of Tiers	No. of (BTS)	Radius Cells	Coverage Area $[2.6 \times (R)^2] \times$ BTS	Coverage's Area
0	1	1	0	$[2.6 \times (0)^2] \times 1$	0 Km^2
1	7	127	1.73 ≅ 2	$[2.6 \times (2)^2] \times 127$	1,320.8 Km^2
3	7	381	3	$[2.6 \times (3)^2] \times 381$	8,915.4 Km^2
4	7	508	3.46	$[2.6 \times (3.46)^2] \times 508$	15,812.08 Km^2
7	7	889	4.58	$[2.6 \times (4.58)^2] \times 889$	48,484.85 Km^2
9	7	1143	5.19	$[2.6 \times (5.19)^2] \times 1143$	80,048.70 Km^2
12	7	1524	6	$[2.6 \times (6)^2] \times 1524$	142,646.40 Km^2
13	7	1651	6.24	$[2.6 \times (6.24)^2] \times 1651$	167,143.54 Km^2
19	7	2413	7.54	$[2.6 \times (7.54)^2] \times 2413$	356,675.56 Km^2
27	7	3429	9	$[2.6 \times (9)^2] \times 3429$	722,147.4 Km^2

Tiers = Coverage of BTS
Number of Tiers = 1 + 6 + 12 + 18 + 24 + 30 + 36 ⇒ 127 BTS

If, Cluster Size N = 7 seven groups, BTS radius cell = 4.58 km, the number of Base Transmission Station BTS = 889 and the commonly coverage area = 48,484.85 km^2.

The fiber type will be multi-mode fiber because for short distances this type is suitable, unlike single mode which is better for long distances. Conversion from (E/O) and from (O/E) will be used for transmission and reception of signals, by the employment of RoF technique utilized in this work for the connection between base stations.

Wave Division Multiplexing (WDM) technique was used to connect each group of base stations to their central base station.

After the radio access design, calculations for the network parameters were done, especially for the fiber optics parameters like dispersion, numerical aperture, relative refractive index, the difference between Brillouin and Raman powers as threshold minimum and maximum powers launched to the fiber, and calculation of data rates with different fiber lengths.

Practical RoF experiments were done with a fiber length of 2 km for transmitted and received signals. Figure 4.3 is the experimental setup circuit, using RoF technique as the connection between two base station transceivers, which the practical setup is corresponding to the methodology of this work.

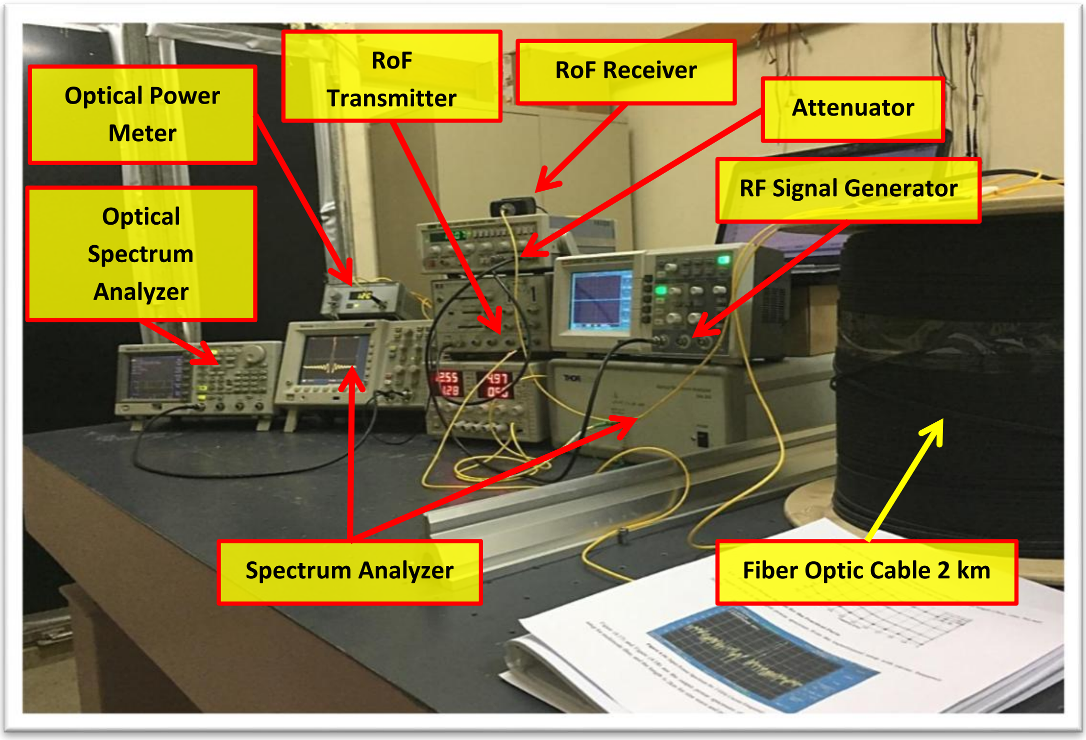


Figure 4.3: Experimental Setup Components and Connection.

The experimental components shown in figure 4.3 are Radio over Fiber (RoF) transmitter and receiver, spectrum analyzer, optical spectrum analyzer, attenuator, RF signal generator, and SMF optical fibers with lengths 3m 10m and MMF with 2km.

4G mobile system coverage is about one-third of that in 3G mobile systems, and therefore, the coverage area for 4G will 2-3 km. Using Matlab software, the optimum parameters were obtained, and these parameters and simulation are detailed in this chapter with the complete results are given in this chapter.

4.2. Proposed Design and Optimization Results Using MATLAB Software

After Radio Access Network design was completed, RoF technique is employed using fiber optic links as a connection between the base stations. Multimode Fiber (MMF) with 2 km is used, and also 3 m and 10 m Singlemode Fiber (SMF) are used in the experiment as a link method between two neighbor base stations, as shown in figure 4.1 and figure 4.2.

Figure 4.4 (A and B) shows the relation between data rate and the fiber length using multimode graded index fiber optics with different relative refractive index differences (Delta). It is shown that fiber length is about 2km. Thus, relative refractive index difference must be less than 0.04 for a higher data rate as given in Table 4.3.

$$\sigma_g = \frac{Ln_1\Delta^2}{20\sqrt{3c}}$$

Where is;

L = (1000 to 6000),

n1 = (1.5) constant,

Δ Delta = (0.04, 0.05, 0.06, 0.07, 0.08),

C = $3*10^{8.}$

$$\sigma_{m=}\sigma_\lambda \times L \times M$$

Where is;

$\sigma_{\lambda\,=}$ $20*10^{-9}$,

L = (1000 to 6000),

M = $100*10^{-12}$

$$\sigma_T = \sqrt{\sigma_g^2 + \sigma_m^2}$$

Where σ_T = Total dispersion, σ_g = intramodal dispersion, σ_m = intermodal dispersion.

$$\text{Data Rate} = \frac{0.2}{\sigma_T}$$

As σ_T increased the data rate will decrease, by MATLAB software we do an optimization for σ_T, Data Rate = DR.

Table 4.3: Comparison between Fiber Length (m) versus Data Rate (Mbps) for delta.

Fiber Length (m)	Data Rate (Mbps) for Delta				
	DR 1	DR 2	DR 3	DR 4	DR 5
1000	886	554.24	384.88	282.77	216.50
1500	577.33	369.49	256.59	188.51	144.33
2000	433	277.12	192.44	141.38	108.25
2500	346.40	221.69	153.95	113.11	86.60
3000	288.66	184.74	128.29	94.25	72.16
3500	247.42	158.35	109.96	80.79	61.85
4000	216.50	138.56	96.22	70.69	54.12
4500	192.44	123.16	85.53	62.83	48.11
5000	173.20	110.84	76.97	56.55	43.30
5500	157.45	100.77	69.97	51.41	39.36
6000	144.33	92.37	64.14	47.12	36.08

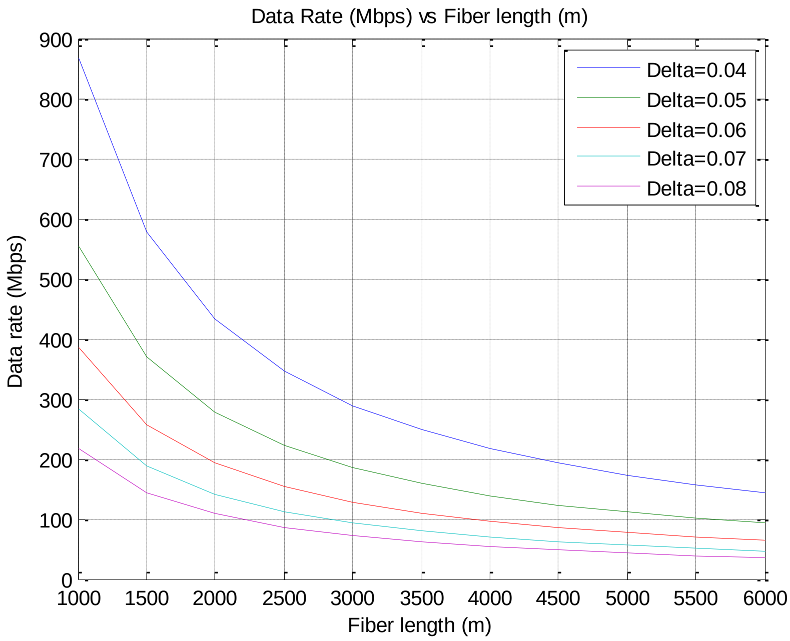


Figure 4.4-A: Data Rate versus Fiber Length for Delta by MATLAB Code.

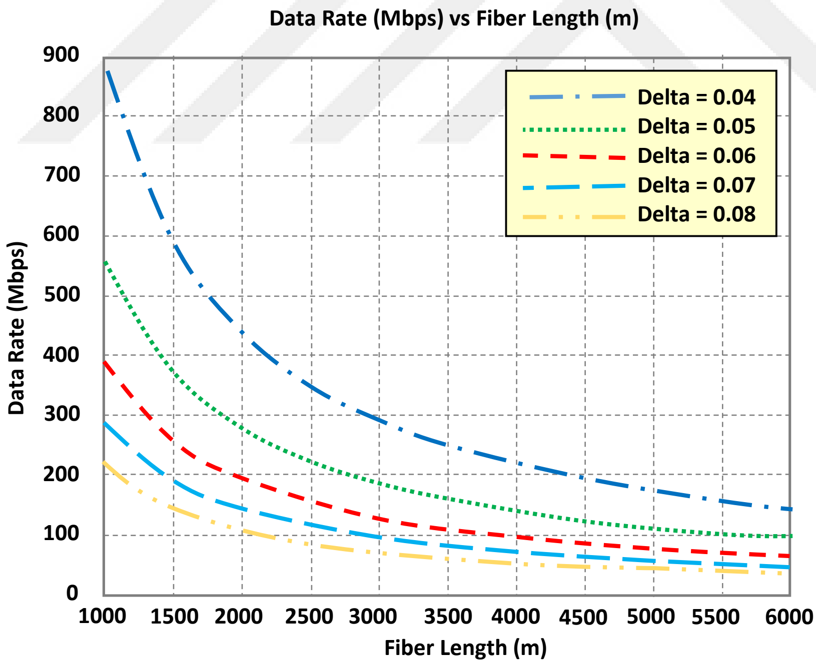


Figure 4.4-B: Data Rate versus Fiber Length for Delta by Simulation.

Figure 4.5 (A and B) shows the relationship between fiber length and data rate with different numerical apertures (NA), using multimode step index fiber optics, it is found that for higher data rate and fiber length about 2km, the numerical aperture must be less than 0.028 as given in Table 4.4.

$$\sigma_s = \frac{L(NA)^2}{4\sqrt{3n_1c}}$$

Sigma S = L * (Na1.^2) / (6.8 * c * n1)

Where is;

L = (1000 to 6000),

n1 = (1.5) constant,

Numerical Aperture (NA) = (0.028, 0.03, 0.034, 0.036, 0.038),

C = $3*10^{8.}$

$$\sigma_m = \sigma_\lambda \times L \times M$$

Where is;

$\sigma_\lambda = 20*10^{-9}$,

L = (1000 to 6000),

M = $100*10^{-12}$

$$\sigma_T = \sqrt{\sigma_s^2 + \sigma_m^2}$$

Where $\sigma_T =$ Total dispersion, $\sigma_g =$ intramodal dispersion, $\sigma_m =$ intermodal dispersion.

$$\text{Data Rate} = \frac{0.2}{\sigma_T}$$

As σ_T increased the data rate will decrease, by MATLAB software we do an optimization for σ_T, Data Rate = DR.

Table 4.4: Comparison between Fiber Lengths (m) versus Data Rate (Mbps) for Numerical Aperture (NA).

Fiber Length (m)	Data Rate (Mbps) for Numerical Aperture (NA)				
	DR 1	DR 2	DR 3	DR 4	DR 5
1000	780.61	680	529.41	472.22	423.82
1500	520.40	453.33	352.94	314.81	282.54
2000	390.30	340	264.70	236.11	211.91
2500	312.24	272	211.76	188.88	169.52
3000	260.20	226.66	176.47	157.40	141.27
3500	223.03	194.28	151.26	134.92	121.09
4000	195.15	170	132.35	118.05	105.95
4500	173.46	151.11	117.64	104.93	94.18
5000	156.12	136	105.88	94.44	84.76
5500	141.92	123.63	96.25	85.85	77.05
6000	130.10	113.33	88.23	78.70	70.63

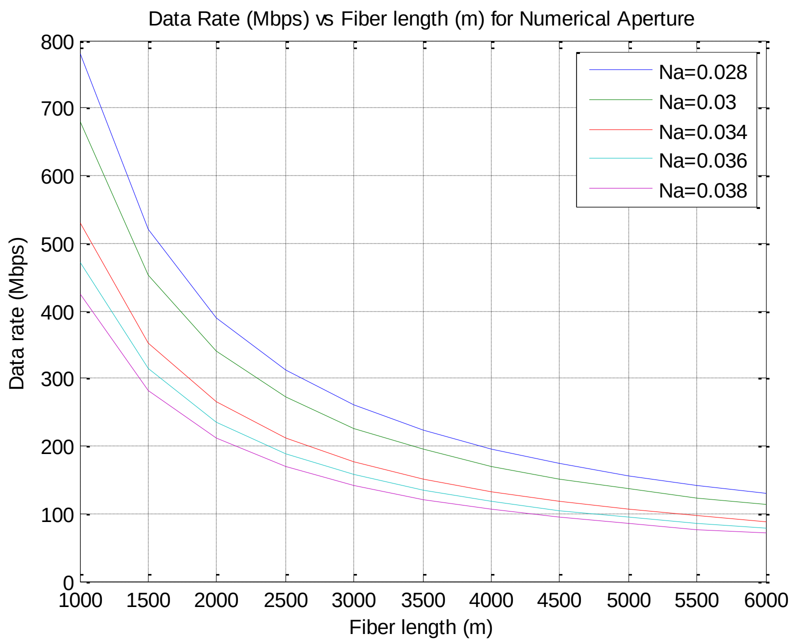


Figure 4.5-A: Data Rate versus Fiber Length for Step Index Fiber by MATLAB Code.

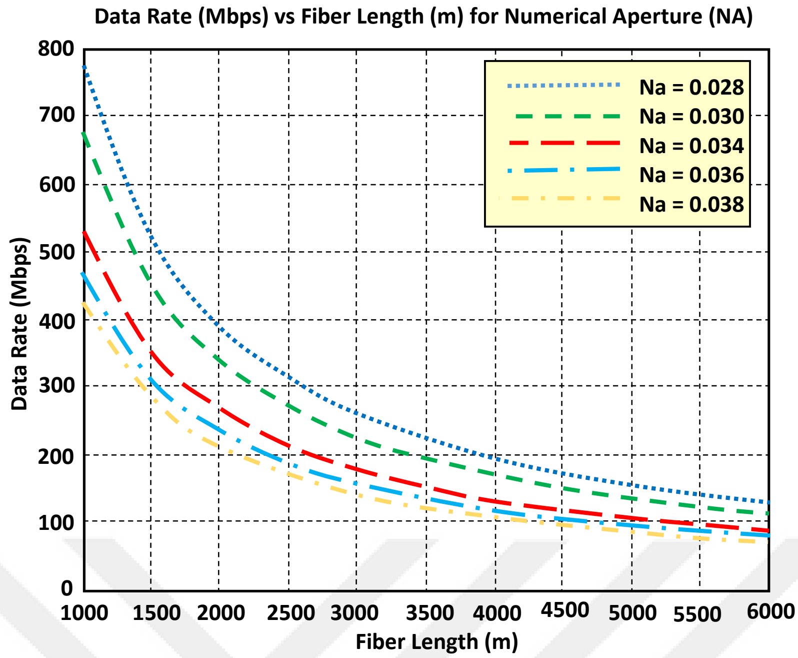


Figure 4.5-B: Data Rate versus Fiber Length for Step Index Fiber by Simulation.

Figure 4.6 (A and B) shows the relationship between data rate and relative refractive index difference (Delta) for different cluster sizes (N) using multimode step index fiber optics. It is shown that without clustering (N=1), the data rate is higher, but this causes higher CCI and ACI, and hence SIR will be decreased. Therefore, N=3 and N=7 clustering would be more optimal. Using the cluster size N=4, the distribution for the base stations will not be uniform and using N=7, base station numbers will be increased, but the number of carriers will be decreased. On the other hand, using N=3, the number of base stations is decreased, but the carrier frequencies used will be increased. Therefore, this work proposed that for the RAN, the two cluster sizes N =3 and N=7 are to be used. In addition, for step index multimode fiber, the relative refractive index difference must be less than 0.0004 for higher data rate as shown in figure 4.7 as given in Table 4.5.

Distance (L) = $\sqrt{3 \times N \times R}$

Where is;

Cluster Size (N) = (1, 3, 4, 7 and 12)

R = 2 * 10^6

$$\sigma_s = \frac{L(NA)^2}{4\sqrt{3n_1c}}$$

Where is;

Numerical Aperture (Na) = (0.02)

Lambda (λ) = 1.8 * 10^{-6}

Delta (Δ) = (0.2, 0.4 to 1.8)

Data Rate = (0, 100 to 600)

n1 (Constant) = 3* 10^8

R = 2 * 10^6

$$\sigma_m = \sigma_\lambda \times L \times M$$

Where is;

$\sigma_{\lambda} =$ 20 * 10^{-9}

M = 100 * 10^{-12}

$$\sigma_T = \sqrt{\sigma_s^2 + \sigma_m^2}$$

Where $\sigma_T =$ Total dispersion, $\sigma_g =$ intramodal dispersion, $\sigma_m =$ intermodal dispersion.

$$\text{Data Rate} = \frac{0.2}{\sigma_T}$$

As σ_T increased the data rate will decrease, by MATLAB software we do an optimization for σ_T, Data Rate = DR.

Table 4.5: Comparison between the Relative Refractive Index Difference (Delta (Δ)) step Index Fiber versus Data Rate (Mbps) for Cluster Size (N).

Delta (Δ) Step Index	Data Rate (Mbps) for Cluster Size (N)				
	DR 1	DR 2	DR 3	DR 4	DR 5
0.2	588.89	340	294.44	222.58	170
0.4	294.44	170	147.22	111.29	85
0.6	196.29	113.33	98.14	74.19	56.66
0.8	147.22	85	73.61	55.64	42.50
1	117.77	68	58.88	44.51	34
1.2	98.14	56.66	49.07	37.09	28.33
1.4	84.12	48.57	42.06	31.79	24.28
1.6	73.61	42.50	36.80	27.82	21.25
1.8	65.43	37.77	32.71	24.73	18.88

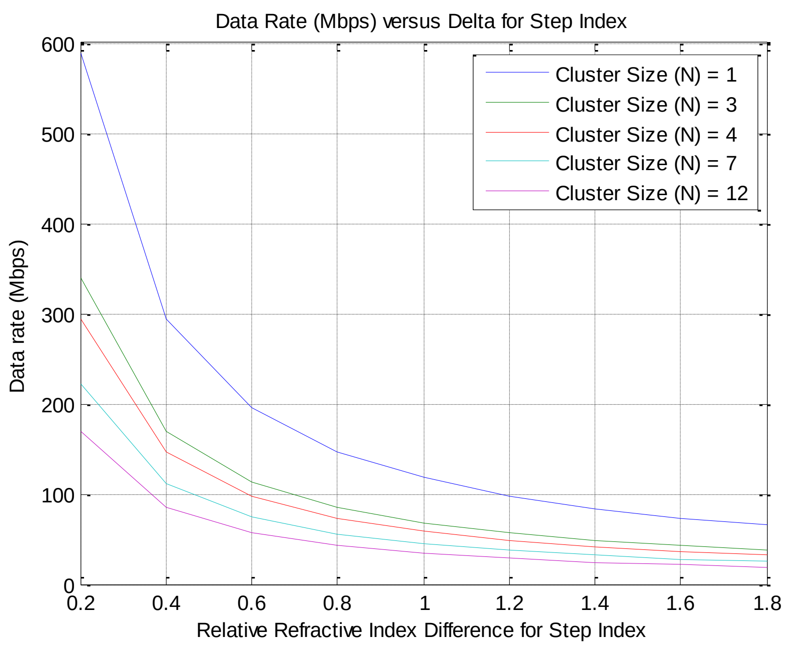


Figure 4.6-A: Data Rate versus Relative Refractive Index Difference for Step Index by MATLAB Code.

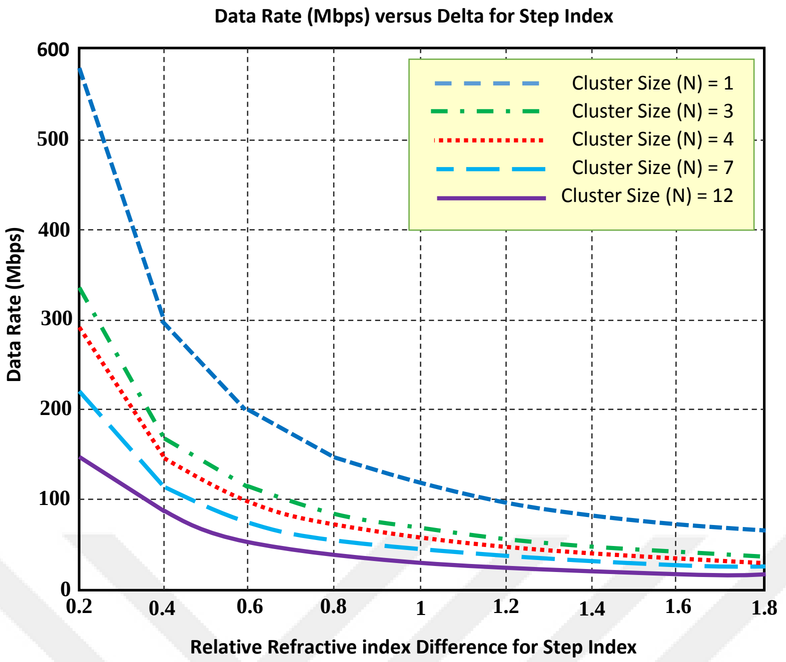


Figure 4.6-B: Data Rate versus Relative Refractive Index Difference for Step Index by Simulation.

Figure 4.7 (A and B) shows the relation between data rate and relative refractive index difference (Delta) for different cluster sizes (N) with graded index multimode fiber optics. It is demonstrated that without clustering (N=1), the data rate is increased, but this causes higher CCI and ACI, and hence SIR will be decreased. Therefore, again, N=3 and N=7 were deemed better. Using the cluster size N=4, the distribution for the base stations will not be uniform and using N=7, the base station numbers will be increased, but carriers will be decreased. Again, using N=3, the number of base stations decreased, but the carrier frequencies used increased. Thus the two cluster sizes N =3 and N=7 are used. For graded index multimode fiber, the relative refractive index difference must be less than 0.04 for a higher data rate, as shown in figure 4.8 as given in Table 4.6.

Distance (L) = $\sqrt{\boldsymbol{3} \times \boldsymbol{N} \times \boldsymbol{R}}$

Where is;

Cluster Size (N) = (1, 3, 4, 7 and 12)

R = 2 * 10^6

$$\sigma_m = \sigma_\lambda \times L \times M$$

Where is;

σ_λ = 20 * 10^{-9}

M = 100 * 10^{-12}

$$\sigma_g = \frac{Ln_1\Delta^2}{20\sqrt{3c}}$$

σ_g = n1 * Δ^2 * L / (3.464 * c)

Where is;

n1 = (1.5) constant,

Δ Delta = (0.02, 0.04 to 2.2),

C = 3*$10^{8.}$

$$\sigma_T = \sqrt{\sigma_s^2 + \sigma_m^2}$$

Where σ_T = Total dispersion, σ_g = intramodal dispersion, σ_m = intermodal dispersion.

$$\text{Data Rate} = \frac{0.2}{\sigma_T}$$

As σ_T increased the data rate will decrease, by MATLAB software we do an optimization for σ_T, Data Rate = DR.

Table 4.6: Comparison between the Relative Refractive Index Difference (Delta (Δ)) Graded Index Fiber versus Data Rate (Mbps) for Cluster Size (N).

Delta (Δ) Graded index	Data Rate (Mbps) for Cluster Size (N)				
	DR 1	DR 2	DR 3	DR 4	DR 5
0.02	999.97	577.33	499.98	377.95	288.66
0.04	249.99	144.33	124.99	94.48	72.16
0.06	111.10	64.14	55.55	41.99	32.07
0.08	62.49	36.08	31.24	23.62	18.04
0.1	39.99	23.09	19.99	15.11	11.54
0.12	27.77	16.03	13.88	10.49	8.01
0.14	20.40	11.78	10.20	7.71	5.89
0.16	15.62	9.02	7.81	5.90	4.51
0.18	12.34	7.12	6.17	4.66	3.56
0.2	9.99	5.77	4.99	3.77	2.88
0.22	8.26	4.77	4.13	3.12	2.38

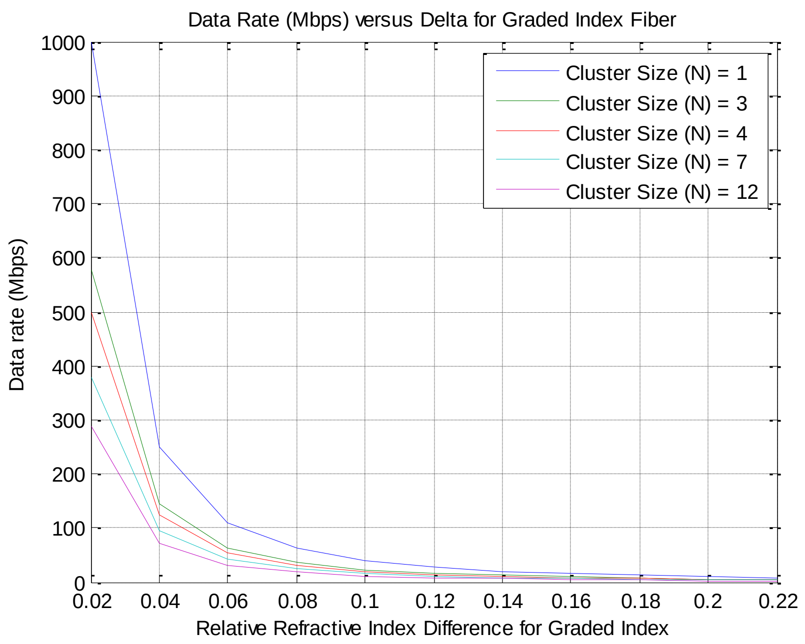


Figure 4.7-A: Data Rate versus Relative Refractive Index Difference for Graded Index by MATLAB Code.

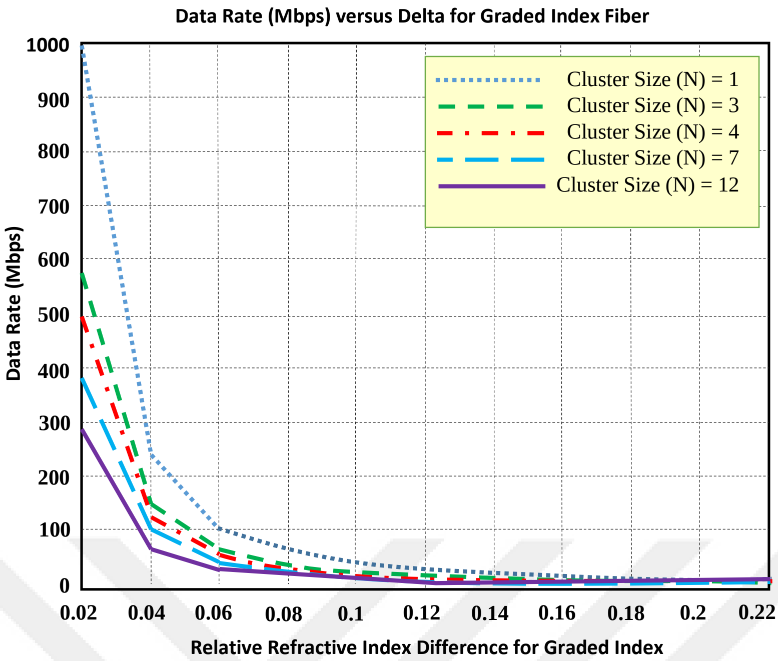


Figure 4.7-B: Data Rate versus Relative Refractive Index Difference for Graded Index by Simulation.

Table 4.7 is the comparison between the parameters obtained and theoretical values.

Table 4.7: RoF Parameters Comparison

Parameter	In this work	Theoretically
Delta (Δ)	0.04 for graded fiber index	0.0198 ➔ (Senior J. M.) (1984)
	0.0004 for step fiber index	0.00019 ➔ (Senior J. M.) (1984)
(NA)	0.03	0.298 ➔ (Senior J. M.) (1984)
(L)	1.5 km < L < 2 km	2 km (Mauricio Arango) (2001)
(DR)	200 Mbps > DR > 1Gbps	100 Mbps > DR > 200 Mbps (Mauricio Arango) (2001)

Using the proposed RAN, the data rate will be increased to a level suitable for a 4G mobile system. Figure 4.8 (A and B) shows the DR versus (SNR) using the proposed RAN for (3G and 4G mobile systems). It is shown that as SNR increases, the data rate will be somewhat increased for 4G. But for 3G, a further increased SNR yields only a very small data rate increase (approximately constant), Comparison between the signal to noise ratio versus data rate (Mbps) for three generation (3G) and four generation (4G) as given in Table (4.8, 4.9 and 4.10)

$$C = B.W \times \log 2\left(1 + \frac{S}{N}\right)$$

Where is;

C= channel capacity,

B.W= Bandwidth: (3G= 60 * 10^6 MHz), (4G= 2 * 10^9 GHz),

S/N= Signal to noise ratio.

Where is Signal to Noise Ratio = SNR, Data Rate = DR.

Table 4.8: Signal to Noise Ratio and Data Rate for Three Generation (3G).

Signal to noise ratio (SNR)	Data Rate (Mbps) to 3G
1	**60**
2	**95.09**
3	**120**
4	**139.31**
5	**155.09**
6	**168.44**
7	**180**
8	**190**
9	**199.31**
10	**207.56**

Table 4.9: Signal to Noise Ratio and Data Rate for Four Generation (4G).

Signal to noise ratio (SNR)	Data Rate (Mbps) to 4G
1	200
2	316.99
3	400
4	464.38
5	516.99
6	561.47
7	600
8	645
9	664.38
10	691.88

Table 4.10: Comparison between the Signal to Noise Ratio versus Data Rate (Mbps) for Three Generation (3G) and Four Generation (4G).

Signal to noise ratio (SNR)	Data Rate (Mbps)	
	3G	4G
1	60	200
2	95.09	316.99
3	120	400
4	139.31	464.38
5	155.09	516.99
6	168.44	561.47
7	180	600
8	190	645
9	199.31	664.38
10	207.56	691.88

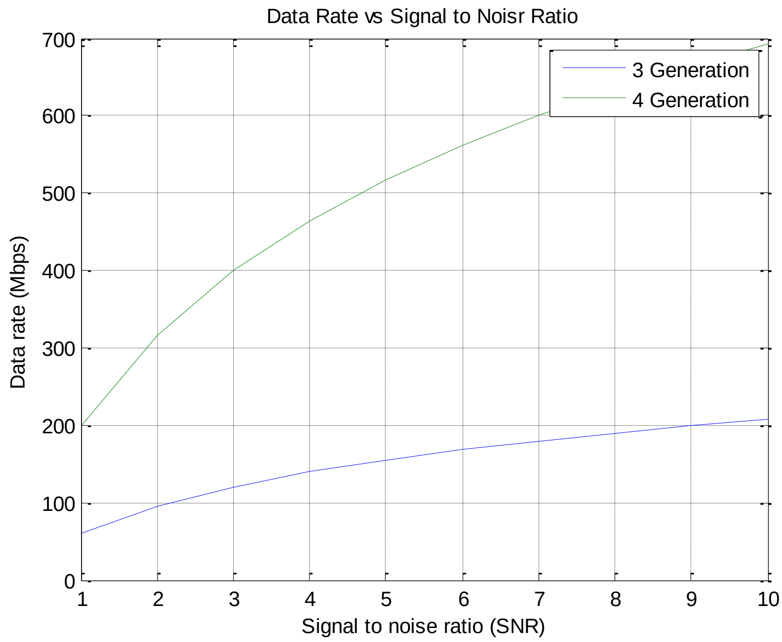


Figure 4.8-A: Signal to Noise Ratio (SNR) and Data Rate (Mbps) by MATLAB Code.

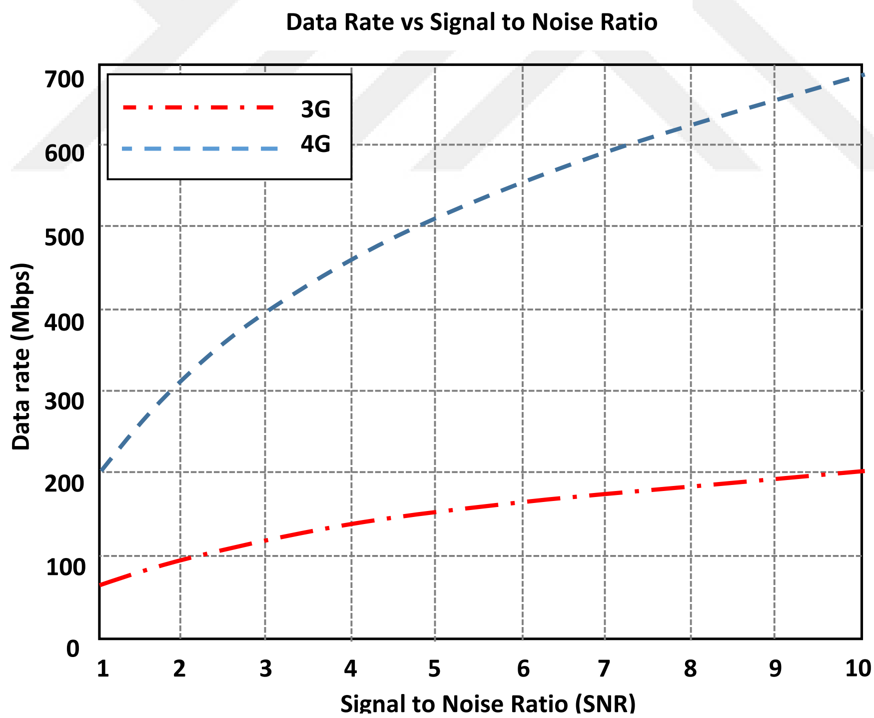


Figure 4.8-B: Signal to Noise Ratio (SNR) and Data Rate (Mbps) by Simulation.

Figure 4.9 (A, B to H), the relation between input power and output power obtained in the experimental setup for different fiber lengths as shown in figure 4.9 by block diagram for comparison between input and output power for fiber length, Comparison between the input power (dB) versus output power (dBm) for fiber length (2km, 10m, 9m and 3m) as given in Table (4.11, 4.12 to 4.15).

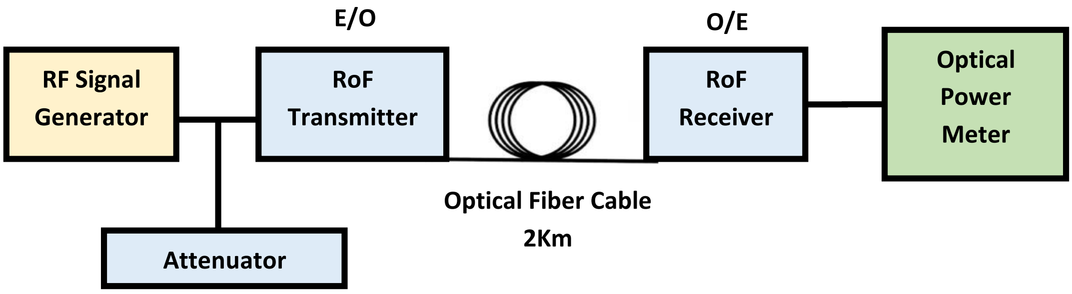


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Figure 4.9-A: Block Diagram for Comparison between Input and Output Power for Fiber Length (3m, 9m, 10m and 2 km).

Figure 4.9-B: Practically at working in Laboratory RoF Using Fiber Cable (2km, 10m, 9m, and 3m).

Table 4.11: The Relation between Input Power (dB) and Output Power (dBm) for 2 Km.

Input (dB)	Output Power (dBm) for 2 Km
0	-14.2
1	-15.2
2	-16.3
3	-17.5
4	-18.6
5	-19.6
6	-20.6
7	-21.6
8	-22.7
9	-23.7
10	-24.7

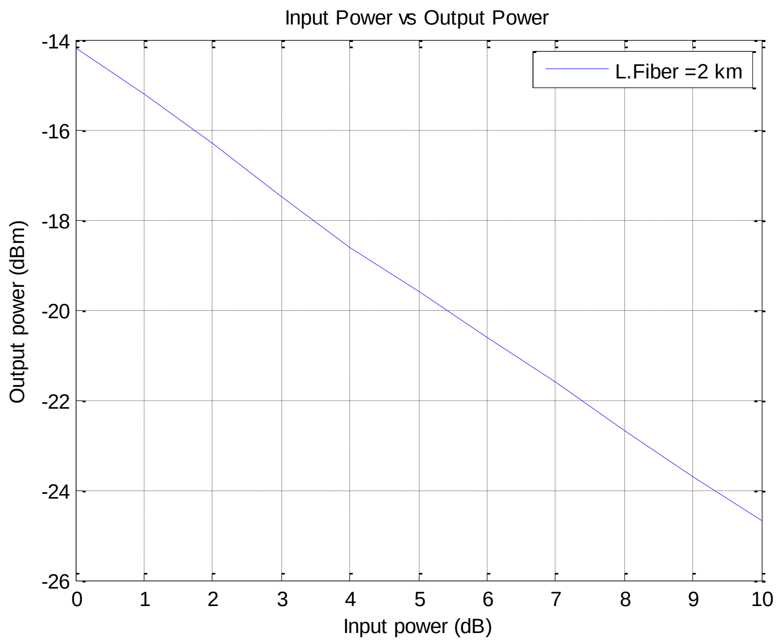

Figure 4.9-C: The Relation between Input Power (dB) and Output Power (dBm) for 2 km by MATLAB Code.

Table 4.12: The Relation between Input Power (dB) and Output Power (dBm) for 10 m.

Input (dB)	Output Power (dBm) for 10 m
0	**-16.7**
1	**-17.5**
2	**-18.5**
3	**-19.4**
4	**-20.5**
5	**-21.5**
6	**-22.5**
7	**-23.6**
8	**-24.6**
9	**-25.6**
10	**-26.7**

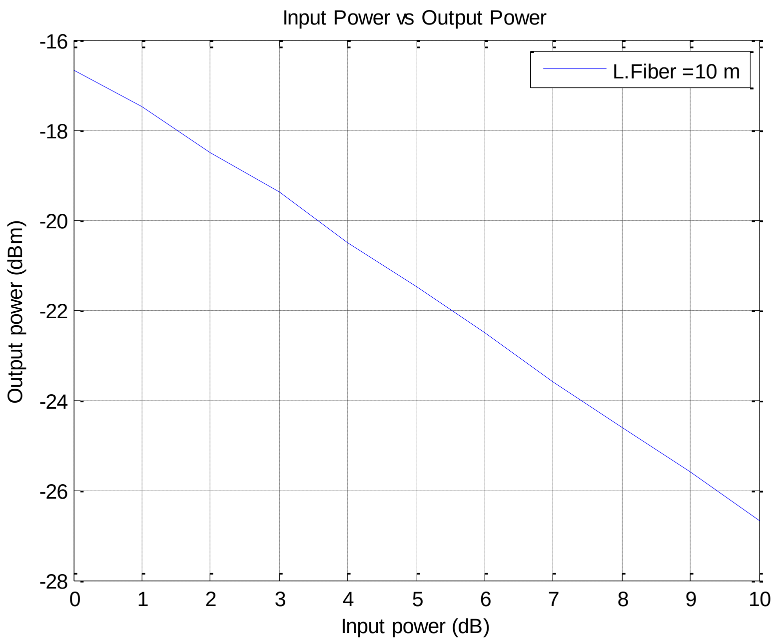

Figure 4.9-D: The Relation between Input Power (dB) and Output Power (dBm) for 10m by MATLAB Code.

Table 4.13: The Relation between Input Power (dB) and Output Power (dBm) for 9m.

Input (dB)	Output Power (dBm) for 9 m
0	-19.2
1	-20
2	-21
3	-22
4	-23
5	-24
6	-25
7	-26.1
8	-27.1
9	-28.1
10	-29.2

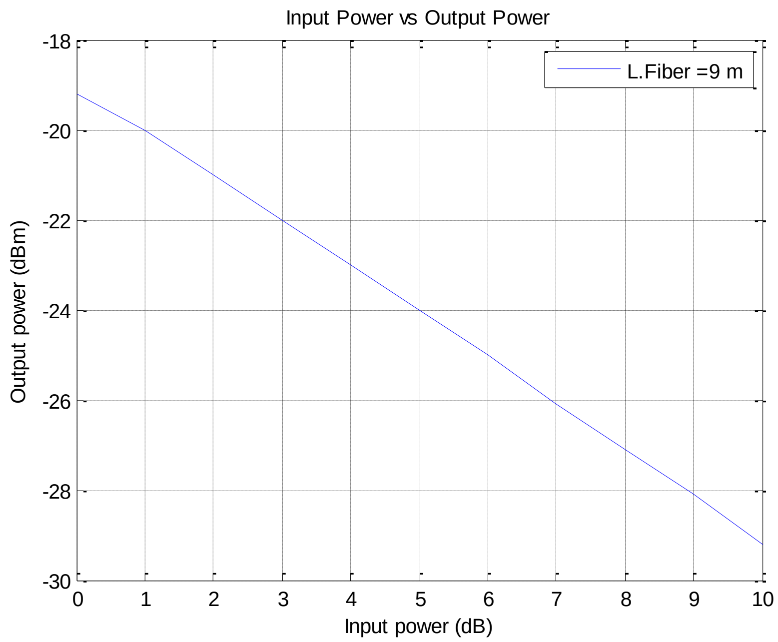

Figure 4.9-E: The Relation between Input Power (dB) and Output Power (dBm) for 9m by MATLAB Code.

Table 4.14: The Relation between Input Power (dB) and Output Power (dBm) for 3m.

Input (dB)	Output Power (dBm) for 3 m
0	-29.1
1	-29.9
2	-30.8
3	-31.8
4	-32.8
5	-33.8
6	-34.8
7	-35.9
8	-36.9
9	-37.9
10	-39.1

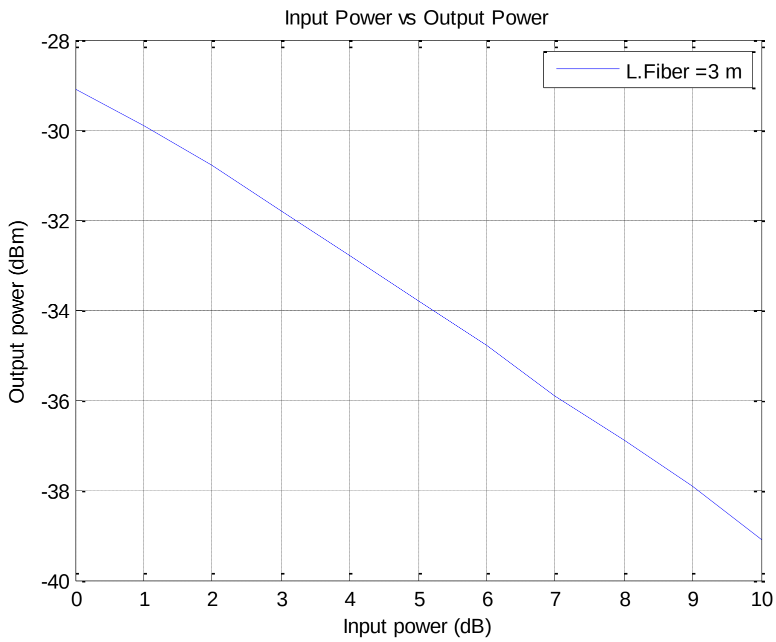

Figure 4.9-F: The Relation between Input Power (dB) and Output Power (dBm) for 3m by MATLAB Code.

Table 4.15: Comparison between the Input Power (dB) versus Output Power (dBm) for Fiber Length (2km, 10m, 9m, and 3m).

Input (dB)	Output Power (dBm)			
	2 km	10 m	9 m	3 m
0	-14.2	-16.7	-19.2	-29.1
1	-15.2	-17.5	-20	-29.9
2	-16.3	-18.5	-21	-30.8
3	-17.5	-19.4	-22	-31.8
4	-18.6	-20.5	-23	-32.8
5	-19.6	-21.5	-24	-33.8
6	-20.6	-22.5	-25	-34.8
7	-21.6	-23.6	-26.1	-35.9
8	-22.7	-24.6	-27.1	-36.9
9	-23.7	-25.6	-28.1	-37.9
10	-24.7	26.7	-29.2	-39.1

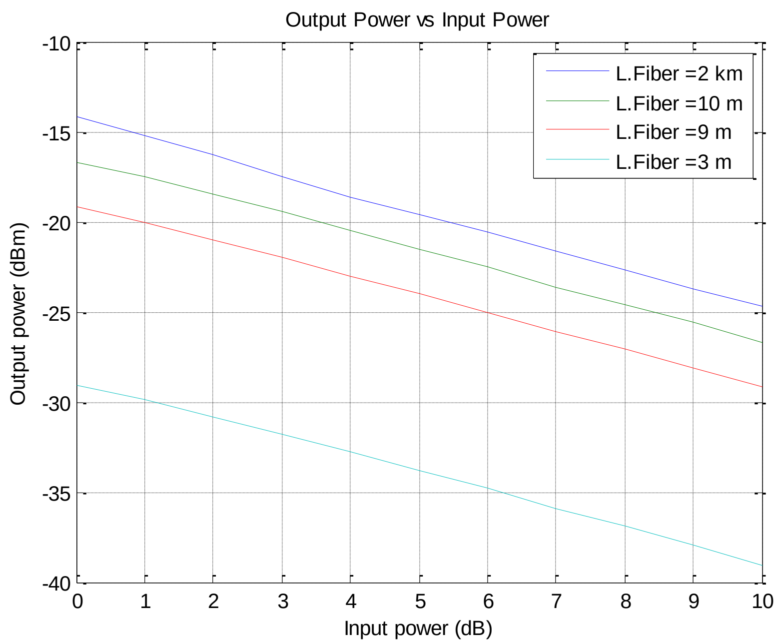

Figure 4.9-G: The Input Power (dB) versus Output Power (dBm) for Fiber Length (2km, 10m, 9m, and 3m) by MATLAB Code.

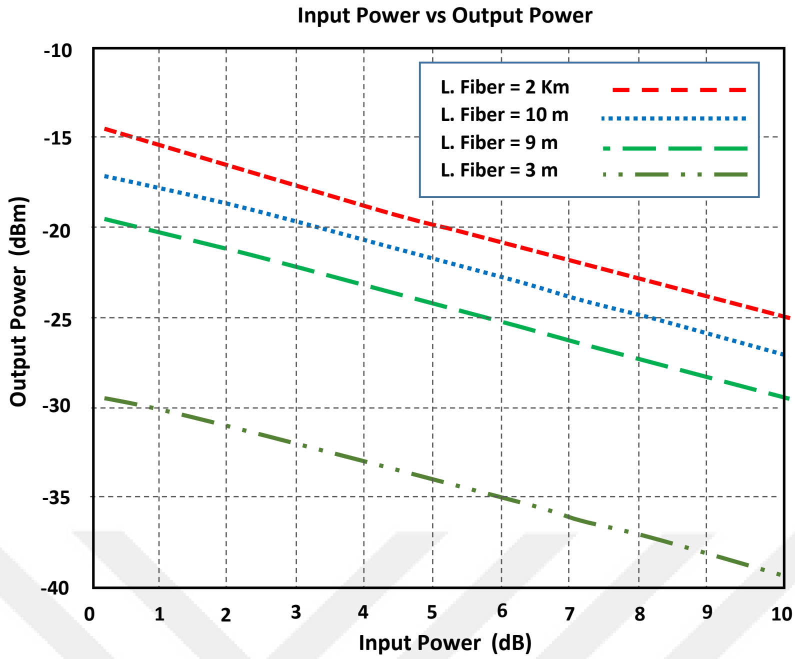

Figure 4.9-H: The Input Power (dB) versus Output Power (dBm) for Fiber Length (2km, 10m, 9m, and 3m) by Simulation.

Figure 4.10 (A, B to G), is the relation between output power and input carrier frequency obtained in the experimental setup for different fiber length and as shown in figure 4.10 by block diagram for comparison between frequency and output power for fiber length, Comparison between the frequency (GHz) versus output power (dBm) for fiber length (2km, 10m, 9m and 3m) as given in Table (4.16, 4.17 to 4.20).

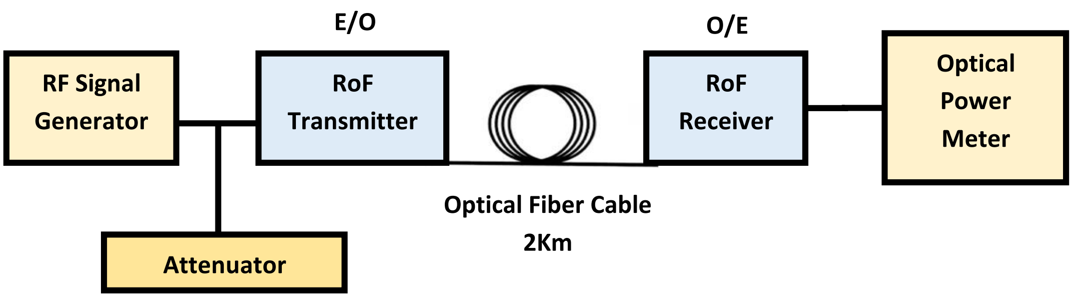

Figure 4.10-A: Block Diagram for Comparison between Frequency and Output Power for Fiber Length (3m, 9m, 10m and 2 km).

Table 4.16: The Relation between Frequency (GHz) and Output Power (dBm) for Fiber Length 2 km.

Frequency (GHz)	Output Power (dBm) for 2 Km
2	-73.13
2.1	-74.43
2.2	-77.01
2.3	-77.66
2.4	-78.31
2.5	-79.5
2.6	-80.17
2.7	-80.47
2.8	-80.52
2.9	-81.17
3	-81.78

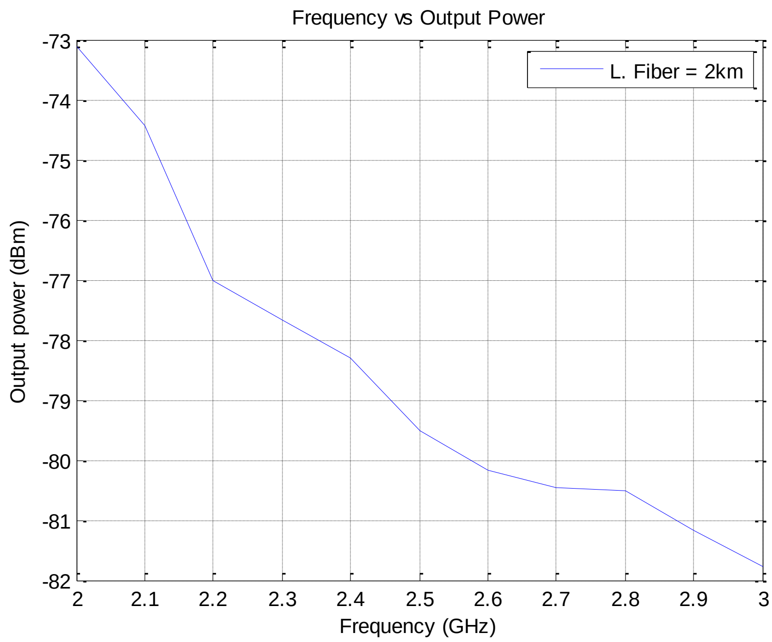

Figure 4.10-B: The Relation between Frequency (GHz) and Output Power (dBm) for 2km by MATLAB Code.

Table 4.17: The Relation between Frequency and Output Power for Fiber Length 10m.

Frequency (GHz)	Output Power (dBm) for 10 m
2	**-82.66**
2.1	**-85.05**
2.2	**-85.06**
2.3	**-85.24**
2.4	**-85.95**
2.5	**-86.35**
2.6	**-86.54**
2.7	**-86.59**
2.8	**-86.66**
2.9	**-87.69**
3	**-88.39**

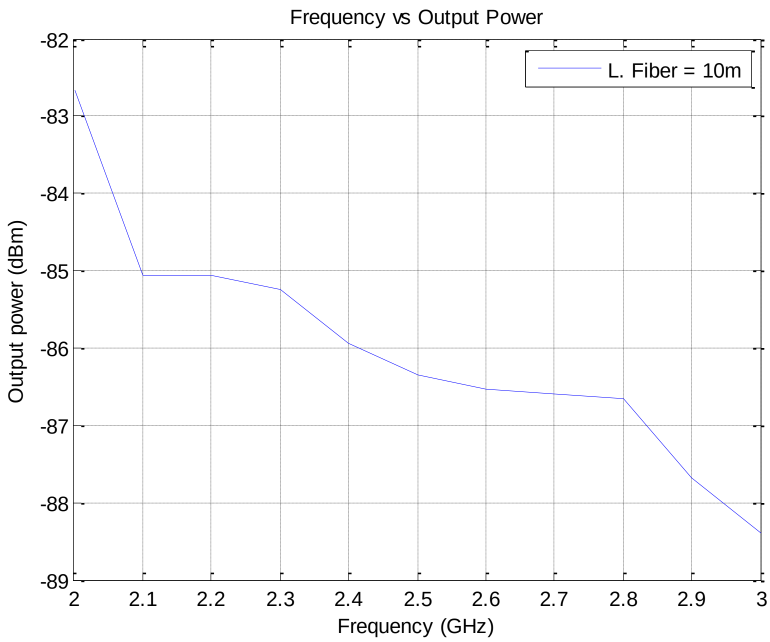

Figure 4.10-C: The Relation between Frequency (GHz) and Output Power (dBm) for 10m by MATLAB Code.

Table 4.18: The Relation between Frequency (GHz) and Output Power (dBm) for Fiber Length 9m.

Frequency (GHz)	Output Power (dBm) for 9 m
2	**-65.48**
2.1	**-67.07**
2.2	**-67.88**
2.3	**-68.02**
2.4	**-68.49**
2.5	**-68.49**
2.6	**-70.07**
2.7	**-70.22**
2.8	**-71.39**
2.9	**-71.76**
3	**-71.9**

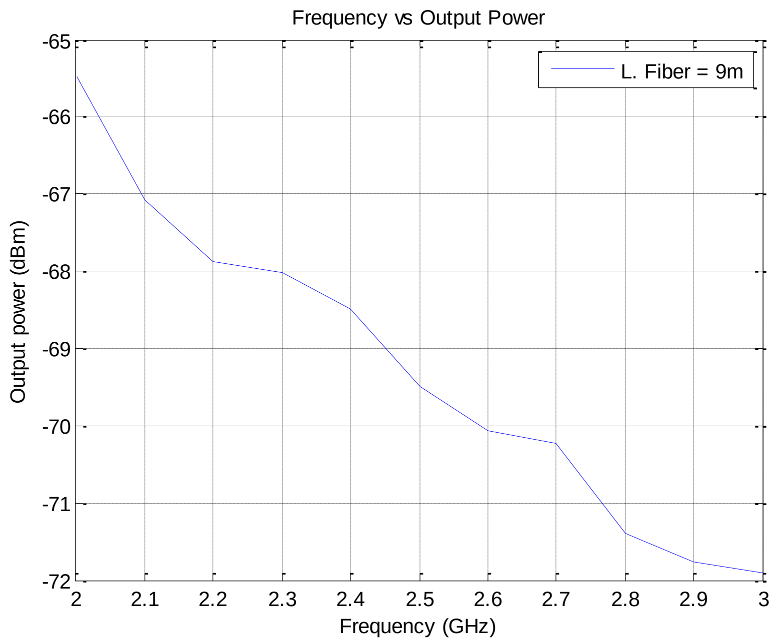

Figure 4.10-D: The Relation between Frequency (GHz) and Output Power (dBm) for 9m by MATLAB Code.

Table 4.19: The Relation between Frequency (GHz) and Output Power (dBm) for Fiber Length 3m.

Frequency (GHz)	Output Power (dBm) for 3 m
2	-57.35
2.1	-58.42
2.2	-58.63
2.3	-58.76
2.4	-59.28
2.5	-60.73
2.6	-60.80
2.7	-61.08
2.8	-61.61
2.9	-61.82
3	-62.07

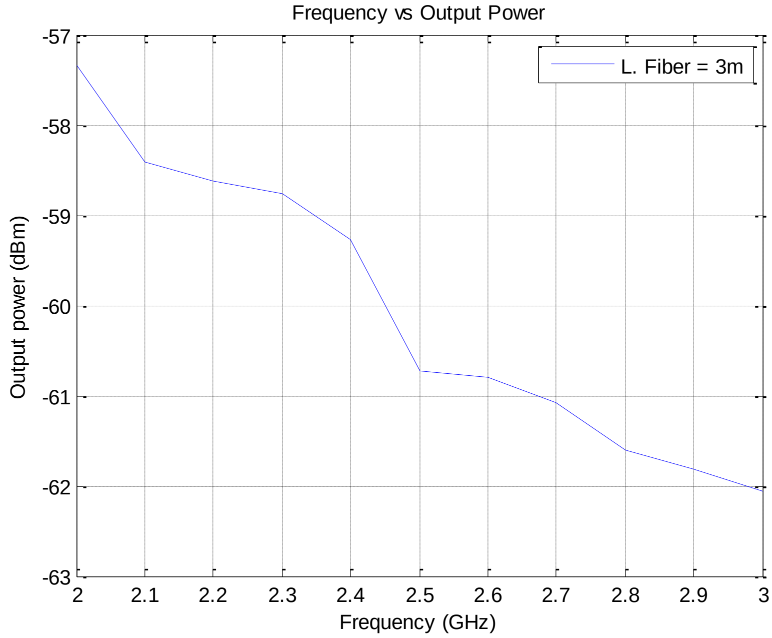

Figure 4.10-E: The Relation between Frequency (GHz) and Output Power (dBm) for 2km by MATLAB Code.

Table 4.20: Comparison between the Frequency (GHz) versus Output Power (dBm) for Fiber Length (2km, 10m, 9m, and 3m).

Frequency (GHz)	Output Power (dBm)			
	2 km	10 m	9 m	3 m
2	-73.13	-82.66	-65.48	-57.35
2.1	-74.43	-85.05	-67.07	-58.42
2.2	-77.01	-85.06	-67.88	-58.63
2.3	-77.66	-85.24	-68.02	-58.76
2.4	-78.31	-85.95	-68.49	-59.28
2.5	-79.5	-86.35	-68.49	-60.73
2.6	-80.17	-86.54	-70.07	-60.8
2.7	-80.47	-86.59	-70.22	-61.08
2.8	-80.52	-86.66	-71.39	-61.61
2.9	-81.17	-87.69	-71.76	-61.82
3	-81.78	-88.39	-71.9	-62.07

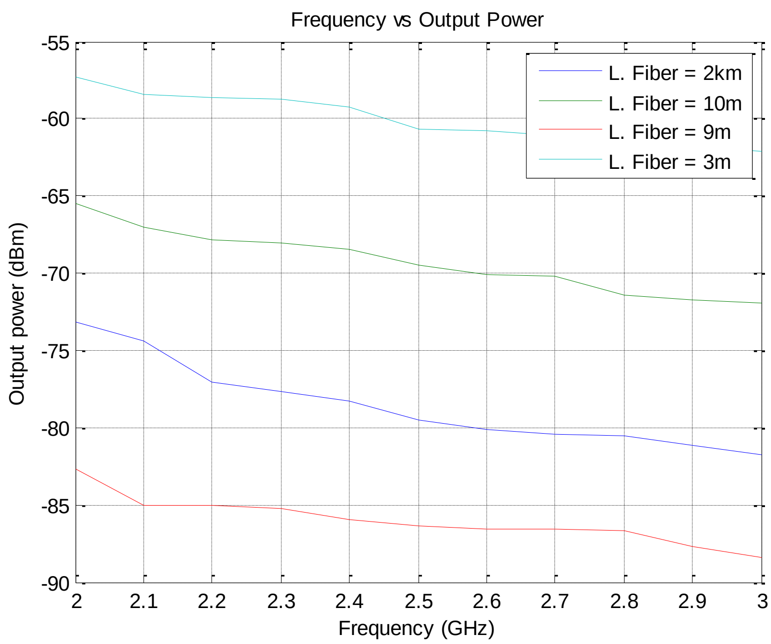

Figure 4.10-F: The Frequency (dB) versus Output Power (dBm) for Fiber Length (2km, 10m, 9m, and 3m) by MATLAB Code.

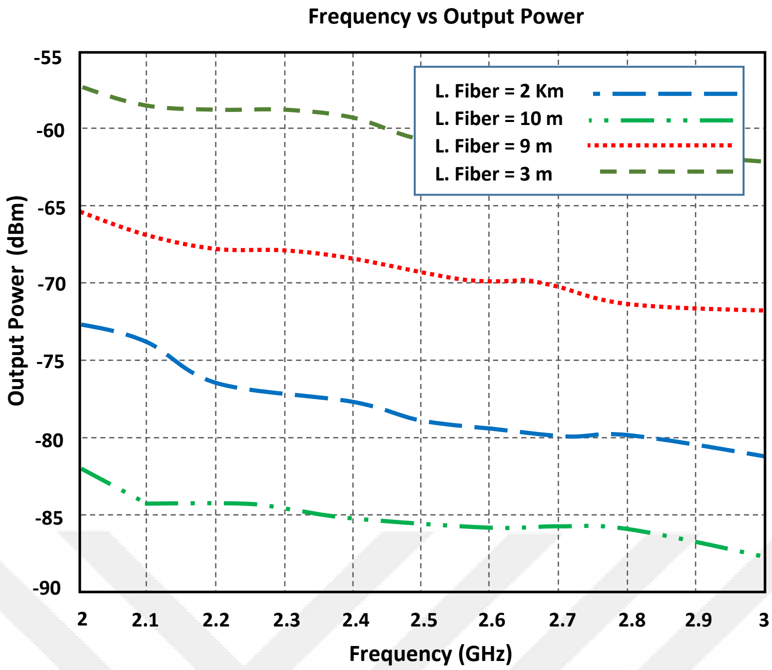

Figure 4.10-G: The Frequency (dB) versus Output Power (dBm) for Fiber Length (2km, 10m, 9m, and 3m) by Simulation.

For 4G mobile systems, the coverage is about 2 km; therefore multimode fiber will be a suitable link in this proposed RAN for the system. Figure 4.11 (A, B to E) is the relation between Brillouin power and Raman powers versus fiber length for the practical experiment done in this work. The first part of the figure is for 3G and 4G mobile systems as a comparison, and the second part is for a 4G mobile system with Raman power. The threshold Brillouin power is less than 15 mW and the threshold Raman power less than 0.8W, Comparison between the Brillouin Power (Watts) versus Raman power (Watts) for fiber length (3G and 4G) as given in (4.21, 4.22 to 4.24).

$$\text{Brillouin Power} = 4.4 \times 10^{-3}(\text{diameter})^2(\text{Lambda})^2 a_{db} \text{ V watts}$$

Where is;

Diameter (L) = (1 to 6) km.

Lambda (λ) = (1 to 3).

Attenuation = Loss / Length ➔ (Loss = 0.5), (L = 1 to 6).

V = Bandwidth = 0.06 (Watts), for three generation (3G).

V = Bandwidth = 0.2 (Watts), for four generation (4G).

Table 4.21: The Relation between Fiber Length (km) and Brillouin Power (Watts) for Three Generation (3G).

Fiber Length (km)	Brillouin Power (Watts) for 3G
1	**0.0080**
1.5	**0.0054**
2	**0.0040**
2.5	**0.0032**
3	**0.0027**
3.5	**0.0023**
4	**0.0020**
4.5	**0.0018**
5	**0.0016**
5.5	**0.0015**
6	**0.0013**

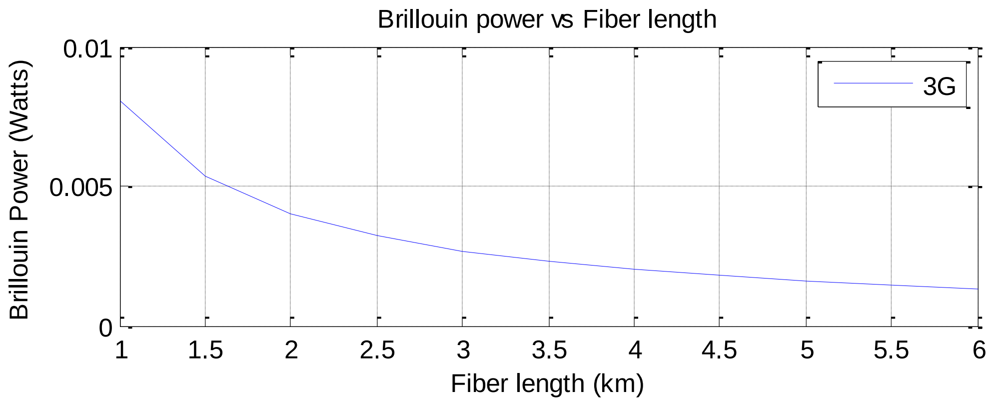

Figure 4.11-A: The Relation between Brillouin Power and Fiber Length for 3G by MATLAB Code.

Table 4.22: The Relation between Fiber Length (km) and Brillouin Power (Watts) for Four Generation (4G).

Fiber Length (km)	Brillouin Power (Watts) for 4G
1	**0.0268**
1.5	**0.0178**
2	**0.0134**
2.5	**0.0107**
3	**0.0089**
3.5	**0.0076**
4	**0.0067**
4.5	**0.0059**
5	**0.0054**
5.5	**0.0049**
6	**0.0045**

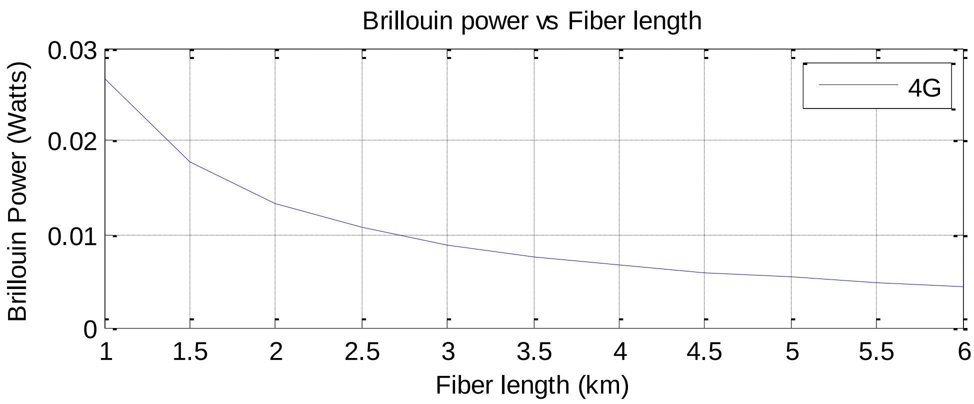

Figure 4.11-B: The Relation between Brillouin Power and Fiber Length for 4G by MATLAB Code.

$$\text{Raman Power} = 5.9 \times 10^{-2} \times (\text{diameter})^2 \times (Lambda) \times \text{a}_{\text{dB}} \text{ watts}$$

Where (λ and *d)* are the operating wavelength and the fiber core diameter, α_{dB} = fiber attenuation in decibels per km.

Diameter (L) = (1 to 6) km.

Lambda (λ) = (1 to 3).

a_{dB} = Attenuation = Loss / Length ➔ (Loss = 0.5), (L = 1 to 6).

Table 4.23: The Relation between Fiber Length (km) and Raman Power (Watts) for Four Generation (4G).

Fiber Length (km)	Raman Power (Watts) for 4G
1	**1.3806**
1.5	**0.9204**
2	**0.6903**
2.5	**0.5522**
3	**0.4602**
3.5	**0.3945**
4	**0.3452**
4.5	**0.3068**
5	**0.2761**
5.5	**0.2510**
6	**0.2301**

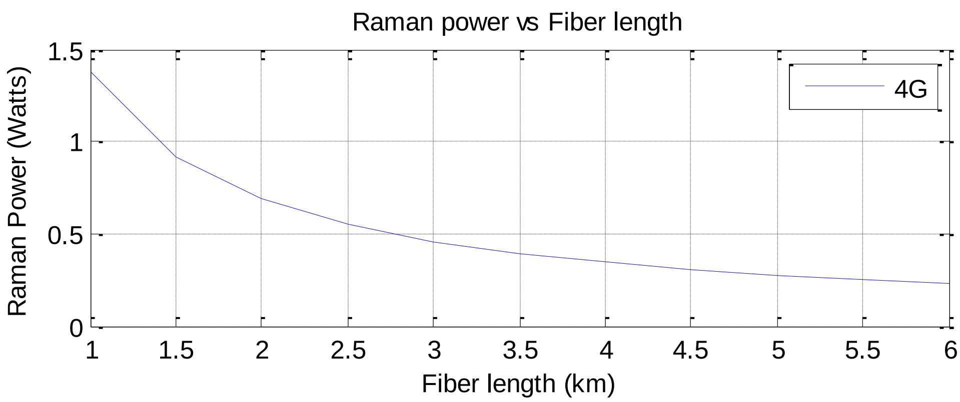

Figure 4.11-C: The Relation between Raman Power and Fiber Length for 4G by MATLAB Code.

Table 4.24: Comparison between the Brillouin Power (Watts) versus Raman Power (Watts) for Fiber Length (3G and 4G).

Fiber Length (km)	Brillouin Power (Watts)		Raman Power (Watts)
	3G	4G	4G
1	0.0080	0.0268	1.3806
1.5	0.0054	0.0178	0.9204
2	0.0040	0.0134	0.6903
2.5	0.0032	0.0107	0.5522
3	0.0027	0.0089	0.4602
3.5	0.0023	0.0076	0.3945
4	0.0020	0.0067	0.3452
4.5	0.0018	0.0059	0.3068
5	0.0016	0.0054	0.2761
5.5	0.0015	0.0049	0.2510
6	0.0013	0.0045	0.2301

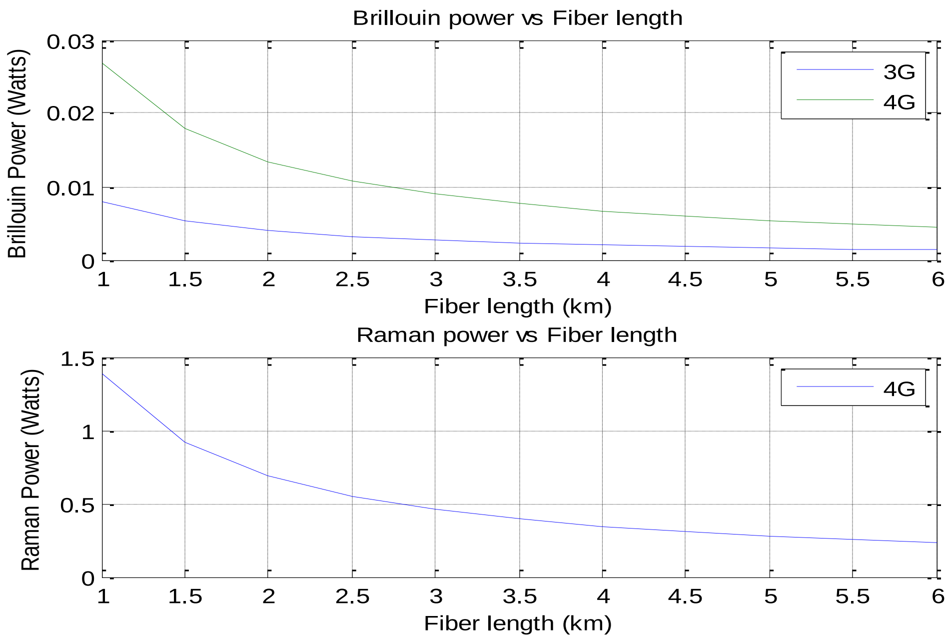

Figure 4.11-D: Comparison between the Brillouin Power (Watts) versus Raman Power (Watts) for Fiber Length (3G and 4G) by MATLAB Code.

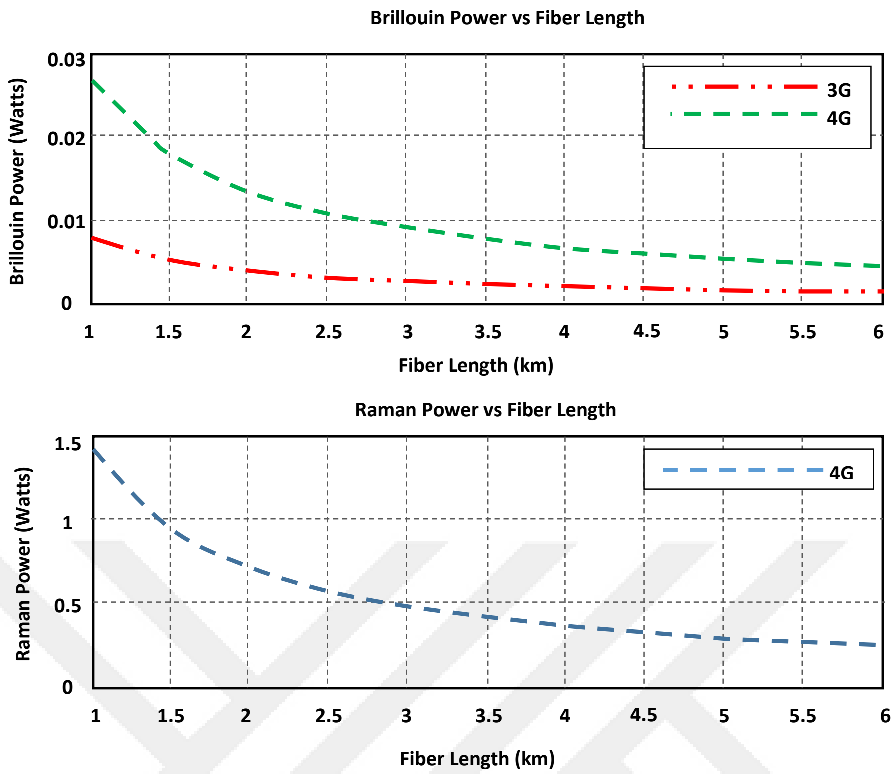

Figure 4.11-E: Comparison between the Brillouin Power (Watts) versus Raman Power (Watts) for Fiber Length (3G and 4G) by Simulation.

4.2. Proposed Design Results in Design Using OptiSystem Software

Second after of the work after optimization to obtain best values of dispersion and then data rate, using OptiSystem software the RAN design using RoF done, figure 4.12 is the designed system whereas figure 4.13 is the transmitted pulse, figure 4.14 is the received pulse at the end of the fiber, figure 4.15 is the output pulse after minimization of the pulse broadening and dispersion using Fiber Bragg Grating (FBG) technique for dispersion minimization.

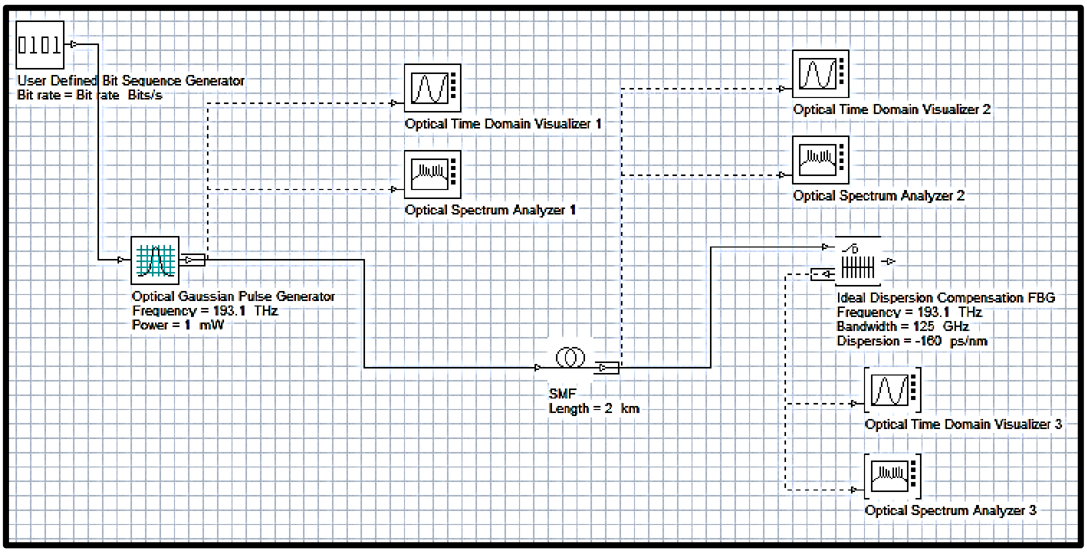

Figure 4.12: The Designed RAN Project Using OptiSystem.

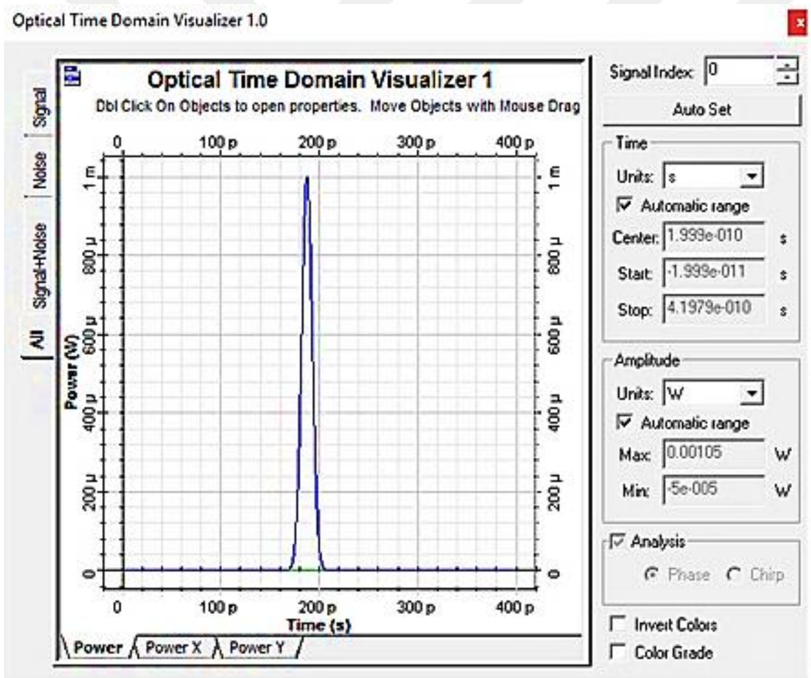

Figure 4.13: The Transmitted Pulse Launched Top The Fiber Optic.

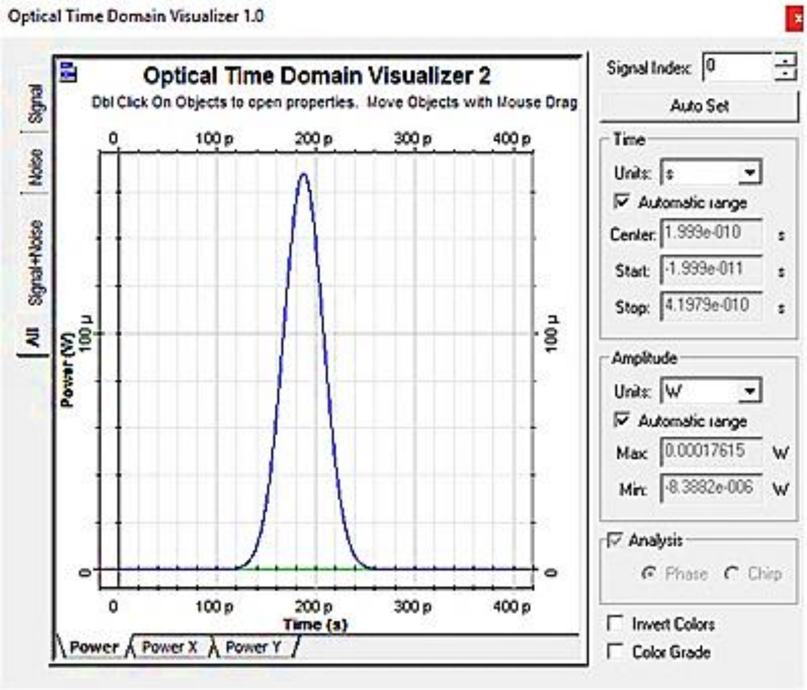

Figure 4.14: The Output Pulse from the Fiber Optic.

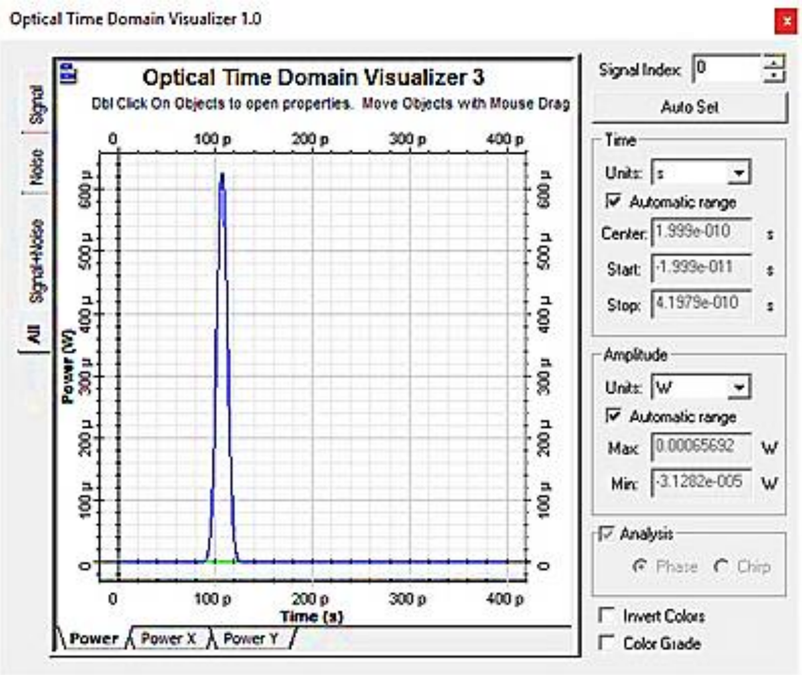

Figure 4.15: The Output Pulse from FBG.

4.3. Proposed Design Results for the Practical Parts

Figure 4.16 (A, B to E) is the input power spectrum from the experimental setup with carrier frequency 2GHz.

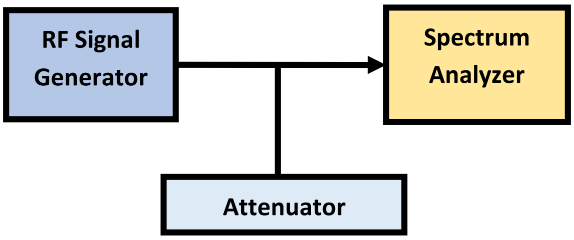

Figure 4.16-A: Block Diagram in Input Power Spectrum for 2 GHz Carrier Frequency.

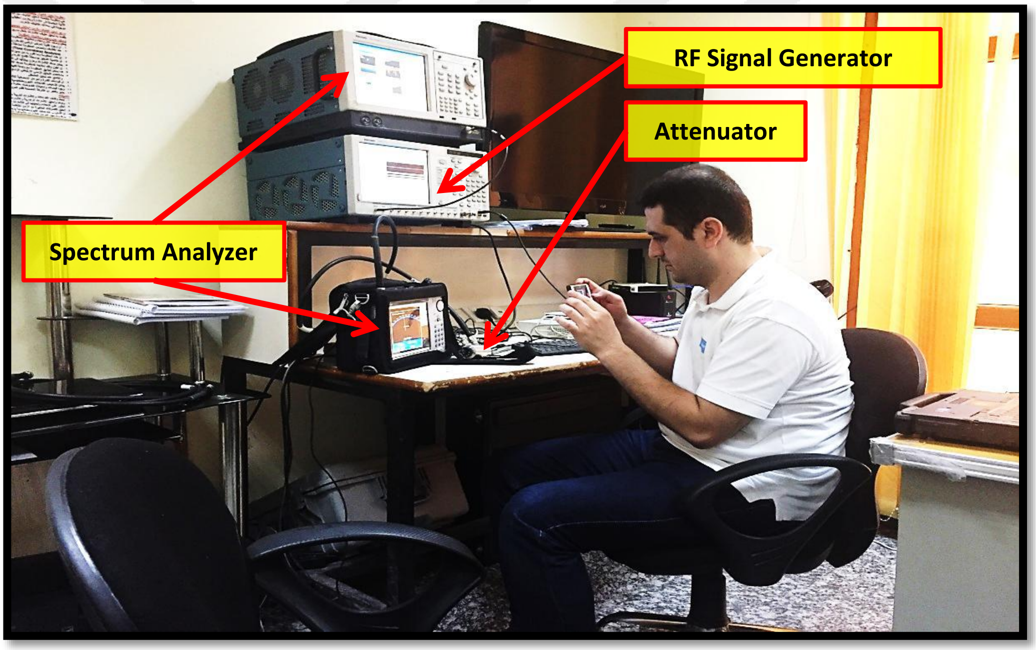

Figure 4.16-B: Laboratory at Working in Input Power Spectrum for 2 GHz Carrier Frequency

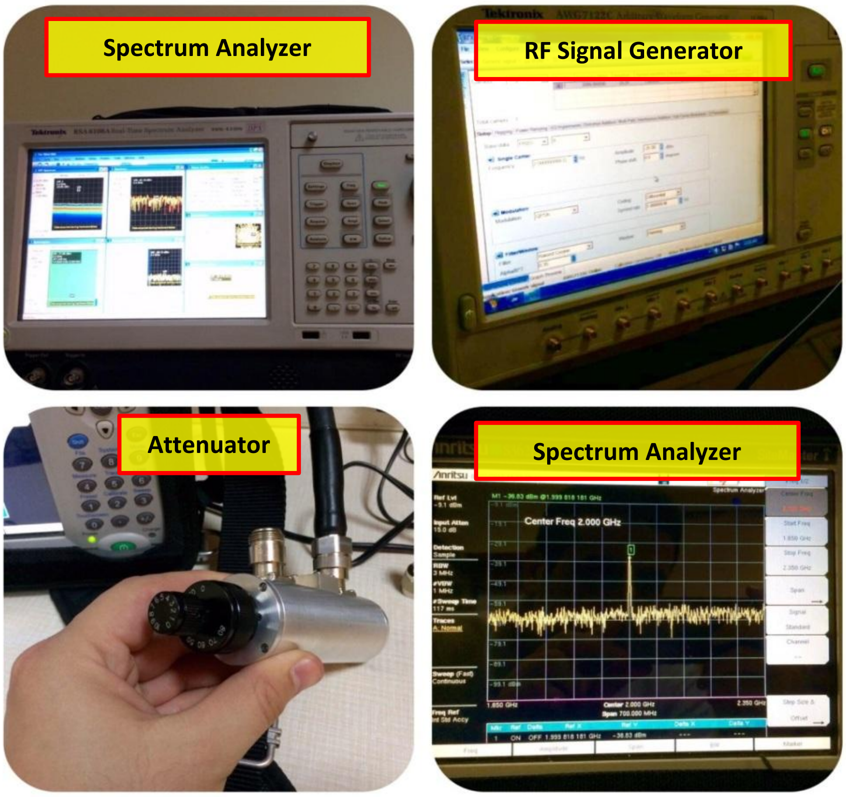

Figure 4.16-C: All Device in Laboratory at working in Input Power Spectrum for 2 GHz Carrier Frequency.

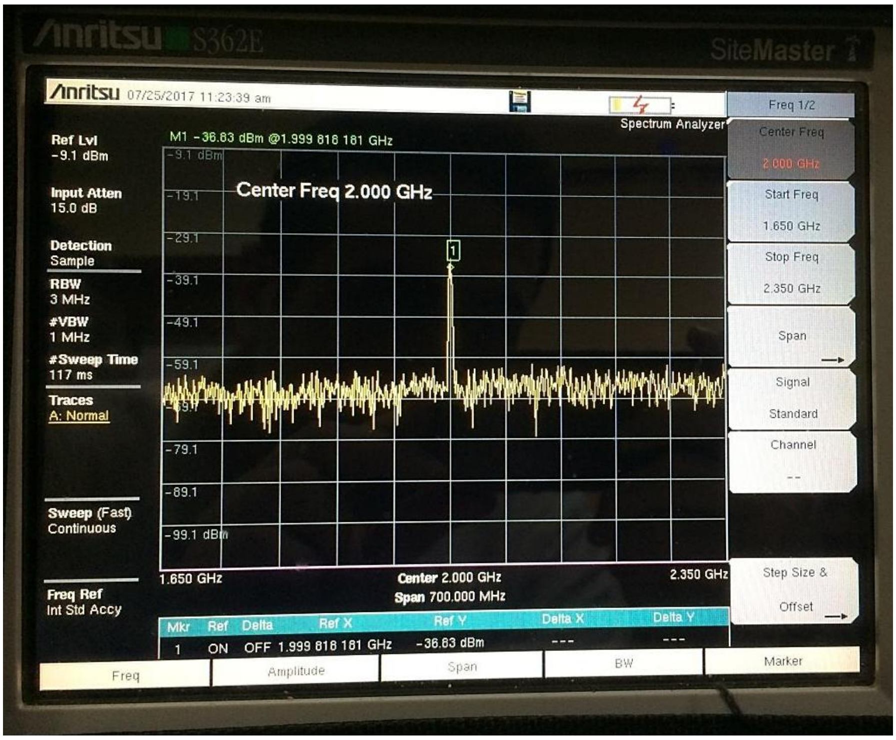

Figure 4.16-D: Input Power Spectrum for 2 GHz Carrier Frequency.

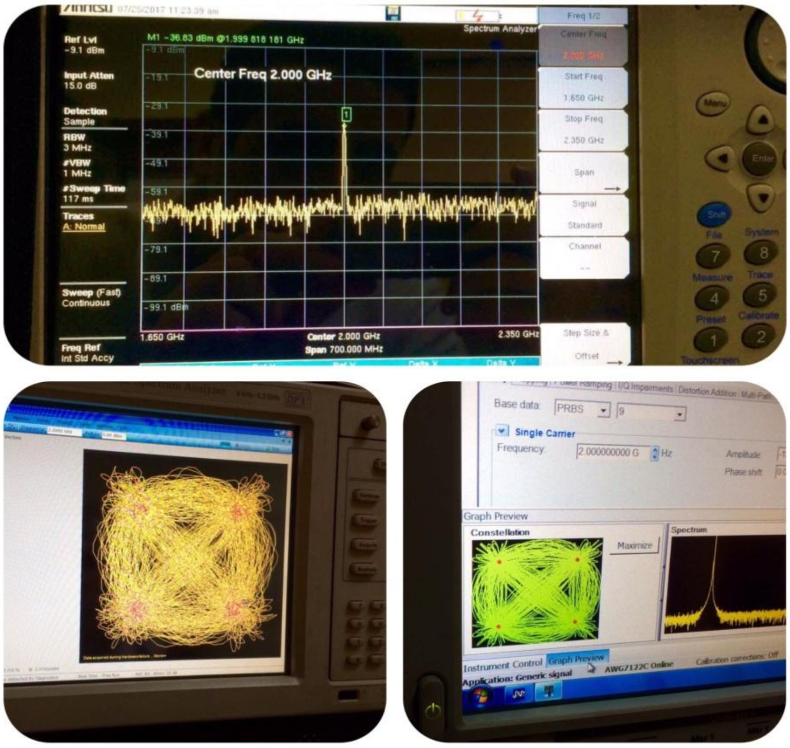

Figure 4.16-E: Input Power Spectrum Analyzer for 2 GHz Carrier Frequency by Difference View Device.

Figure 4.17 and figure 4.18 are the output power spectrums obtained in the experimental setup for multimode fiber, and the length is 2km for sine wave and pulse inputs respectively.

It is shown that the output power for sin wave input has greater (which is about -48dB) than that when the input is a pulse (which is about – 75dB) because of the optical fiber will affect more when the input is a pulse which is by the effect of dispersion figure 4.19.

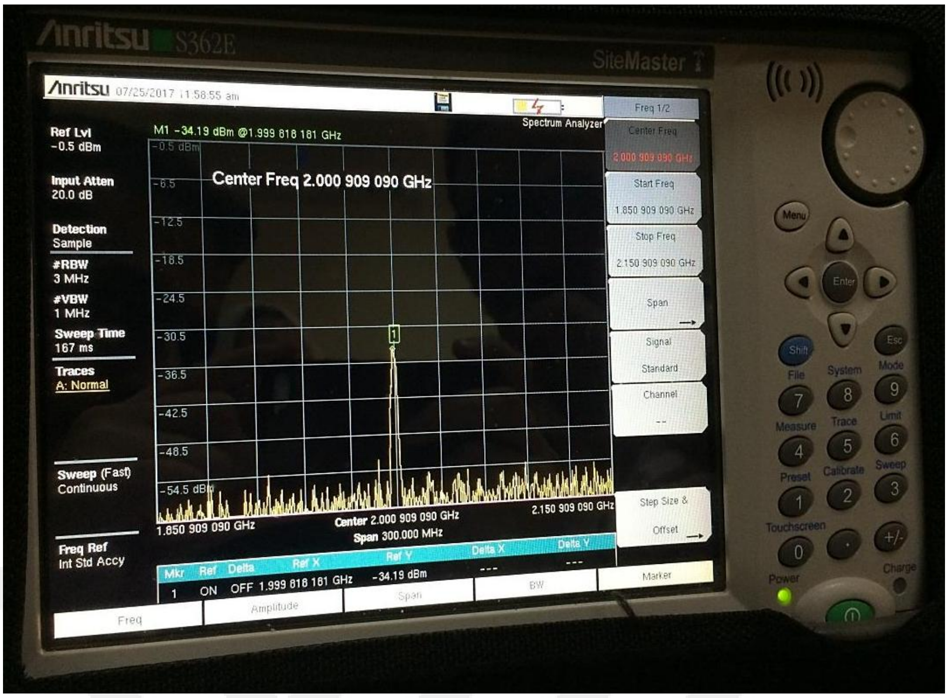

Figure 4.17: Output Power Spectrum for 2 GHz Carrier Frequency with Sine Wave Input.

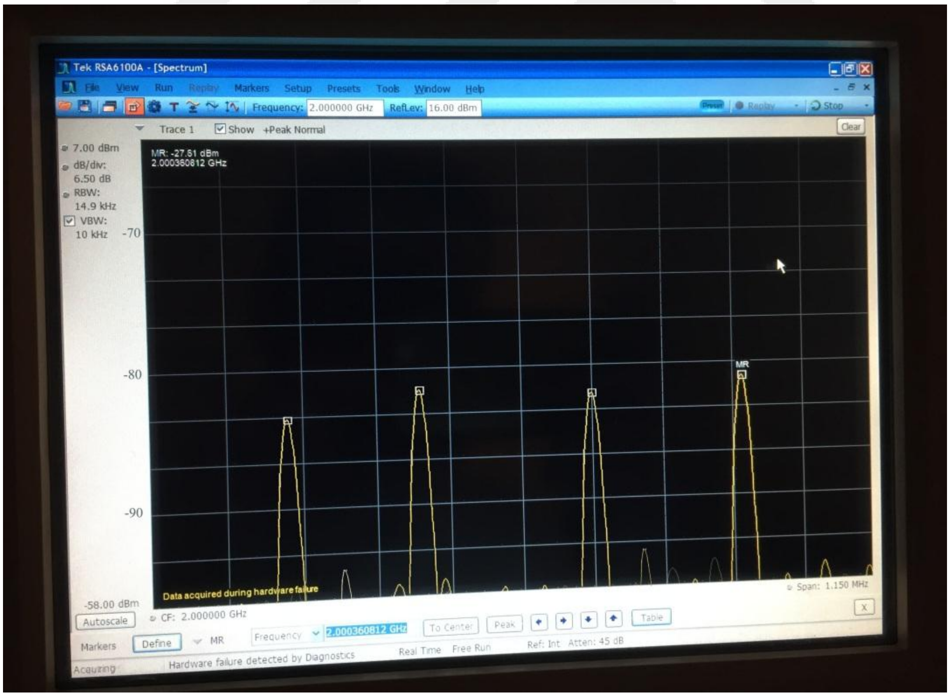

Figure 4.18: Output Power Spectrum for 2 GHz Carrier Frequency with Pulse Input, Fiber Length is 2 km and Multimode.

Figure 4.19 (A and B) and figure 4.20 are the optical output power optical spectrums obtained in the experimental setup for multimode fiber, and the length is 2km for sine wave and pulse inputs respectively. It is shown that the output power for sin wave input has greater (which is about -3dBm) than that when the input is a pulse (which is about –5.7dBm) because of the optical fiber will affect more when the input is a pulse which is by the effect of dispersion.

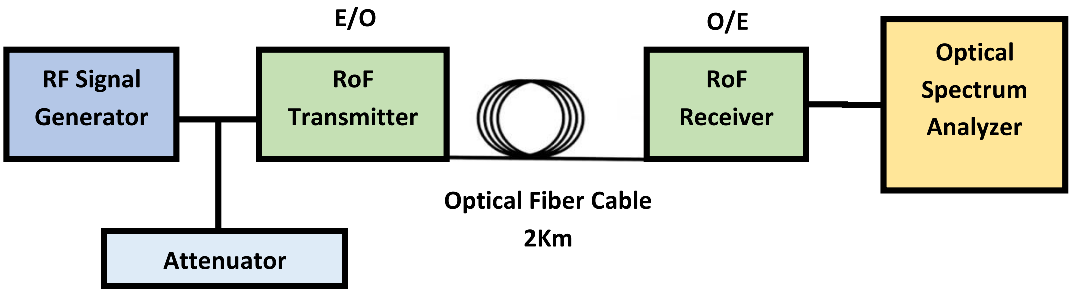

Figure 4.19-A: Block Diagram the Output Power Optical Spectrum for 2 GHz Carrier Frequency with Sin wave Input, Fiber Length is 2 km and Multimode.

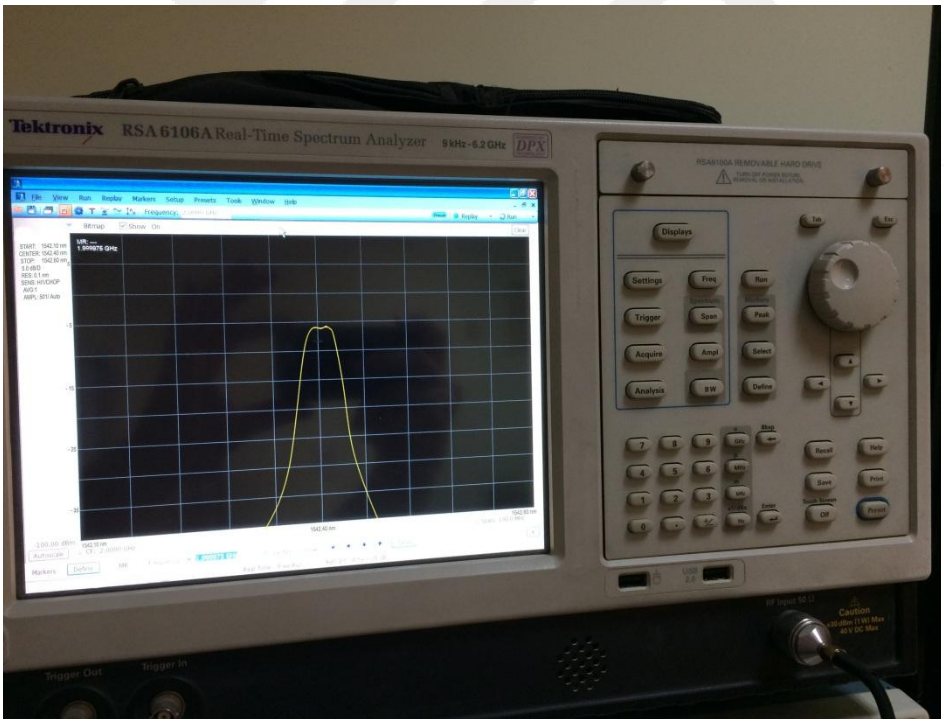

Figure 4.19-B: Practically the Output Power Optical Spectrum for 2 GHz Carrier Frequency with Sin wave Input, Fiber Length is 2 km and Multimode.

Figure 4.20 shows the equipment and practical parts used in this work.

Figure 4.20: Are The Other Units With Rof Transmitter and Receiver Units Used in this Work.

5. CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

5.1. Conclusions

4G mobile systems will be the integration of the other wireless systems like GSM, UMTS, and WiMAX systems. This work describes the 4 Generation mobile base station BS distribution, connection and channel allocation with a new topology which is mesh topology. Moreover, with the newly introduced technique, the connection between the cells improves the QoS and data rate. The signal strength also increases because there are no free space losses; also the fiber optic network has very small losses, of approximately (0.02 dB/km). The proposed new techniques improve the quality of 4 Generation the signal quality and services, although the installation cost is normally higher. Nevertheless, the running-cost is very-small because of the use of the fiber optic system.

With higher bandwidth and carrier frequencies, each cell in the 4G system has a smaller radius than in 3G mobile systems. In this context, signal quality is improved because fiber optic links, which ensure the absence of free space losses and interference, are used. Consequently, the result is an increased data rate. Results further indicate that data rates could be higher than 200 Mbps for outdoor and near 1Gbps for indoor communications. For this purpose, the dispersion effect on the signal is studied and the optimum values for the fiber parameters are calculated.

Also, a new RoF topology is proposed for the 4G mobile system. The topology involved grouping the coverage into N groups. Each group has many base stations connected to a central base station; thus, there are N central base stations connected to the core network through access gateways, and finally, to the Internet. The use of fiber optic channels allows for high data rate and improved signal quality. Moreover, no interference and free space losses were observed. The maintenance of the proposed topology would be easier, and the overall network would be more reliable. Thus, despite its high installation cost, the proposed RoF topology should provide low running costs.

5.2. Suggestions for Future Work

The 4G mobile system network architecture is very important and more development can be done in the future, also the air interface access for the system, the following are some suggestions for the future work:

- The radio access network can be improved further through the use of radio over fiber technique, hence, like the global internet backbone, the 4G mobile system also can have a mini backbone network architecture and the overall microwave links can be removed as an attempt to further data rate increase, therefore, the overall network architecture will be the integration of the other wireless communications systems and other mobile systems can be replaced by the new 4G network architecture.
- The overall 4G mobile system radio access network can replace the other mobile systems like 2G and 3G mobile systems, and these systems remain operating without removing their networks and operating as a part of the 4G mobile system, this process needs more 4G modifications of a 4G mobile system suitable with handover with other 2G and 3G systems.

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CURRICULUM VITAE

Shwan Asaad Othman was born in 1985 at Erbil-Iraq. His Completed bachelor's degree in Computer Engineering / Hardware from Koya University / Engineering College in 2008 – 2009. He has been working at Erbil Polytechnic University/ Erbil technical institute as an administration staff from 2009 till date. He has been a Master Student at Firat University Faculty of Technology Software Engineering Department.