FLEXIBLE PLATFORM FOR ROF NETWORK USING ADVANCED MODULATION FORMATS BASED ON MMF

ALI MUSTAFA ALI ALSHAYKHA

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Submitted by **Ali Mustafa Ali ALSHAYKHA**

Approval of the Graduate School of Natural and Applied Sciences, Çankaya University.

Prof. Dr. Mehmet YAZICI
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

Prof. Dr. Erdoğan DOĞDU
Head of Department

This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

Assist. Prof. Dr. Barbaros PREVEZE
Supervisor

Examination Date: 15.03.2017

Examining Committee Members

Assist. Prof. Dr. Barbaros PREVEZE	(Çankaya Univ.)	
Assist. Prof. Dr. Reza ZARE HASSANPOUR	(Çankaya Univ.)	
Assist. Prof. Dr. Thamer ALMASHHADANI	(Yildirim Beyazit Univ.)	

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Name, Last Name : Ali Mustafa ALSHAYKHA

Signature :

Date : 15.03.2017

ABSTRACT

FLEXIBLE PLATFORM FOR ROF NETWORK USING ADVANCED MODULATION FORMATS BASED ON MMF.

Ali Mustafa Ali ALSHAYKHA
M.Sc., Department of Computer Engineering
Supervisor: Assist. Prof. Dr. Barbaros PREVEZE
Co-supervisor: Assoc. Prof. Essa Ibrahim Essa AL-JUBORIE

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The connected devices in the networks are increased and the data flow between each of them is increased too. The wireless connectivity is preferable, but it has a short range and needs to enlarge the signal coverage. New wireless technologies and new access networks based on Fiber can be real solutions and it can be used with modulation techniques to achieve multi-gigabit wireless links. RF signal can be transported over optical fiber from a central location to remote antenna units by using radio over fiber (ROF). In this thesis, two test beds are demonstrated as a software simulation for the ROF, based on hybrid optical fiber and WDM. Multiple users have been also taken into consideration with the cost-effectively and bandwidth. Some passive or active components have been used with fiber length 50km. In the simulations, the ROF architecture has been simulated in C-band wavelength which has ranged between 1530 nm and 1565 nm. Then, to overcome nonlinearities problem, EDFAs are used to compensate the loss in signal. As a result of the first experiment, the average of total power for the three output signal is determined as 13.333dBm with 2.5Gbps bitrate. As a result of the second analysis with 1Gbps bitrate, the average Q-factor for two output signals is 6.0846, and the average of minimum BER is 3.7738E-10. Meanwhile, there is limitation of degradation in the signal along the whole networks by using optical and electrical amplifiers; the simulation results show that the networks are fully exploited, with low error rate.

Keywords: Radio-over-fiber, radio frequency, MMF, WDM, Q-factor.

ÖZ

MMF'YE DAYANAN GELIŞMIŞ MODÜLASYON FORMATLARINI KULLANAN ROF AĞI IÇIN ESNEK PLATFORM.

Ali Mustafa Ali ALSHAYKHA
Yüksek Lisans, Bilgisayar Mühendisliği Bölümü
Tez Yöneticisi: Yrd. Doç. Dr. Barbaros PREVEZE
Ortak Tez Yöneticisi: Doç. Dr. Essa Ibrahim Essa AL-JUBORIE

Mart 2017, 60 sayfa

Şebekelerdeki bağlı cihaz sayısı arttıkça, bu cihazlar arası gerekli hız oranı da artmaktadır. Kablosuz bağlantı daha çok tercih edilmektedir ancak bağlantı mezilinin daha çok genişletilmesi gerekmemektedir. Fiber'e dayalı yeni kablosuz teknolojiler ve yeni erişim ağlarının kullanımı bu konuda çözüm olabilir ve çoklu gigabit kablosuz bağlantı elde etmek için modülasyon teknikleriyle birlikte kullanılabilir. RF sinyali, radyo üzerinden fiber (RoF) kullanarak optik fiber üzerinden merkezi bir konumdan uzaktaki anten ünitelerine taşınabilir. Bu tezde, hibrid optik fibere ve WDM'ye dayanan ROF için bir yazılım simülasyonu olarak iki test yatağı gösterilmiştir. Çoklu kullanıcı da ayrıca, hesaplılık ve bant genişliği açısından dikkate alınmıştır. Fiber uzunluğu 50km olan bazı pasif / aktif bileşenler kullanulmıştır. Simülasyonlarda, C-bandında (1530-1565nm) ROF / WDM mimarisi simüle edilmiştir. Daha sonra doğrusal olmama probleminin üstesinden gelmek için

EDFA lar kullanılarak sinyal kaybını telafi edilir. İlk deneyin sonucu olarak, 2.5 Gbps veri oranı ile, üç çıkış sinyalinin her biri için ortalama toplam güç 13.333dBm olarak elde edilmiştir. İkinci analizin sonucu olarak, 1 Gbps veri oranı ile, iki çıkış sinyali için ortalama Q-faktörü 6.0846 ve minimum BER ortalaması 3.7738E-10 'dur. Bu sırada, şebekede kullanılan optiksel ve elektriksel yülkselteçler ile tüm ağ boyunca oluşlan bozulmada bir limitte tutulmaktadır; Simülasyon sonuçları, ağların düşük hata oranıyla, tam olarak kullanılmakta olduğunu göstermiştir.

Anahtar Kelimeler: Radyo-aşırı-fiber, radyo frekansı, MMF, WDM, Q-faktörü.

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First Praise is to Allah, who gives everything... unrequited.

To whom Allah implanted their love in my heart, and they were and still supporting me even I become a man able to overcome the difficulties, mother and father...

To my friend and my love and my partner in the life, my hidden assistant who is putting her beautiful footprint in my life, my wife.

To my dear family and other friends who supported me in this journey.

To the first and last refuge, my country.

I dedicate them this work.

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AM	AMPLITUDE MODULATION
APD	AVALANCHE PHOTODIODE
ASK	AMPLITUDE SHIFT KEYING
AWG	ARRAYED WAVEGUIDE GRATINGS
BER	BIT ERROR RATE
BS	BASE STATIONS
CATV	COMMUNITY ACCESS TELEVISION
CD	CHROMATIC DISPERSION
CNR	CARRIER-TO-NOISE RATIO
CS	CENTRAL STATION
CSRZ	CARRIER-SUPPRESSED RETURN-TO-ZERO
CW	CONTINUOUS-WAVE
DPSK	DIFFERENTIAL PHASE SHIFT KEYING
DQPSK	DIFFERENTIAL QUADRATURE PHASE SHIFT KEYING
DSB-SC	DOUBLE-SIDEBAND SUPPRESSED CARRIER TRANSMISSION
DSL	DIGITAL SUBSCRIBER LINE
EAM	ELECTRO-ABSORPTION MODULATOR
EDFA	ERBIUM DOPED FIBER AMPLIFIERS
FM	FREQUENCY MODULATION
FTTX	FIBER TO THE X
GB	GIGABYTE
GHZ	GIGAHERTZ
GPRS	GENERAL PACKET RADIO SERVICE
GSM	GLOBAL SYSTEM FOR MOBILE COMMUNICATION
LINBO3	THE LITHIUM NIOBATE
LTE	LONG-TERM EVOLUTION

MAC	MEDIA ACCESS CONTROL
MIMO	MULTI-INPUT-MULTI-OUTPUT
MM	MILLIMETRE
MMF	MULTI-MODE OPTICAL FIBER
MZI	MACH–ZEHNDER INTERFEROMETER
MZM	MACH-ZEHNDER MODULATOR
NRZ	NON-RETURN-TO-ZERO
OFDM	ORTHOGONAL FREQUENCY-DIVISION MULTIPLEXING
OOK	ON-OFF KEYING
OSNR	OPTICAL SIGNAL TO NOISE RATIO
PIN	POSITIVE INTRINSIC NEGATIVE
PON	PASSIVE OPTICAL NETWORKING
PRBS	PSEUDO RANDOM BIT SEQUENCE GENERATOR
PSK	PHASE SHIFT KEYING
QAM	QUADRATURE AMPLITUDE MODULATION
Q-FACTOR	QUALITY FACTOR
RF	RADIO FREQUENCY
ROF	RADIO OVER FIBER
RSOA	REFLECTIVE SEMICONDUCTOR OPTICAL AMPLIFIERS
RZ	RETURN-TO-ZERO
SCM	SUBCARRIER MULTIPLEXING
SMF	SINGLE-MODE OPTICAL FIBER
SNR	SIGNAL-TO-NOISE RATIO
UWB	ULTRA-WIDEBAND
WDM	WAVELENGTH DIVISION MULTIPLEXING
WIMAX	WORLDWIDE INTEROPERABILITY FOR MICROWAVE ACCESS

CHAPTER 1

INTRODUCTION

1.1 Overview

There is a constant increasing in the connected devices in networks around the world and inside the local networks, also with overabundance in exchanging data between them. Because of the advancement in our life, there is an increasing in the need for systems, such as a movement broadband, remote cloud and support, data transfer, live conferences, and so on. These increases can be observed in the number of Internet users between 2001 and 2016 in Figure 1.

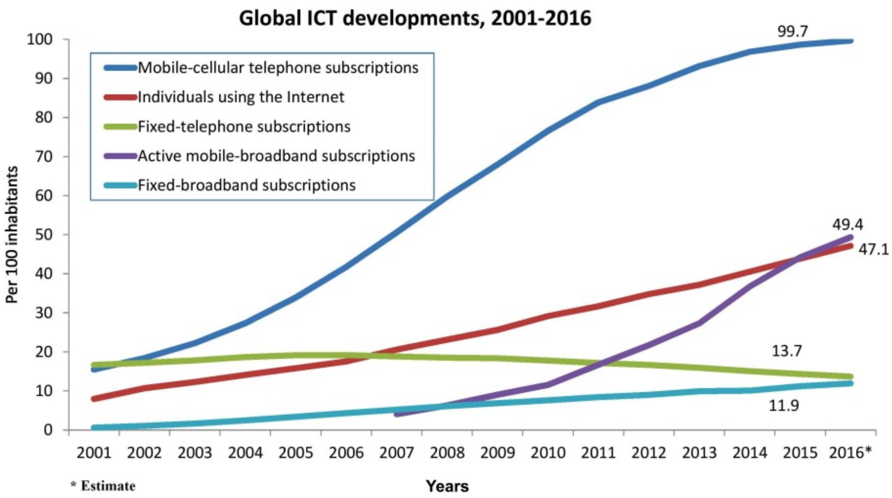


Figure 1 Global Telecommunication subscriptions per 100 inhabitants (Source: ITU)[1]**.**

Every part and person in the community of communication and information technology has a primary goal, which is to give any service to everyone from everywhere whether wire or wireless fields. This can be achieved by creating a new technique of networks depending on mixing between wire and wireless accesses to give the ultimate users various options, comfort, and diversity in a useful style [2]. Trustworthy movement besides transmission with a large-scale bandwidth and great distance are the requirements of current telecom systems [3].

Wireless connectivity is a better choice for the last connection to a device because it is restful to use and flexible. Wi-Fi devices grew rapidly such as smartphones, tablets, and laptops with the increase of mobile data traffic shared among them. Table 1 shows the average mobile data traffic for the modern devices that were used by clients during the year 2014 and the estimate for the year 2019. The data are collected from Cisco as global mobile data traffic prediction[4]. The average traffic per device is that listed in Table 1 is in MB per month. This increase leads to creating a need for innovating new frequency bands for future wireless communications.

Table 1 Average Cellular Traffic per Mobile Device Type (Source: Cisco [4]).

Device Type	2014 MBs per Month	2019 MBs per Month
Non-Smartphone	22	105
M2M module	70	366
Wearable Device	141	479
Smartphone	819	3,981
Tablet	2,076	10,767
Laptop	2,641	5,589

Note: In 2014, 4G smartphones generated 2GBs/month and 4G tablets generated 3GBs/month.

The range of frequency used a design for the spectrums of Amplitude Modulation (AM), Frequency Modulation (FM) radio, high-definition TV, cellular, satellite communications, GPS and Wi-Fi between 535 KHz and 30 GHz presently [5]. A reason of that, it provide an expansion in mobile data exchange for advanced mobile broadband networks via the use of underused millimetre wave (mm-wave) frequency spectrum, between 30 GHz and 300 GHz frequency bands [6]. Preventing spectral overcrowding can be done by running in microwave and millimetre frequencies and the essential thing is a decrease in cell size. One of the reasons to increase the cost in networks is the hugely rise in the number of base stations, and each carrying some of the functions of direction and processing. The solution is to design a central control station (CS) which is connected with many base stations (BS) to assemble functionalities.

There are few RF spectrums usable for broadband running on Wireless communication systems because it's operating at low frequencies, under 5 GHz, so it has insufficient capacity. Furthermore, the limited RF spectrum requires distributing to various services and users. For instance, just 100 MHz of bandwidth is available in GSM (Global System for Mobile communication) bands (900 MHz and 1.8 GHz). It's possible to obtain the advantage from a wireless link with high range acts in higher bandwidth through Heading to higher RF frequencies, mostly bandwidth around 500 MHz can be handle if it has been worked in 5 GHz band. There is Gigahertz of spectrum accessible for Gbit-per-second data connections by operating at frequencies in millimetre wave over 60 GHz [7][8].

The performance of the spectral can be enhanced by applying another procedure is the increment of a bit rate above a given bandwidth. Multiplexing and complex modulation formats can be used to obtain spectral efficiencies above 2 bit/s/Hz, QAM (Quadrature Amplitude Modulation) and PSK (Phase Shift Keying) are examples of this modulation formats. OFDM (Orthogonal Frequency-Division Multiplexing) and subcarrier multiplexing are standards of multiplexing schemes. On the other hand, 1 bit/s/Hz can be achieved by using OOK (On-Off Keying). There is a direct proportion for increasing the capacity in wireless links and loss of propagation, therefore when working at frequencies with high RF carrier, the large capacity links of Wireless will produce propagation losses with significant value.

Wireless links with little coverage can be disregard when highest capacity been concentrated on. This limitation occurs during applying the strict specifications of high modulation formats through Signal-to-Noise Ratio (SNR) combined with the propagation losses, which affect the value of the distances encasement. The last mile section is the location of the end-user that can use the wireless connection to access networks and transport the data with high capacity links. In a particular geographic area, there are requires to a type of wireless signal distribution regards cellular networks by using many antenna base stations (BS) to provide wireless coverage. Work on high RF carriers and powerful modulation formats could obtain links with high capacity. This increase in capacity utilized in next generation cellular networks makes the capability to reach the wireless links short in a small coverage zone.

Solving the problem of limit coverage could be done by increasing the density of antennas in a particular area with distributing a large number of nodes controlled by the network. The modern construction will provide a multi number of base stations with a multi number of antennas for each base station. This multiplicity will lead to support multi-input-multi-output (MIMO). The exchange of aggregated data between all antennas and a main central station (CS), where the control of data flowing, needs a high capacity backbone infrastructure such as optical fiber [9][10]. Fiber link has low attenuation and high capacity when it is used for transmission media, because of that its most suitable alternative to connect the (CS) is located some tens of kilometres far away from base stations.

Extend signal coverage of radio standards could be done by providing solutions with guaranteed the economic cost, protected backup service, and immediate deployment. Current wireless technologies like ultra-wideband (UWB), WiMAX, 60GHz and new access networks based on Fiber to the X (FTTX) and mobile (4G, LTE-advance) could be practical solutions to enlarge the coverage, and it could be used with modulation techniques to produce multi-gigabit wireless links. RF signal could transport from wireless devices to remote antennas over an optical carrier across optical fiber from a central location to remote antenna units by using radio over fiber (ROF).

Economic solutions with establishing high-speed intermediaries solve this issue by radio over fiber (ROF) [11]. RF up and down conversion baseband in radio over fiber (ROF) conventionally is accomplished at the base stations to provide the information with the digital transportation through backhaul of fiber. In the next generation of wireless access networks could provide the demand with high capacity by transporting the wireless signal transparently over the fiber infrastructure. This is because of the possibility of the analog transport of wireless signals by using optical fiber between base stations and the central station in a wireless over- fiber architecture [12][13].

Technologies of the radio over fiber (ROF) used as a reliable solution for providing the requirements when it is to take into consideration an advantage of collectively the systems of optical communications offer broad bandwidth with systems of wireless provides flexibility and mobility [14]. Heterogeneous networks created by optical links with wireless links produce the (ROF) systems [15].

Fibers in the systems of ROF used to transport individual or various analogous carriers. The Modulated laser created by the analogous signal of radio frequency performs transmission via externally or directly modulating. The photodiode is used to retrieve the signal that transmitted to the receiver side. Reducing electronic to optical and optical to electronic converters could be done by getting the advantages provided by ROF technologies. These things lead to make the complexity of the system simpler; costs of operation comparatively are inexpensive and reduce the expenses of site rental and acquisition [16]. A unit remote antenna is much uncomplicated consequently maintenance decreased. A lot of applications used the ROF systems, such as fixed broadband, external cellular systems, access to mobile wireless and coverage inside the buildings [17] Figure 2 illustrates the ROF system concept.

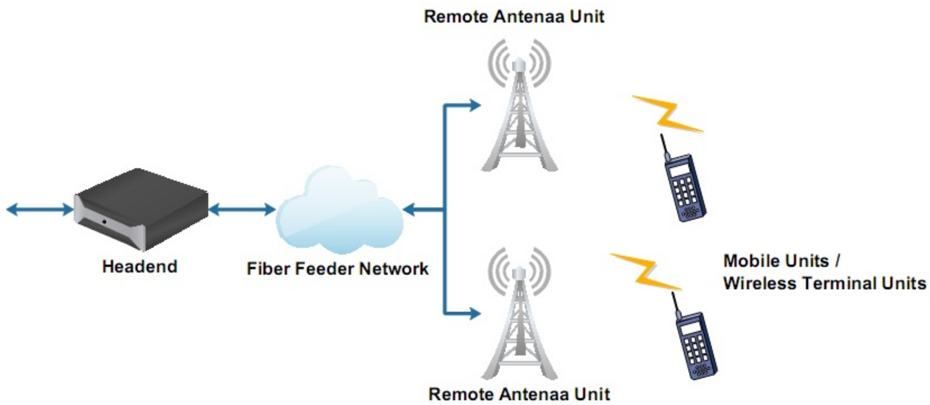


Figure 2 ROF system concept

1.2 Advantages of Radio over Fiber:

- Extremely cost-effective in the lengthy run.
- Transportable Broadband Internet.
- Resistance to interpenetration radio inside the fiber.
- Decreased energy consumption.

- Adaptability of devices.
- Effective Resource Allocation.
- Mobility.
- Transportation of millimetre waves.

1.3 The weakness of Radio over Fiber:

- Effects of dispersion in the fiber that can be reduced through using multi-mode graded Index fiber or by using single mode fiber, as used in proposed method in this thesis, which has a minuscule core diameter inasmuch 5 to 10 μm [18]. Also could be solved by adding DCF after SMF if the distances are in long length, and users 4 or more, and bitrate equal to 10G or 40G
- The possibility of detrimental could be achieved in nonlinearities of devices.
- Weak dynamic range which is a very significant factor for cellular communication networks like GSM and its used to determine the lowest limit and highest limit parameters in microwave systems like (signal, and light). [19].
- Proportional concentration noise in laser sources [20][21].

1.4 The necessity for Hybrid Technologies

A Huge number of computer networks around the world have a dependency with economic international. This necessitating leads to creating systems with highly accurate by engineers and researchers such as that provide the broadband subscribers connection with high reliability. The customers around the globe operate on multitude types of the services and networks which are not at all standardized and uniform.

The customers could get what is useful from broadband services like data sharing or HD live streaming or could connect to the internet, in many techniques such as digital subscriber line (DSL) and FTTH which are a wired connections methods or GPRS which are a wireless connections technology [22]. Therefore observed predominate in the market is a mixture of various techniques. The main reason for haven't finding a standard technique for many of the participants is the inability to conduct modernization and development immediately if necessary. If the company is built according to the foundations of modern and sophisticated technology then it could expect the possibility of the need for a particular type of connection after several years. Consequently, the necessities of hybrid technologies are the requirements of new constructions. These techniques would be useful in future for many years later.

Hybrid optical access network integrating its term refers to fiber-to-the-home with radio over fiber (ROF) systems and also belong to conjunction the single-mode with the multi-mode fiber [23]. There are some limitations of hybrid technologies such as:

- The noise sources in the laser's Relative Intensity Noise (RIN).
- The laser's phase noise which could be solved by select VCSEL.
- The photodiode's shot noise which could be solved by APD.
- The amplifier's thermal noise which could be solved by Raman Amplifier.
- The fiber's dispersion which could be solved by DCF.
- The chromatic dispersion in MMF which could be solved by shifted dispersive fiber (-, +).

1.5 Contributions of the thesis

This work provides many contributions in the networks, and communication fields, by closer the big hole between users as the following:

- Exploiting current infrastructure owned by the Ministry of Communication at the Republic of Iraq to apply our simulation without the need to install new fiber cables.
- By using RoF and WDM network can allow many users to use current fiber in an efficient manner.

- Provides flexibility to the mobility users at the last mile networks.
- Make rural and urban communicate with each other through electronic-society (E-Society).

1.6 Organize of the thesis

The thesis report is organized as follows: Chapter 2 represents the literature survey then the results and applications illustrated in chapter 3. Finally, chapter 4 includes the conclusion and feature works of the thesis.

CHAPTER 2

LITERATURE SURVEY

2.1 Overview

An example of the natural options was the optical fiber communication because of the attractions of multimedia technology. In fact, light possesses a property known that it has a very high frequency of up to ultra-high frequency or terahertz, so light provides extreme data rates if designed with professional ways. But when a survey has been taken on the networks, the optical fiber will end toward nominated place. This is a disappointment when the optical communication comes to the mobility of end terminal because of the noteworthy feature of it. That makes characteristics of the technology of fiber optic very demotivating. Even though the fact that communications through radio waves technology have known since that time, but unluckily it does not naturally support high bandwidths as in fiber optics. Therefore, rather than operating as separated technologies, Optical and wireless communications complement each other which is substance of the radio over fiber.

The advantage of complementation of these both techniques, highest information rate accompanied by the terminal portability will be obtained. Fiber optic constitutes the backbone, and it will be placed underground, and the wireless technologies produce the final mile connections. Radio over fiber guarantees the communication of an important data would inevitably happen for users inside area and coverage of the network operator. There is a modern conception in wire line communications which is the wavelength division multiplexing (WDM), is the expansion of the frequency division multiplexing to the optical domain when basically transmission various sources of data in multi colours. This is the one from more important inventions that have had the effect of human and technical life in recent years.

After finding WDM, new ways discovered the amplification in the optical fields such erbium doped fiber amplifiers (EDFA) which are colourless or agnostic amplifiers. In the communications of long-range optical fiber, this amplifier works inside a window of attenuation with 1.55 um wavelength region. Furthermore, these amplifiers are upholding a lot of colors up to hundreds of them in the self-same fiber since they are broad banded in nature. According to that, multiple and customized devices occur in presence for providing the requirement of the wavelength division multiplexing system [24].

Wireless technology at the same time also performs important development in industry, economy, and market. Wireless technology created an excitement in the communication and broadcasting segments when Marconi conducted transatlantic communication during 1901. Radio entered into the world of communications early in 1920 through the various broadcasting stations around the world which have used devices that still used until the present time [25]. After a very short period, television broadcasting has been discovered. The cellular concept developed at Bell Labs and during 1960 satellites launched and associated with communications. Requirements of the military also dramatically support the wireless technologies development[26].

During the beginning of 1990, there was the discovery of the Cellular phone, Wi-Fi, and WLAN. At the beginning of the millennium, entered into the wireless platforms new technologies such as EDGE and WiMAX. In the mobile era, there is another common classification that is the first generation from 1970 to 1985 or so which was consisting of just analog communications that include supporting just the voice. The discovery of the third generation was in the year 2001, which has the ability to support video calling, as well as the internet with mobility and many of the multimedia. While the second generation, which was discovered during the year 1990 consists of a fully digital system. Thousands of kilometers of an optical fiber distance had spread in the 3G system for mobile phone exclusively[27].

Consequently, there is unprecedented demand of the investigation, schemes, and achievement of the next technologies of bit rate with high capacity, it leads to being, in essence, a further mature and sophisticated which is the technology of radio over fiber [24][28]. The end users could access data rate more than 7 Mbps with using ROF. Developing the technologies of broadband and increasing the users around the world will prompt to discover new methods to improve the radio over fiber technology. During the last years, the technology of ROF has been studied by many research groups. In the literature, most published works have implemented in laboratories and it have been based on experiments with simulations or achieved by simulations only.

2.2 Outline of Radio over Fiber technology

The discovery of the technology of radio over fiber (ROF) for the first time was during the year 1991.What they want to access, was to provide the mobility for users in markets and domestic, where it will implement the radio communication using poles of the telegraph. The aim of the coverage was between 200-300m inside the local area [29]. The microwave photonics problem has become relevant just after the great achievement of mobile communications. Laser sources got a lot of promotions after the improvements of lasers with the solid state during the beginning of the year 1960. The development of laser sources has been conducted because of the line-width of them is extremely tight. In WDM systems there are also laser arrays. At the beginning of 1996, 40 GHz signals discovered as a modulator for the solid state laser. Analog community access television (CATV) applications used the direct modulation with the restricted input data rate up to 10 Gbps. For high speed, data transmission using external or indirect modulation is most attractive such us Mach-Zender modulator which is the most typical example with supporting 40Gbps error-free transaction of data. Broad bandwidth is also available in the receivers with somewhat acceptable switching speed. Regularly, pin photo detectors are favored over avalanche photodiodes. Single-mode fiber with compensation of dispersion and the index are used in the commercial. Whole optical communications usually are focused on 1.55um. This is because of attenuation with a little amount and the ripe technology of erbium doped fiber amplifiers, which works in that wavelength window [30]. There are multifold problems in analog connections and the transmission of microwave signals, generally in light, not unique to ROF technology. These problems are like fiber and all-optical amplifiers nonlinearities, external modulator nonlinearity, photo detectors nonlinearities, and source intermodulation and harmonic distortions.

2.3 Problems confront the mm-wave signals during transmission over optical.

The analog mm-wave is intensity-modulated sparsely over the light carrier because of an effectiveness of modulator nonlinearity. The external modulation reduces the real strength of the signal over the light because of its nonlinear characteristics. The highest rate of a transmissions distance is affected by the chromatic dispersion value of the fiber. The beneficial information probability is small for researchers compared with the occupied spectrum 40 GHz (<3GB/s as it described in [9]). Also, the detector nonlinearity could be influenced clearly on the signal deterioration.

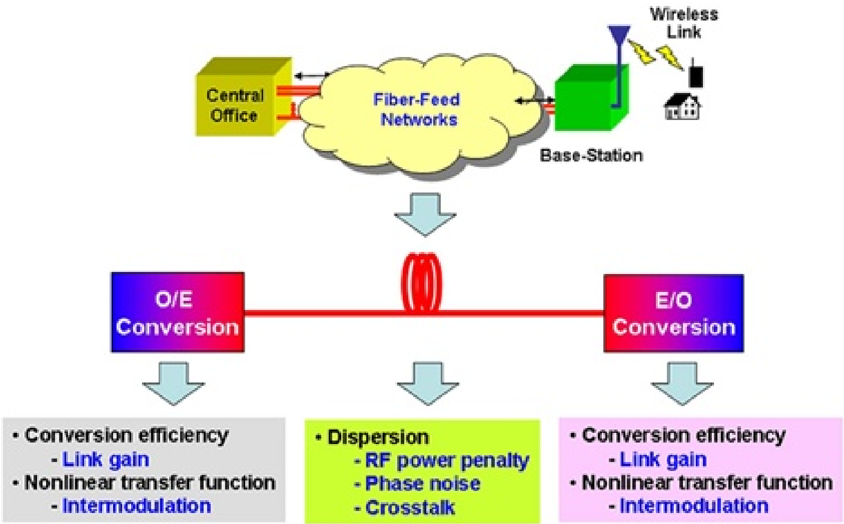


Figure 3 Radio over fiber connections notable problems [9]

2.4 Optical mm-wave modulation strategies

1. Modulation of the intensity: Despite the problems related to power and in fact spectrally incompetent, but it has simplicity in the generation.

2. Carrier with optical single-sideband: Inappropriate for lengthy distances communication but spectrally effective.

3. The technique of optical carrier suppression: Needs RF power with a high drive but it has effective spectrally.

The essential design for base station and a traditional central office, etc. is distinctly explained in [9]. Figure 4 explains a general fundamental structure [13]. This design is commonly implemented in civilized places with many users of a different kind. Every set of baseband data is strictly modulated over the particular optical carrier and then the specified terminals receive redistributed signals from the central unit where the optical to electronic conversion and another transmission in the electrical area is picking the position inside the coverage zone.

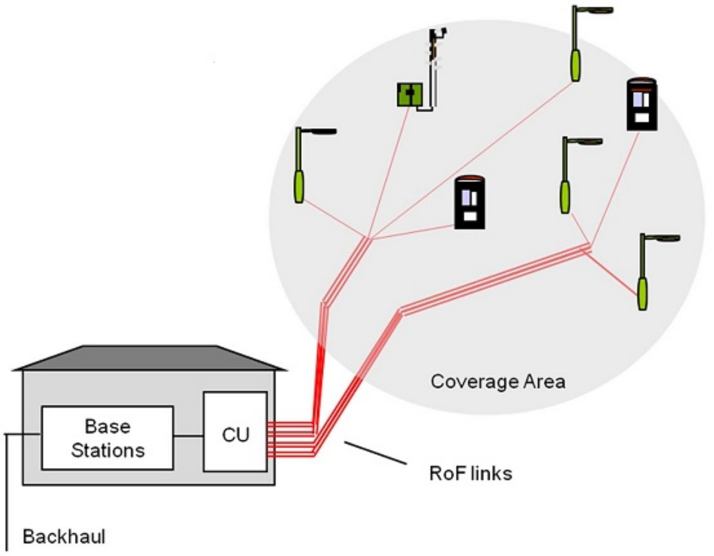


Figure 4 Structure of distributed antenna systems [13]

2.5 Design of radio over fiber link

When there is a demand to create a ROF link according to an actual scientific system, there are various specific factors need to be taken into consideration. The real system relies on geography with the traffic quantity in that selective geological section.

The frequency of carrier: Determines what will be incorporated in the system from optoelectronic components and its types. Additionally, higher bandwidth could be supported by the high frequency with increasing the dispersion inside the fiber.

The bandwidth of the radio channel: This aspect could be determined according to the frequency of the carrier with the numbers of designated users. Allowable bandwidth could be determined by the carrier-to-noise ratio (CNR).

The channels number: Specific remote station is containing many channels depends on requirements of stability and the maximum value of transmitted noise allowable.

The format of modulation: Systems with simple modulation are easy to be designed and inexpensive, but practically it's not useful whereas complex design could provide many users if there are huge traffic increases inside the system which would prove to be cost-effective in a long time.

The Cost: The cost of the spread of efficient system depends on the short-term and long-term benefits.

The distance: The data rate and the effective powers of the laser diodes, are the factors affecting the fiber length value.

The hybridity: A reliable optical system would be significant for hybrid users from wired and wireless connections [13].

Mostly, for a particular scheme, the design team determines the estimated traffic capacity. After that, split the operation region into several smaller geographies blocks. Then calculate the particular parameters connections with additional margin regularly designate to guarantee the safety of the system in the state of power interruption. Finally, the layout structure is building from the most convenient and inexpensive components. Then Install and test the components to check the conformity between them to produce the final decision for finishing the system, or if not, the system would be redesigned.

2.6 Networks of WDM in RoF

Metro networks and extremely high capacity channels are using networks with the WDM. Using the same fiber optic backbone network for designate several colors to various base stations [31]. WDM system has many topologies such as (ring, and metropolitan), by WDM can be multiplexing multiple wavelengths (multiple channels or multiple users) into a single fiber and then demultiplexing them at the end side receiver by a demultiplexer into an individual wavelength. It is work as a peer-to-peer link. The WDM systems provide many features (wavelength reuse, conversion wavelength, transparency, switching, flexible interconnections between users of the optical network, and configurability). This system is effectively used in future because it finds the mistakes and resolves it of the optical network is comparatively simple.

2.7 Multi-gigabit by radio over fiber system with full duplex

Full duplex radio over fiber design was discovered early with baseband modulation, however full bi-directional design working on over 60 GHz was conducted during the beginning of 2003 [32][33].

Early plans were discovered the light as a carrier over millimeter waves, and the performance was not by all standards. The initial design successfully proved by a bit rate 155.52 Mbps. At the transmitter, Continuous-wave (CW) laser source used in the design as a modulator by using electro-absorption modulator (EAM) and at the receiver used the pin diode. In this design, the uplink and the downlink performed by using two different systems as shown in Figure 5. Hence two different fiber links were deployed through a 23km length. Additionally, it directs the ROF connection from the central office to the base station. This also shows that by managing the operation in such small length would demonstrate that the system can be propagated to any area [34]. The drawback of this system is in the uplink, where optical sensitivity can become saturated.

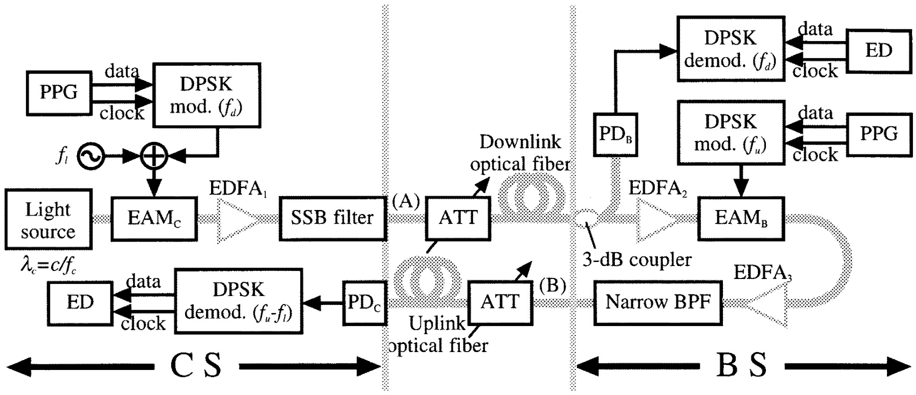


Figure 5 Uplink and Downlink systems [34]

The networks economical deployment requires equally important from the hybrid technologies. The components that used to create the system should be with a high degree of reliability. That means if the new technologies have emerged, the devices that previously placed must support insignificant adjustment on this design to accept the developments. Occasionally, for this goal is the using of a dark fiber which is indicating to the network capability of telecommunication infrastructure, but presently also mentions to the increasingly accepted method of leasing fiber optic wires from a network service provider, or, commonly, to the fiber installations not held or controlled by regular carriers. In general language, the dark fiber may occasionally still called "dark" If it is being lit by a fiber tenant and not the cable's owner. Also, for such purpose hybrid systems are quite valuable. Here it has been shown that fiber optic with a single channel could transport signals for millimeters waves, broadcasting applications like CATV and wireless signals like microwaves and this achieved by using multiplexer at the transmitter and de-multiplexer at the receiver. Hybrid technology is proved to be typical in the future with linear traffic increase and works on a high data rate of 2.5 Gbps [35].

There is another study characterized by simplicity in design with valuable results. Wherein phase modulation was applied on the signal in downlink and intensity modulation was applied on the signal in uplink. It has been achieving good values for data rate which is 2.5Gbps and 10E-9 bit error rate (BER). However phase modulation signal needs a complicated and expensive method for detecting. So, to design dependable and powerful communication links, the modulation formats in addition to the measure of devices preparation should be taken into consideration [36].

Another study work has proposed bidirectional ROF system with Subcarrier Multiplexing (SCM)/ASK transmission. Receiver sensitivity has evaluated for SCM using an optically pre-amplified receiver, and 10 GB/s bit rate was being done [37].

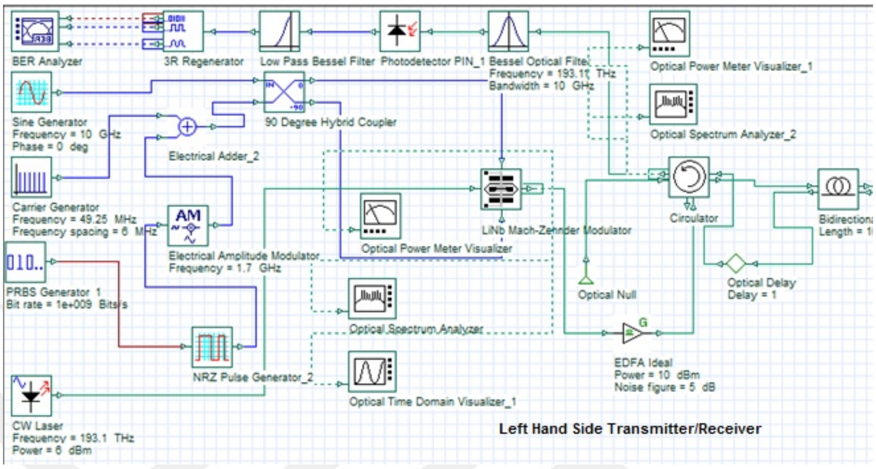


Figure 6 Design of SCM/ASK systems [37]

To prevent each effect of distortion have been utilizing the cross remodulation which characterized by conjugation a pair of fibers optical effectively. For downlink data utilized two of arrayed waveguide gratings (AWG), one of them is used for each wireless signals and another is for all the wire line signals. During utilized four of AWGs alternatively of two, this led to using additional splices and connections consequently reliance on this design is doubtful because it's costly. Additionally, the possibility of deployment of this design is weak and unable to resist the time factor. However, the cross remodulation approach could be used as an inevitable solution for many of the problems in the future [38].

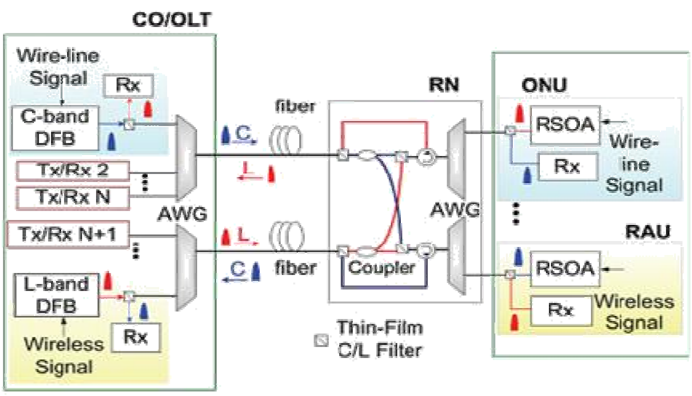


Figure 7 Cross remodulation [38]

2.8 The peak of passive optical networking (PON), WDM, and ROF technologies:

In this area, conventional multiplexer is used for multiplexing the solitary laser sources. This composite signal offers to a Mach-Zehnder Modulator (MZM) well biased which function as an optical carrier suppressor. The carrier signal of the all coming colors will be lost; besides a pair of wings will seem in the spectrum of every color. Then, demultiplex the resulting signal and send it towards two AWGs through separating it into two sections where one AWG operates on the data of wire line whereas the second AWG operates on data of the wireless. Again the signal and the related sources of data modulate by an MZM, and the same signals will be multiplexed over. Lastly, the fiber optic is used to carry this collection of signals toward the base station where is uses a splitter of the power in each channel whereas a photodiode in one section is used to extract the information and a tunable optical filter is used to derive the information. In the base station, same methods are implemented but in the reverse orientation. After of this, it's realized that the peak of the PON with the technology of ROF is effective. Apparently bidirectional hybrid technologies and other correct practical applications indicate that it could be included in the study [39].

Further study in [40], has introduced a hybrid optical link from MMF and SMF beside individual 60 GHz transceiver operates within envelope detection and direct modulation. The experiment proves the ability to create networks for wireless access with an effective solution in terms of cost for the next generation of Gigabit inside the building.

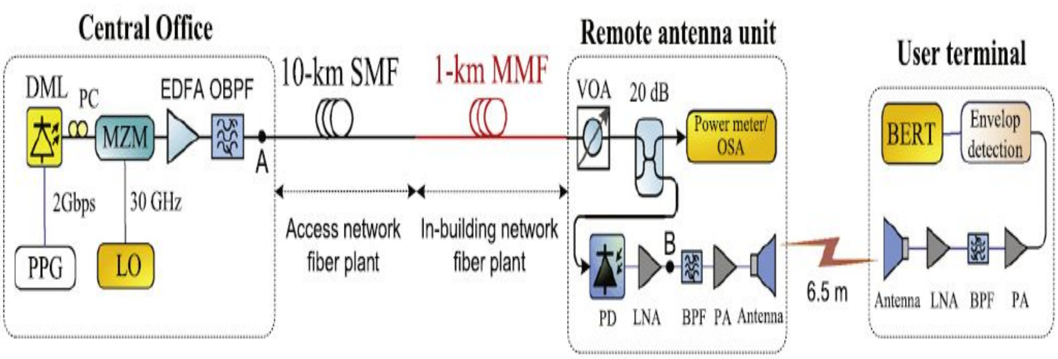


Figure 8 Wireless connections with Hybrid MMF and SMF [40].

The other work related is in [41], which has studied the protocols of media access control (MAC) with network construction based on RoF. They practice RoF systems by using centralized control capability with an efficient way to get efficient bandwidth distribution with quick and manageable transportation. They do not take into account the solutions in ROF networks about the management of resources, but only suggested potential solutions for developing the environments of the network.

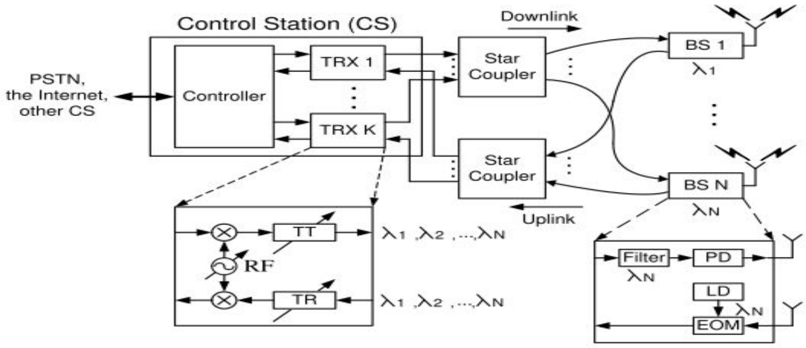


Figure 9 RoF-based network architecture with (MAC) protocols [41].

2.9 Routing of the sideband:

Many double-sideband suppressed carrier transmission (DSB-SC) sources send to circulator after multiplexed, then to demultiplexer to separate the light. In meantime, the data is merged with every color over the wireless and wired then re-integration of this signal with the primary carrier signal. A comparable method is utilized in the base station to implement the comparable action. A quadruple frequency used to carry the big data rate and the imitation is executed just through a single channel. At a frequency carrier with 10 GHz, the CW laser is driving to well bias MZM. Used an optical circulator then the carrier inverted backward to the radix by the fiber Bragg grating, furthermore, the other port of the circulator makes deviate of that carrier signal. After proper indemnification optical gain, each of the signals is mixed. Mach–Zehnder interferometer (MZI) received the signal driven through fiber optic as two parts. Part of the signal utilized to retrieve data of downlink from incoming signal light and another portion is directed to uplink fiber optic after modulating it in the uplink signal. The information is abstracted through the tunable optical filter inside the central station [42].

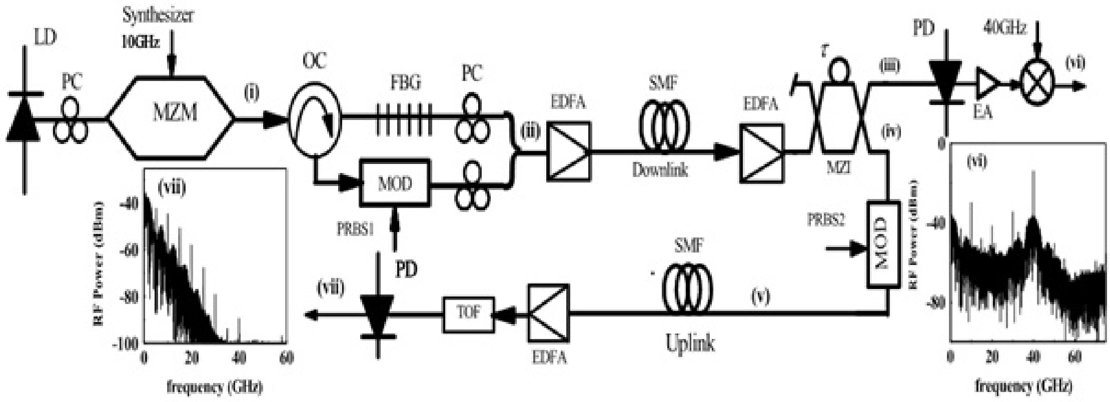


Figure 10 ROF with full duplex and big data flow [42]

The scheme in [43] studies the impact of chromatic dispersion (CD) and increases bandwidth performance. They introduce and explain the using of the reflective semiconductor optical amplifiers (RSOA) with a bidirectional ROF network. An intensity demodulated ROF signal at the RSOA with ROF signal for the phase-modulated has been applied for downloading and uploading communications, sequentially. The test results in determining that ROF signals of 850 Mb/s at 5.25GHz RF download and 850 Mb/s at 10GHz RF upload after 25km SMF link are free from errors and also efficient.

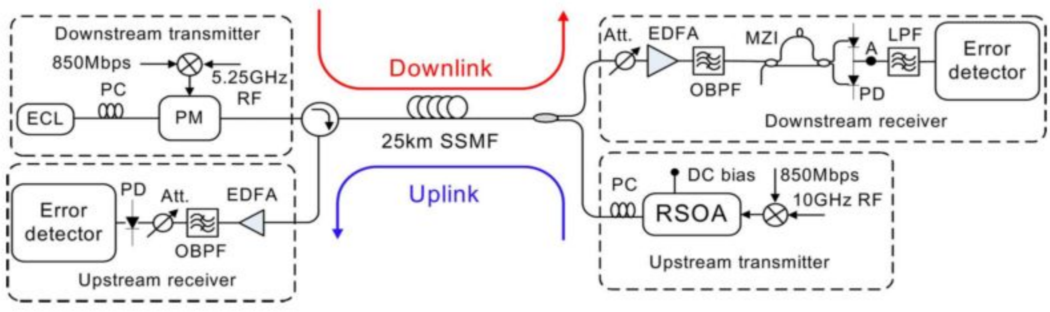


Figure 11 An RSOA utilization with ROF system [43]

Another study has analyzed various modulation formats that are suitable for high bit rate optical communication systems [44]. This study utilizes data rate for transmission as 40 Gb/s, 20 Gb/s, and 10Gb/s. It practices and analyzes RZ, NRZ, DQPSK, DPSK, and CSRZ modulation and evident best modulation format depend on the case and application.

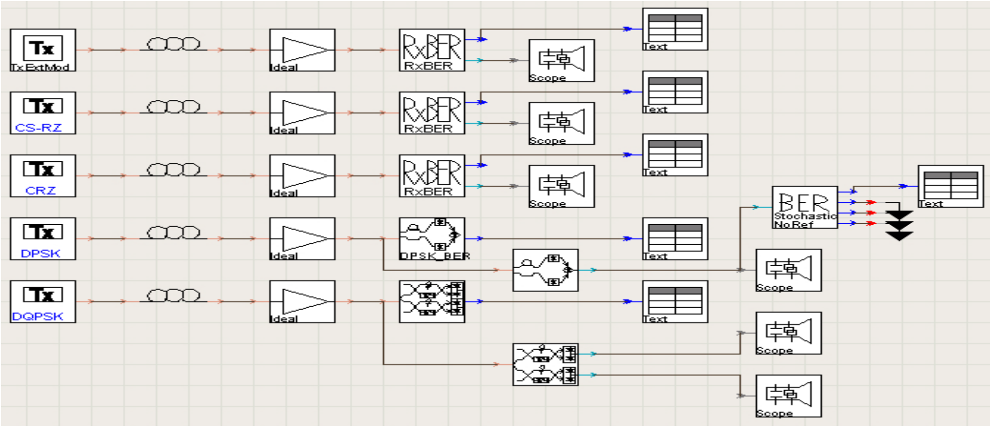


Figure 12 ROF system with various modulation formats [44]

The structure presents in [39] is satisfied enough for high-speed connections when searching for design with flexibility. Different sources are steering the carriers of optical after combining them onto an MZM which functions here as a suppressor for the optical carrier, not as a traditional modulator. Suppression of the optical carrier makes the design more flexible. The signals are separating to wire line and wireless data by an optical interleaver wherein the baseband data placed on by separated MZMs in every channel. It should be noted that waves of the optical millimeter carried data of the baseband. Over the downlink fiber optic, all signals are carrying the data transmission from the central station after mixing it. In the base station, the group of signals classifies again by an interleaver on being wireless and wired then by using tunable optical filters and different combiners of the optic, supplementary processes applied to those signals. It should be noted that the re-use of the optical carrier is not satisfactory through the present design because of the wasteful use of optical filters with additional MZMs. When the networks almost have a similar number of wireless and wire line stations aforementioned suggested design would be appropriate, as in the campus of the universities.

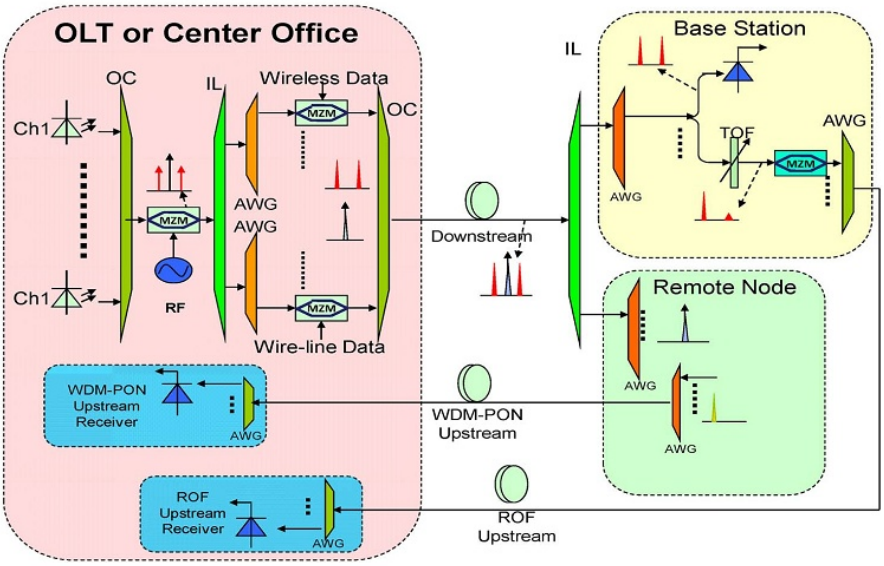


Figure 13 ROF structure with manageable full duplex [39]

The plans discussed aforementioned were ad-hoc in nature and now will analyze a particular connection design plan as publishes in [45] where is applied dependable and cost-effective ROF link implemented by double port MZM appropriate for connections with small distances. The lithium niobate ($LiNbO_3$) dual port modulator received the output carrier from the CW laser source. Fiber optic is carried several collections of the amplified signals after modulated it with the two ports. The MZM two ports modulated as 10 Gbps baseband signal for the first port and by least data rate of 2.5 Gbps of the other port which carried by a 20 GHz RF carrier. To swimmingly obtain the data hidden in the mixed signal, the base station should necessarily possess convenient multiplexer elements with an interleaver. Although this method is appeared to be an extraordinary but again, it depends on the operating costs over the long term. Furthermore, the base station required numerous complex detection methods which will increase the cost of the operational again. However, this study could be satisfactory because of the connections with high data rate where the flow of the data is a significant advantage more than the adaptability or other matters of the system configuration. Essentially, this is a general design expecting to utilize in another place.

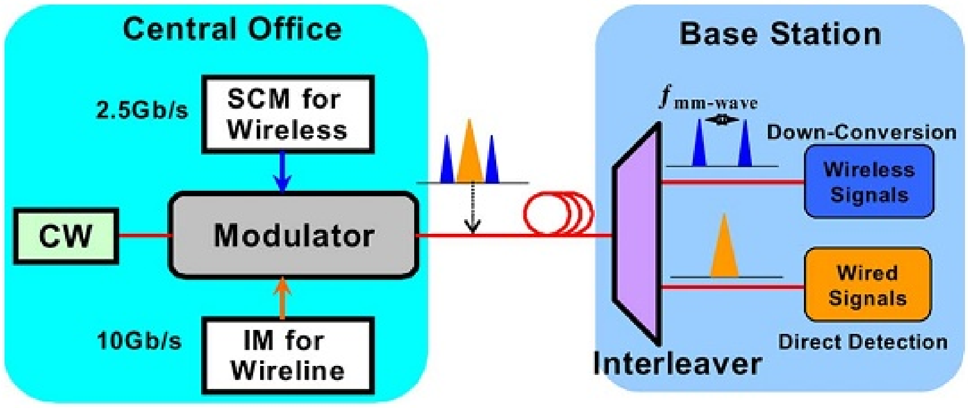


Figure 14 Coincident ROF with wireless and wire line link [45]

CHAPTER 3

PROPOSED METHOD AND EXPERIMENTAL RESULT

A flexible network has been done in this thesis by using RoF networks with minimum components (passive/active) and hybrid optical fiber. The simulation was performed within C-band which refers, in infrared optical communications, to the wavelength range between 1530 and 1565 nm as showning by red coler in ITU frequency grid and corresponding wavelength table 2. C-band corresponds to the amplification range of erbium doped fiber amplifiers [46].

Table 2 ITU frequency grid and corresponding wavelength

Frequency (THz)	Wavelength (nm)	Frequency (THz)	Wavelength (nm)	Frequency (THz)	Wavelength (nm)
197.20	1520.25	193.30	1550.92	189.20	1584.53
197.10	1521.02	193.20	1551.72	189.10	1585.36
197.00	1521.79	193.10	1552.52	189.00	1586.20
196.90	1522.56	193.00	1553.33	188.90	1587.04
196.80	1523.34	192.90	1554.13	188.80	1587.88
196.70	1524.11	192.80	1554.94	188.70	1588.73
196.60	1524.89	192.70	1555.75	188.60	1589.57
196.50	1525.66	192.60	1556.55	188.50	1590.41
196.40	1526.44	192.50	1557.36	188.40	1591.26
196.30	1527.22	192.40	1558.17	188.30	1592.10
196.20	1527.99	192.30	1558.98	188.20	1592.95
196.10	1528.77	192.20	1559.79	188.10	1593.79
196.00	1529.55	192.10	1560.61	188.00	1594.64
195.90	1530.33	192.00	1561.42	187.90	1595.49
195.80	1531.12	191.90	1562.23	187.80	1596.34
195.70	1531.90	191.80	1563.05	187.70	1597.19
195.60	1532.68	191.70	1563.86	187.60	1598.04
195.50	1533.47	191.60	1564.68	187.50	1598.89
195.40	1534.25	191.50	1565.50	187.40	1599.75
195.30	1535.04	191.40	1566.31	187.30	1600.60
195.20	1535.82	191.30	1567.13	187.20	1601.46
195.10	1536.61	191.20	1567.95	187.10	1602.31
195.00	1537.40	191.10	1568.77	187.00	1603.17

Table 3 ITU frequency grid and corresponding wavelength

Frequency (THz)	Wavelength (nm)	Frequency (THz)	Wavelength (nm)	Frequency (THz)	Wavelength (nm)
194.90	1538.19	191.00	1569.59	186.90	1604.03
194.80	1538.98	190.90	1570.42	186.80	1604.88
194.70	1539.77	190.80	1571.24	186.70	1605.74
194.60	1540.56	190.70	1572.06	186.60	1606.60
194.50	1541.35	190.60	1572.89	186.50	1607.47
194.40	1542.14	190.50	1573.71	186.40	1608.33
194.30	1542.94	190.30	1575.37	186.30	1609.19
194.20	1543.73	190.20	1576.20	186.20	1610.06
194.10	1544.53	190.10	1577.03	186.10	1610.92
194.00	1545.32	190.00	1577.86	186.00	1611.79
193.90	1546.12	189.90	1578.69	185.90	1612.65
193.80	1546.92	189.80	1579.52	185.80	1613.52
193.70	1547.72	189.70	1580.35	185.70	1614.39
193.60	1548.51	189.60	1581.18	185.60	1615.26
193.50	1549.32	189.50	1582.02	185.50	1616.13
194.20	1543.73	189.40	1582.85	185.40	1617.00
193.40	1550.12	189.30	1583.96	185.30	1617.88

Two systems based has been intended to match the market and infrastructure components available in the many optical switches in the middle east, and according to the monitors at the end side receive the output signals are suitable because there is limitation of degradation and allowable errors in bit. The output signals in our simulation surveyed depending on the signal shape and the values of output power, and eye opening based on the BER analyzer. In the following subsections two test beds for ROF technology based on different techniques are demonstrated as following:

3.1 Radio Frequency (RF) Based Hybrid Optical Fiber Test Bed:

In this experiment, a simple, economical hybrid Gigabit fiber to the wireless system has been proposed and analytically demonstrated for in-building wireless access. By using hybridity could support many speed infrastructure and it is a right choice at the last mile distance; also it supports a fiber-to-fiber and fiber-to-transceiver techniques. Other reasons are because it has lower transmission losses, reduced sensitivity to noise and reduced sensitivity to electromagnetic interference compared to all electrical signal transmission. To guarantee the best requirements for

RF transmission as high performance the basic configuration of RF system with passive and active components was simulated as it can be seen in Figure 15 where the amplitude modulator consists of three ports. The first one is an electrical signal generated by sine generator named as modulator and the second one, is the carrier which is an optical signal generated by a CW laser, and the last one, is the output optical signal. The powers for three signals are variables and changing them through the software simulation based on the experiment requirements. The main layout of our first experiment designs simulates, tests, and verifies our analysis by the Optisystem 14.0 package software, is a license Canadian product company. In this test bed, there are three frequencies of microwave signals have modulated with the continuous laser (CW) by amplitude modulator (AM) to modulated the optical signal externally. The sine generator is responsible for producing electrical signals (S1=56MHz, S2=116MHz, and S3=176MHz), that was generated using Equation (1):

$$S=0.5+0.5*\sin(2*\pi*f_0*t+\text{phase})\ldots (1)$$

Where:

Π: Pi,

f_0*: initial frequency,*

t:time, and

phase: initial phase of the signal.

Assuming that the optical input signal is E_{in}, the following Equations describe the behaviour of the model:

$$E_{out}(t)= E_{in}*sqrt(mod(t))\ldots(2)$$

$$Mod(t)=(1-MI+MI*modulation(t))\ldots(3)$$

Where:

$E_{out}(t)$*: is the output optical signal,*

MI: is modulation index, and

Mod(t): electrical input signal

The CW laser provides an optical signal of (193.1THz) for all three lasers. To observe the input signals, each signal is forked by fork device (passive device) and received by the photo detector positive intrinsic negative (PIN) then monitored by oscilloscope visualizer. Three signals are multiplexed by the power combiner of (3×1) and then launched into the optical link. The first device is erbium doped fiber amplifier (EDFA) with the length of (5m) as a booster amplification used to amplified signals. To complete signals journey, they entered into the SMF, with the length of (50km), attenuation of (0.2dB/km), and dispersion of (16.75ps/nm/km). To include hybridity of our link the signals are launched into the multimode fiber (MMF) with the length of (1km) and attenuation of (2.61dB/km). Their degradation appears on signal because of fiber nonlinearities phenomena, as a result of this, to overcome this problem an EDFA with the length of (5m) as a preamplifier to compensate losses in the signals is used. After this distance, signals are detected by the avalanche photodiode (APD) to convert an optical signal into the electrical signal. At the receiver side, there is some power signal lost and to compensate this, an electrical amplifier with a gain of (40dB) is used. The splitter of (1×3) used to split three signals based on its frequency and filtered by three band-pass Butterworth filters of (bandwidth=6MHz, and frequency1=56MHz, frequency2=116MHz, frequency3=176MHz). The filter's function is denoted by Equations (4) and (5). Finally, the bitrate of our experiment is (2.5Gbps), (sequence length is 128bits), (sample per bit is 128), and (number of samples is 16384). Figure 16 illustrates the block diagram of the previous test bed.

$$H(f) = \frac{\propto (B/2)^N}{\prod_{k=0}^{N-1}(j(f-f_c)-p_k)} \ldots (4)$$

$$p_k = \frac{B}{2} * e^{j\frac{\pi}{2}(1+\frac{2k+1}{N})} \ldots (5)$$

Where;

H(f): function of filter transfer,

α : lost of parameter insertion,

f_c : frequency of the filter center determined by the frequency of the parameter,

B: bandwidth of the parameter,

N: parameter sequence, and

f: frequency.

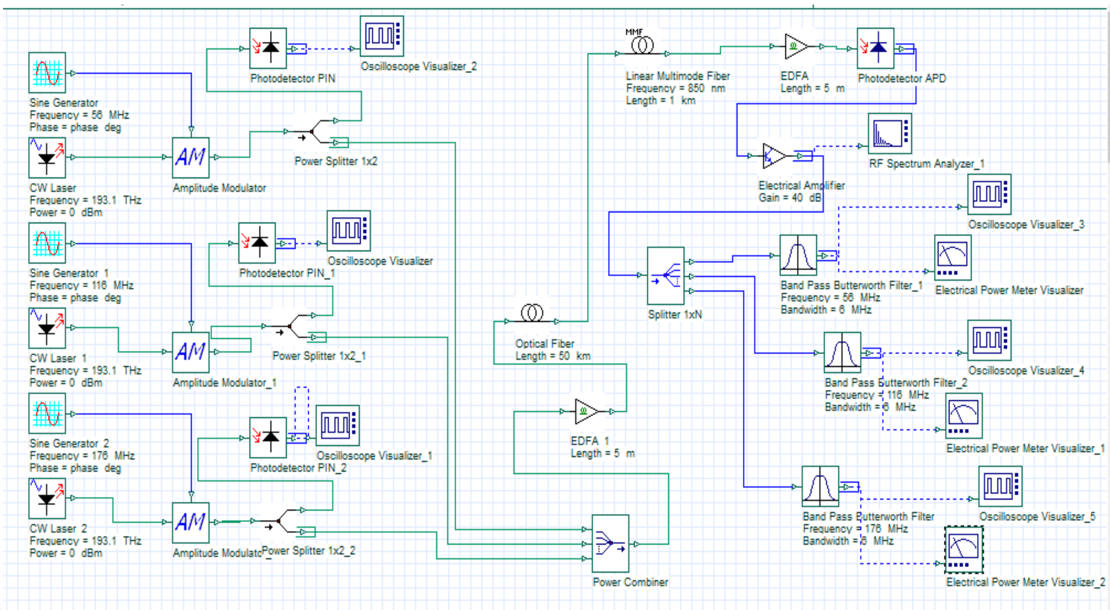


Figure 15 Main layout of radio over fiber with three signals

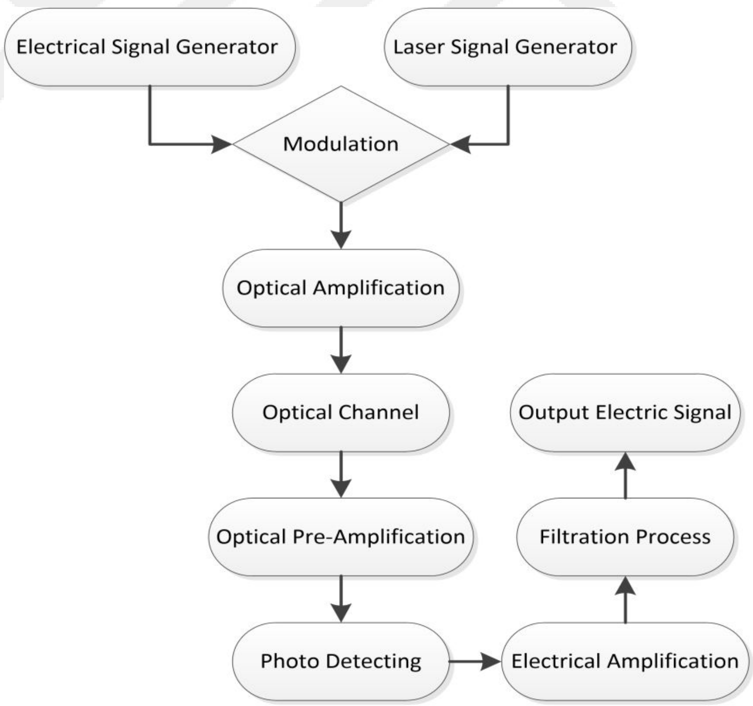


Figure 16 Illustrate the block diagram for experiment 1

3.2 Radio over Fiber based on (WDM) experiment:

Because with hybrid usage there are a dynamic range problem where the dispersion of SMF and MMF are deferent [47], and the limitation of increase the users, this experiment has been proposed by exploiting the benefits of WDM as listed in section (2.6), in an efficient manner. In spite of the increasing in the components and modulations processes like electrical amplitude with Mach-Zehnder, and decreasing the distance and bitrates compared with the first experiment where 51Km distance and 2.5Gbps bitrate for first experiment and 50Km distance and 1Gbps bitrate for the second experiment. But when making a comparing between them, there are balancing in costs, bandwidths, simplicity, and the number of users in each network. To permit the multiple users as 2,4,8,16, or 32 users over the current optical infrastructure here the WDM (active component) as multiplexer/demultiplexer is used, and other elements from the Optisystem 14.0 package as it can be seen in Figure 17. At the sender side, two inputs are used. Sine generator is to provide an analogue signal (frequency=10GHz, and phase=0deg) with two carriers generator to produce a sinusoidal electrical signal with constant amplitude. Also, two electrical adders to add electrical signal from pseudo random bit sequence generator (PRBS), and non-return to zero (NRZ) pulse generator. This signal as exponential rectangle shape can be modelled according to Equation (6). Carrier and amplitude modulator (AM) output with two 90 degrees hybrid coupler were used to combine electrical signals. Two CW laser (193.1THz, and 193.2THz) used with two LiNb Mach-Zehnders modulated to modulate an optical signal with an electrical signal. Each two signals are booster amplified by the EDFA (power=10dBm, and noise figure=5dB) to compensate the losses. These two signals are multiplexed by the WDM and then launched into the SMF with (length of 50km, attenuation=0.2dB/km, dispersion=17ps/nm/km), and pre-amplified EDFA (power=10dBm, and noise figure=5dB). At the receiver side, the signals are demultiplexed by the De-MUX and converted by two PIN, filtered by two band pass Bessel filters (frequency=1.7GHz, and bandwidth=1GHz), and amplified by two electrical amplifiers (gain=15dB). Then demodulated by two electrical amplitude demodulator (frequency=1.7GHz, and cut off frequency=0.6GHz). To observe the output signals used the bit error rate analyser (BER) calculated according to

Equation (7). The two 3R regenerators (regeneration, reshaping, and reclocking) have been utilized. Signals reshaping results the original pulse shape of each one, taking out most of the noise. Digitally modulated signals are mainly produced by reshaping, but sometimes it could be applied to analogue signals. The signal reclocking synchronizes the signal to its original bit rate and bit timing pattern. Digitally modulated signals are introduced only by reclocking. Finally, the bitrate for this test bed is (1Gbps), (sequence length is 128bits), (sample per bit is 32), and (number of samples is 4096).

$$E(t): \begin{cases} 1 - e^{-(t/cr)}, 0 \leq t < t1 \\ 1, t1 \leq t < t2 \\ e^{-(t/cf)}, t2 \leq t < T \end{cases} \quad \ldots (6)$$

Where:

c_r: *rise time coefficient,*

c_f: *fall time coefficient,*

t_1, *and* t_2: *numerical to generate pulses, and*

T: bit period.

$$BER = \frac{M}{N+M} P_{e0} + \frac{N}{N+M} P_{e1} \ldots (7)$$

Where:

M: number of samples for logical 0,

N: number of samples for logical 1,

S: threshold value,

P_{e0} *,and* P_{e1}: *probabilities of symbols*

$$P_{e0} = \frac{1}{2} erfc\left(\frac{S - \mu 0}{\sqrt{2}\,\sigma 0}\right)$$

$$P_{e1} = \frac{1}{2} erfc\left(\frac{\mu 1 - S}{\sqrt{2}\,\sigma 1}\right)$$

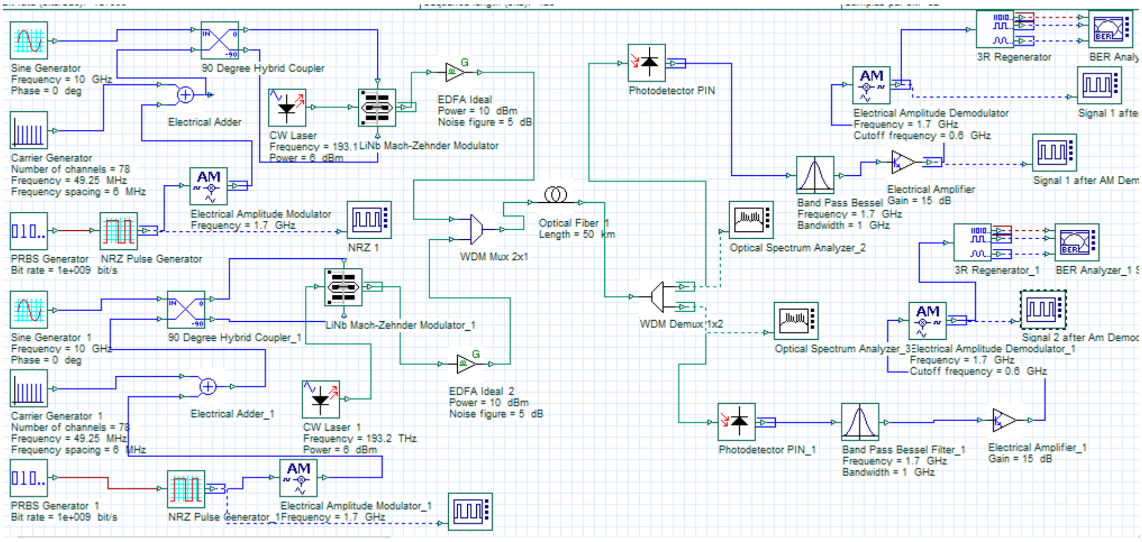


Figure 17 The main layout for RF based 2WDM system

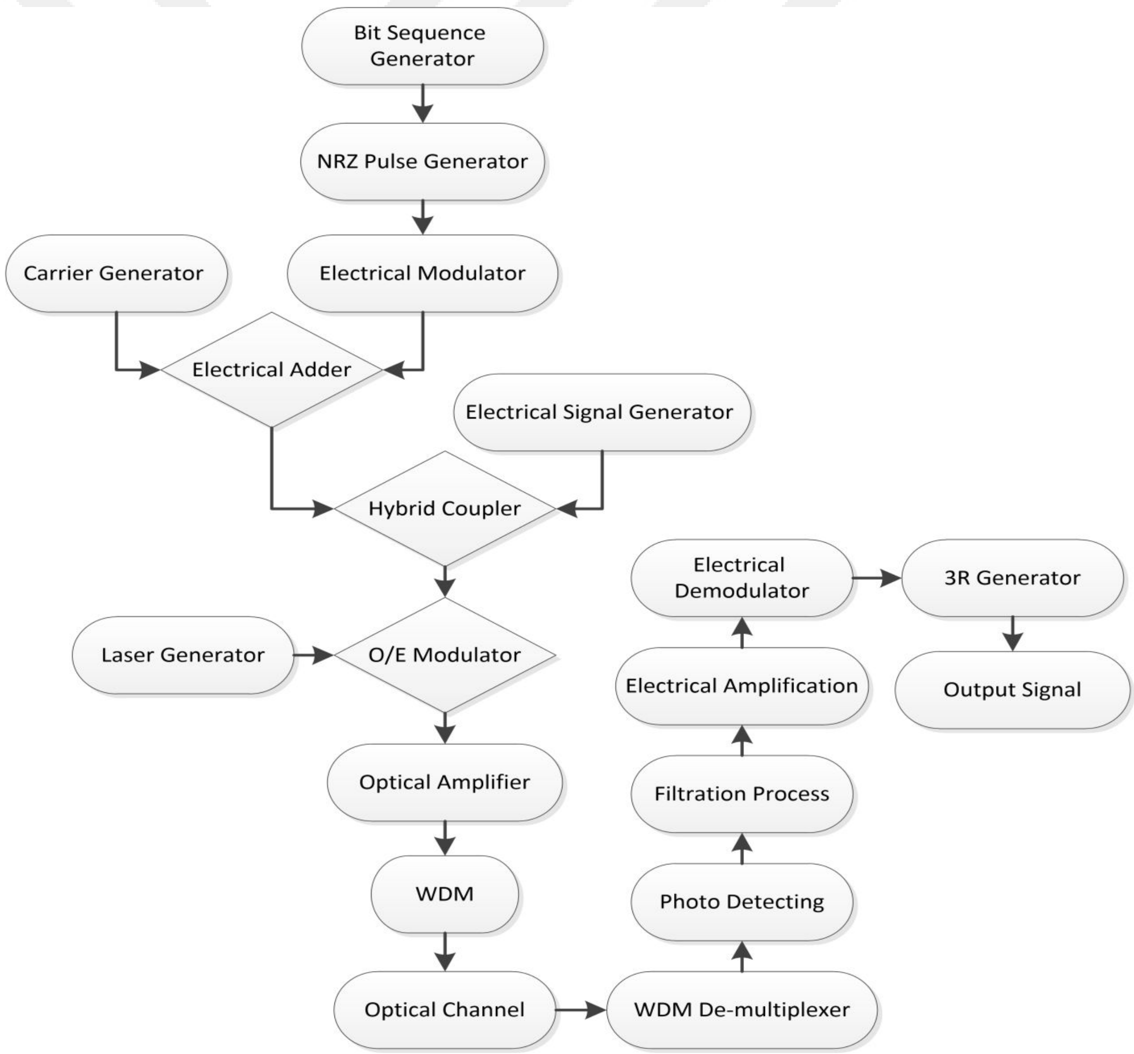


Figure 18 Show the block diagram for experiment 2

Figure 19 shows most of the elements used during simulations in the two experiments.

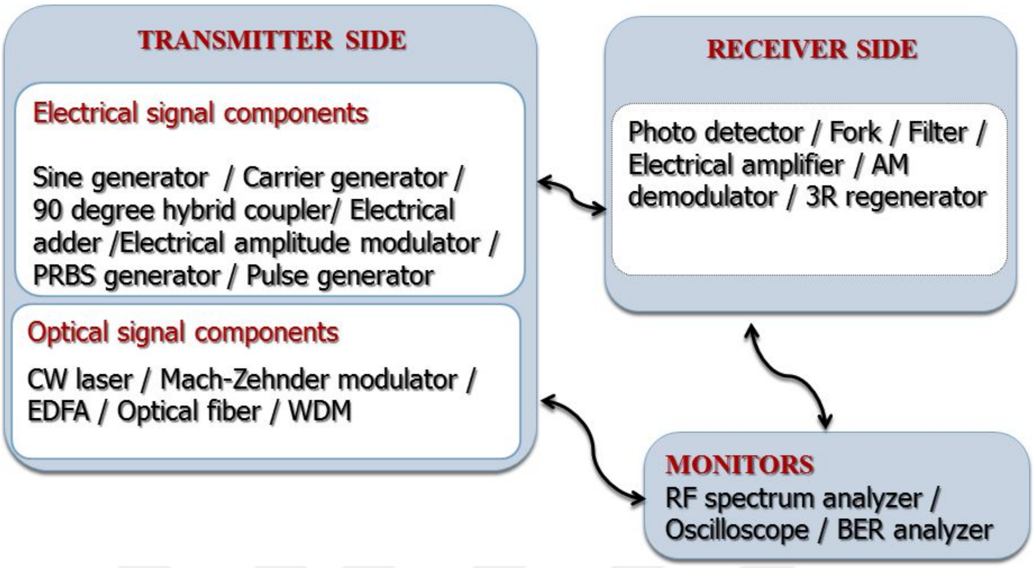


Figure 19 Elements of experiments

3.3 Results and Discussion:

The input and the output signals from our experiments are demonstrated the waveform, BER analyser, oscilloscope visualizer, and optical spectrum analyser. For the first experiment, results have been taken from power meter for many cases. Firstly the bitrate has been changed from 1Gbps to 4.5Gbps with installing the fiber length and the other parameters. The effect on output total power for all three signals (s1, s2, and s3) as shown in table 4. By looking to the result chart in Figure 20, it can be observed the bitrate 2.5Gbps more reasonable from the others values in the first proposal design.

Table 4 Output power for three signals with change the bitrate

	Bitrate (bps)	Electrical Power Meter (dBm)		
		S1	S2	S3
1	1G	5.895	6.585	6.294
2	2G	11.563	8.871	0.400
3	2.5G	15.211	12.735	12.055
4	3.5G	10.809	13.958	8.331
5	4.5G	11.404	14.492	14.179

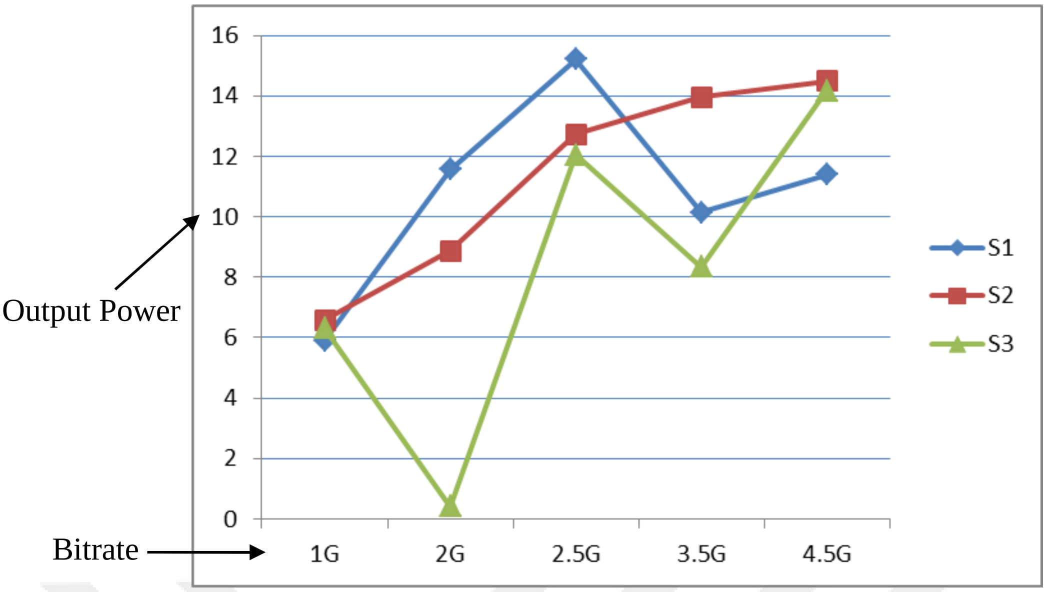


Figure 20 The relationship between bitrate and output power

Another analysis taken was a change in the value of wavelength which has fixed value in frequency, as shown in Table 5, with installing the other parameters. Table 5 show us the effect on output power for the three signals (s1, s2, and s3) and the result chart in Figure 21, turns out that changing the frequency value (wavelength) does not affect the output power value of each signal. This means that any wavelength can be used in c-band with taking into account the parameters of the other elements.

Table 5 Output power for three signals with change the wavelength

	Wavelength (nm)	Frequency (THz)	Electrical Power Meter (dBm)		
			S1	S2	S3
1	1530.33	195.90	15.154	12.6	11.997
2	1545.32	194.00	15.199	12.725	12.003
3	1552.52	193.10	15.211	12.735	12.055
4	1557.36	192.50	15.203	12.735	12.028
5	1565.50	191.50	15.210	12.752	12.061

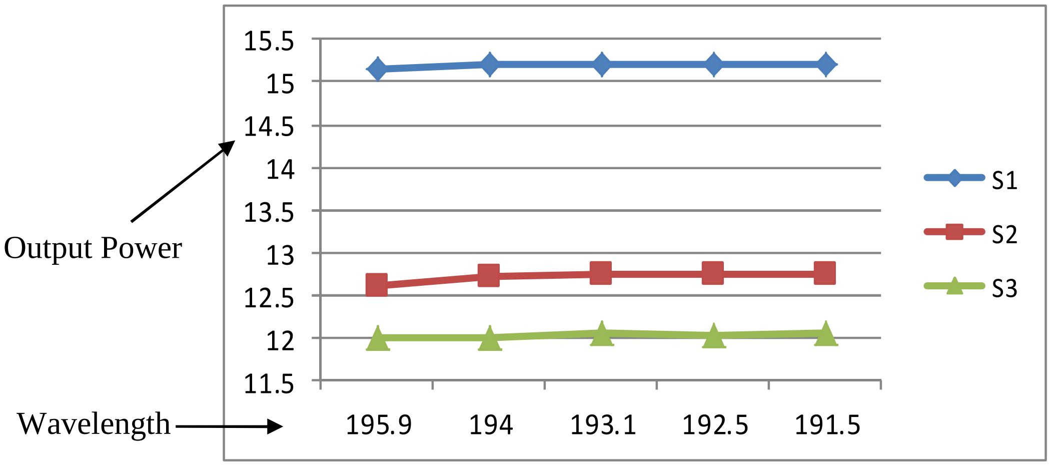


Figure 21 Output power for three signals with change the wavelength

At the end by making analysis for the first proposal experiment, 50Km SMF distance with 1Km MMF distance and 2.5Gbps bitrate its acceptable parameters to get output signal without loss, dispersion or loss of the signals. Figures are shown the input power and result of output power with MMF, and without MMF which have more noise because multimode cables are excellent when it comes to carrying a high amount of total power inside the signals, therefore, the power is almost kept not loss when using it [48]. Results are appearing in the figures from Figure 22 to Figure 30 for the three signals as following:

1) Fig. 22: views the input signal generated by sine generator_1, their some noise appears in it marked by green color.
2) Fig. 23: views the input signal generated by sine generator_2, their some noise appears in it marked by green color.
3) Fig. 24: views the input signal generated by sine generator_3, their some noise appears in it marked by green color.
4) Fig. 25: shows the output signal_1 shape at the receiver side after 50km SMF, and 1km MMF, it seems to be agreeable shape.
5) Fig. 26: shows the output signal_2 shape at the receiver side after 50km SMF, and 1km MMF, it seems to be agreeable shape.
6) Fig. 27: shows the output signal_3 shape at the receiver side after 50km SMF, and 1km MMF, it seems to be agreeable shape.

7) Fig. 28: shows the output signal_1 shape at the receiver side after only 50km SMF, their some noise appears in it marked by green color.
8) Fig. 29: shows the output signal_2 shape at the receiver side after only 50km SMF, their some noise appears in it marked by green color.
9) Fig. 30: shows the output signal_3 shape at the receiver side after only 50km SMF, their some noise appears in it marked by green color.

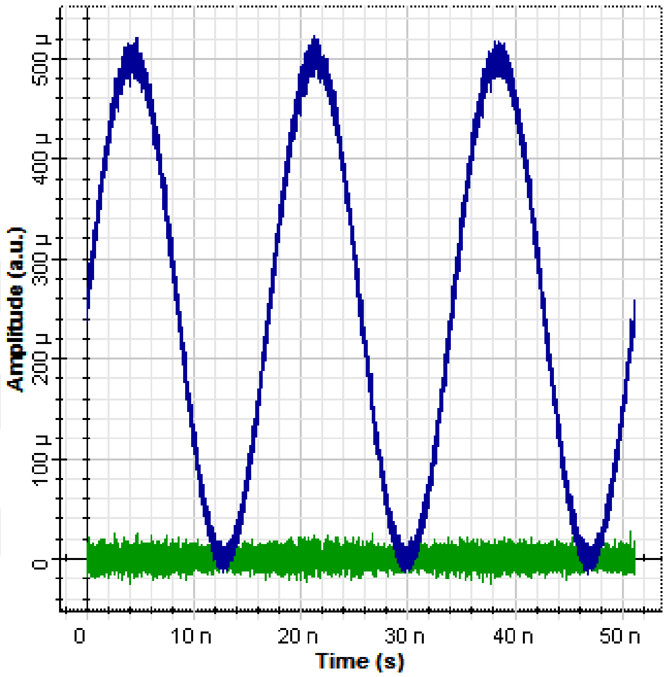


Figure 22 input signal 1

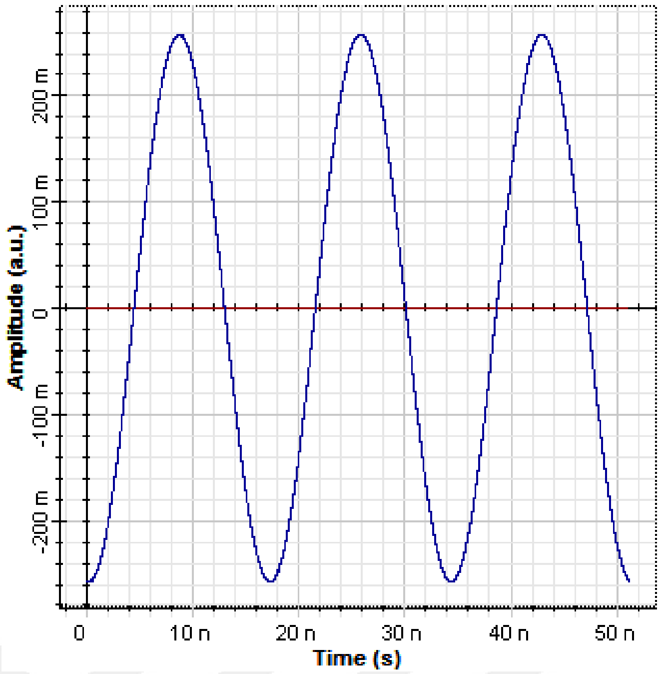


Figure 23 Output signal 1 after 50km SMF and 1km MMF

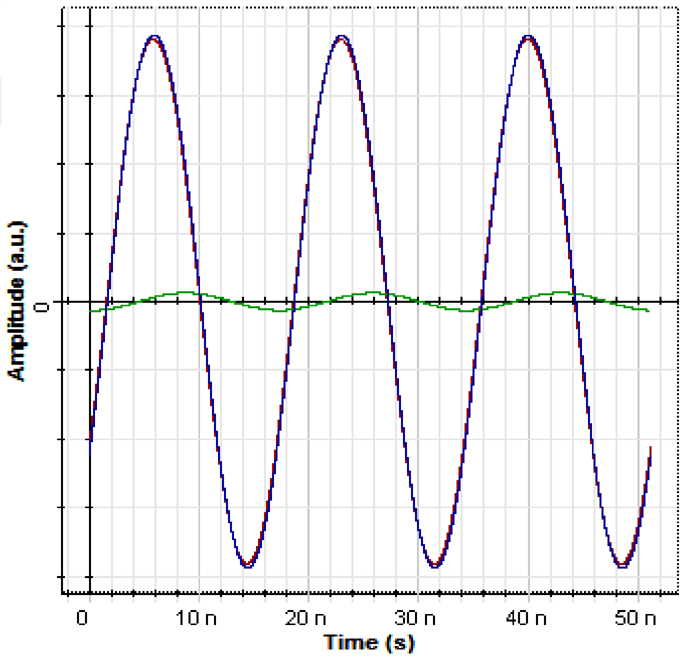


Figure 24 Output signal 1 after only 50km SMF

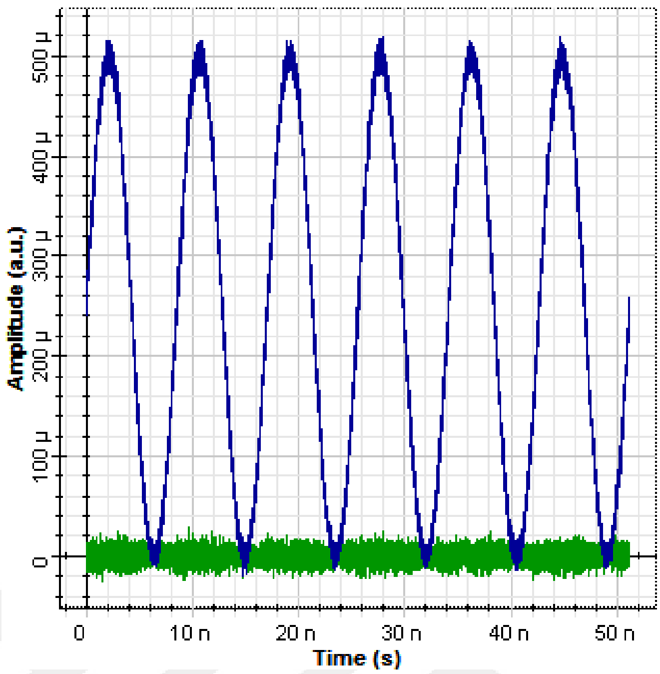


Figure 25 input signal 2

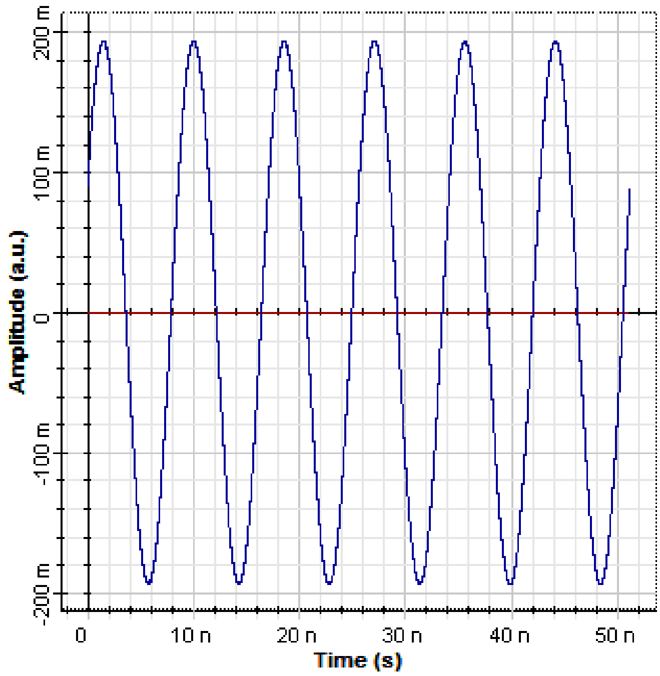


Figure 26 Output signal 2 after 50km SMF and 1km MMF

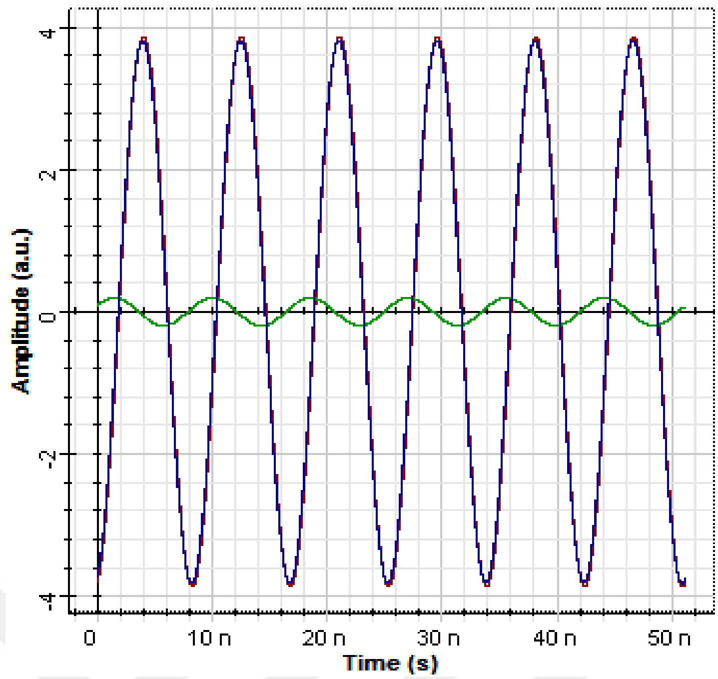


Figure 27 Output signal 2 after only 50km SMF

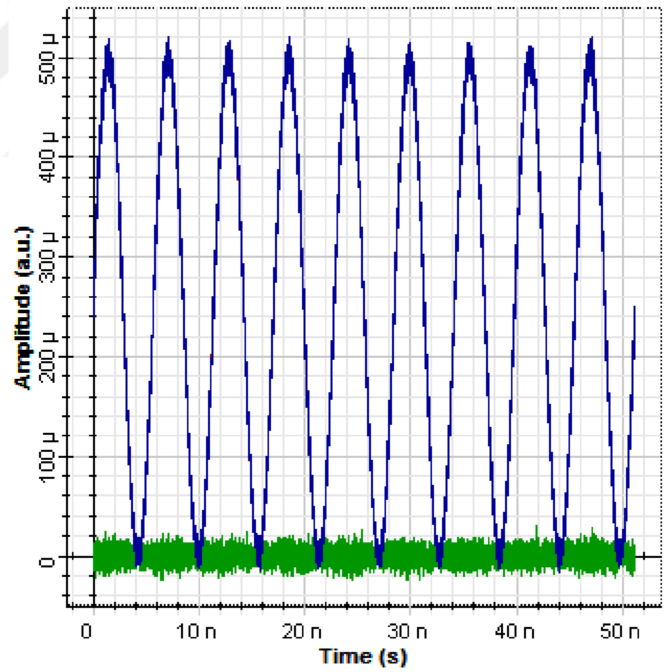


Figure 28 input signal 3

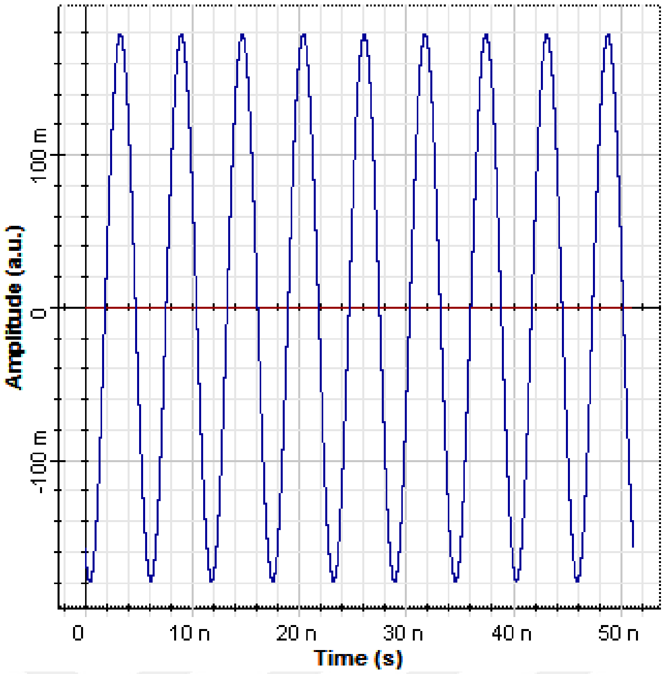


Figure 29 Output signal 3 after 50km SMF and 1km MMF

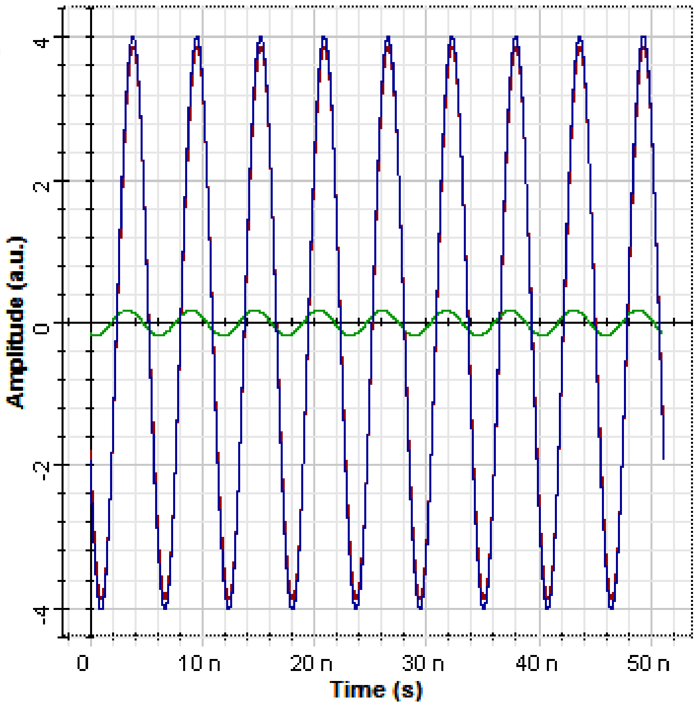


Figure 30 Output signal 3 after only 50km SMF

When increasing the bitrate and distance to critical value of our first proposed experiment, there is no output in receiver side as shown in figures 31, 32 and 33 with 10Gbps bandwidth and 100Km SSMF Length.

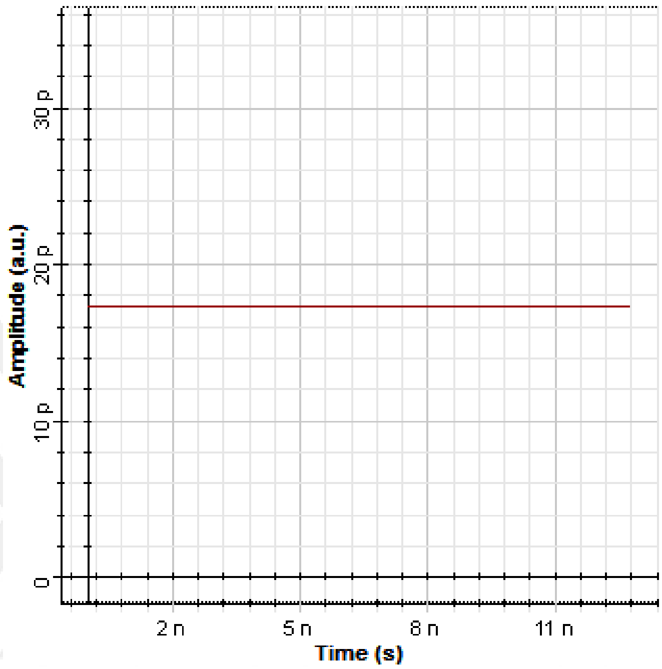


Figure 31 Output signal 1 after 100Km SMF

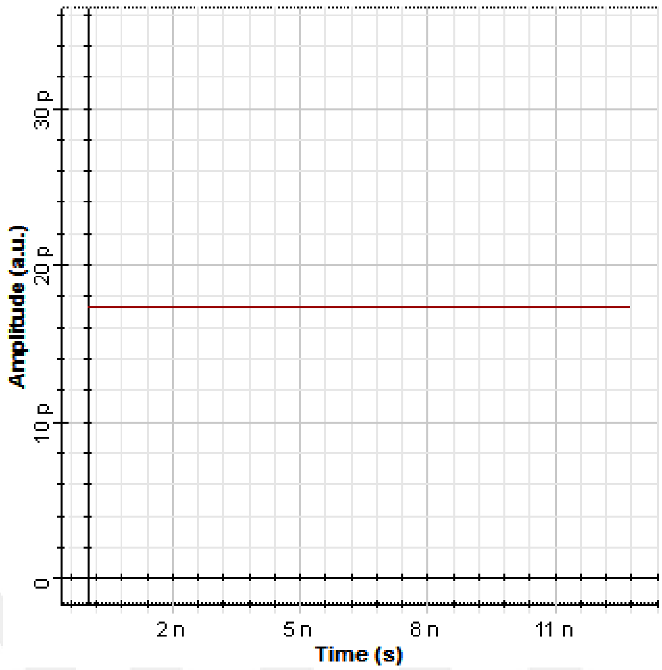


Figure 32 Output signal 2 after 100Km SMF

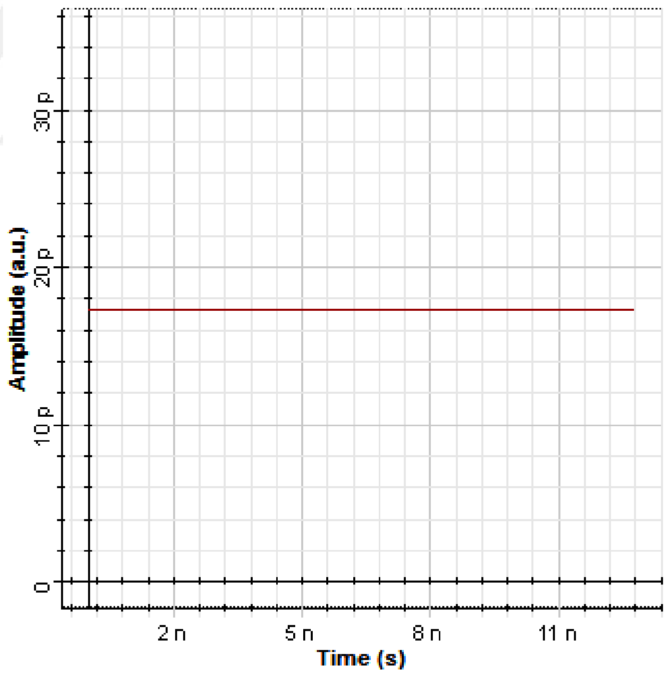


Figure 33 Output signal 3 after 100Km SMF

After select the better values for the elements, the electrical power meter measure the total power for three signals are (15.211dBm, 12.735dBm, and 12.055dBm) respectively, and from the figures due to experiment one, the output radio frequency signal can be seen very attractive at the side receiver, based on a hybrid transmission link consists of SMF and MMF, and save cost-effective for the overall the system.

By sending the data from two users in the second experiment which is the ROF based on WDM experiment, results in receive side have been taken from BER analyzer for many cases. Firstly the bitrate has been changed from 500Mbps to 2.5Gbps with installing the fiber length and the other parameters. The effects on maximum Q-factor and minimum BER for the two users (193.1THz and 193.2THz) have been shown in Table 6. By looking to the results chart in Figure 34 and Figure 35, it can be observed when the bitrate increased; the maximum Q-factor begins to decline markedly. And the minimum BER, which it's represents the error value on the sent signal, starts to increased exactly after 1Gbps bitrate, and this led to making the system in our second proposal design inefficient with this increasing in bitrate value.

Table 6 Changing bitrate for two users

	Bitrate (bps)	193.1THz		193.2THz	
		maximum Q-factor	minimum BER	maximum Q-factor	minimum BER
1	500M	8.67719	2.00377E-018	12.14858	2.91822E-034
2	750M	8.01335	5.58012E-016	10.53760	2.87286E-026
3	1G	5.76130	4.17334E-009	6.782440	5.90693E-012
4	1.5G	2.06438	0.0194793946	1.9754096	0.0240537376
5	2.5G	1.94743	0.0241893609	1.9760297	0.0238427592

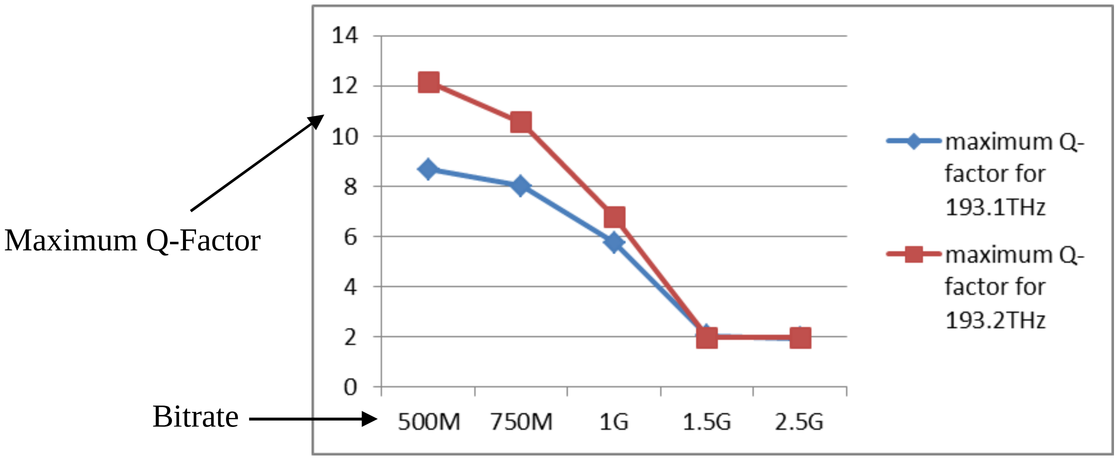


Figure 34 Maximum Q-factor with variable bitrate Ex2

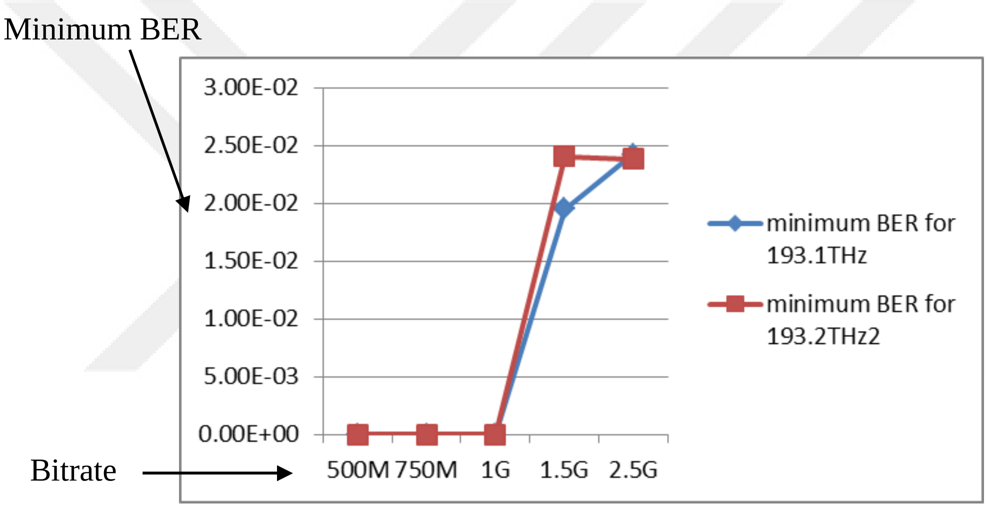


Figure 35 Minimum BER with variable bitrate Ex2

As it can be seen from Fig. 36 to Fig. 45, the output signals for the second proposed experment shown the Eye diagram from the BER analyzer of the two signals with changing the bitrate and fixing the other perameters. By looking to the results, the output for 500Mbps and 750Mbps are good and it's acceptable for 1Gbps. But after 1.5Gbps the dispersion signal begins in the output as in figures from 42 to 45.

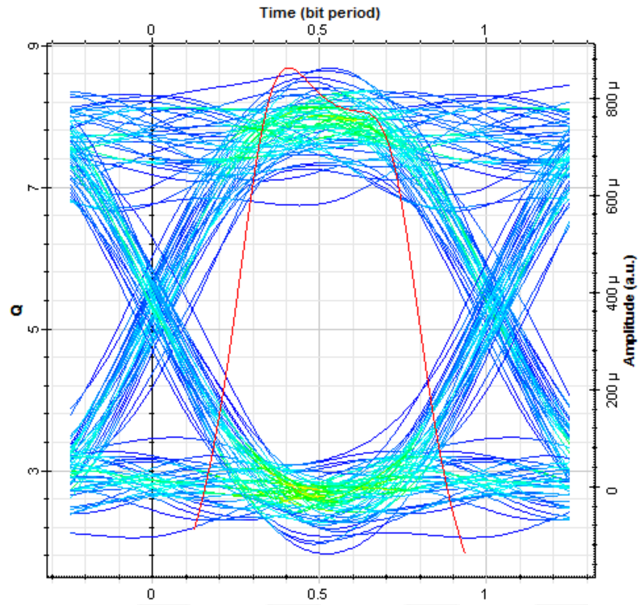


Figure 36 Eye diagram of output signal (193.1THz) with 500Mbps

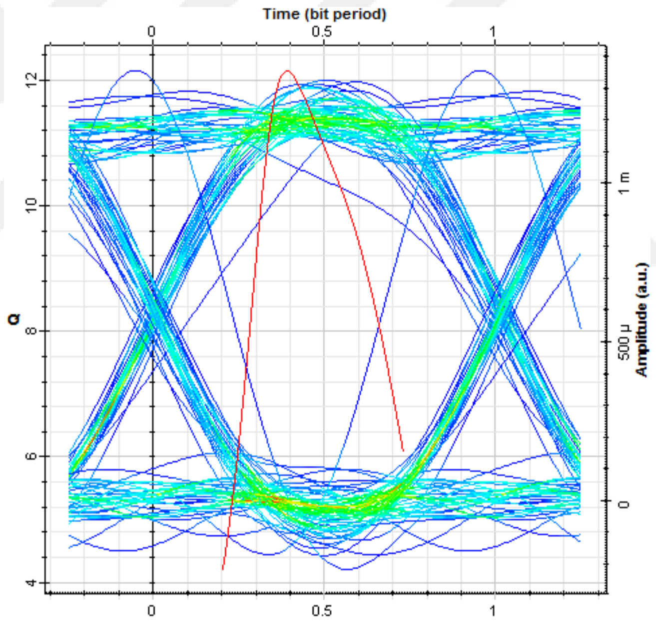


Figure 37 Eye diagram of output signal (193.2THz) with 500Mbps

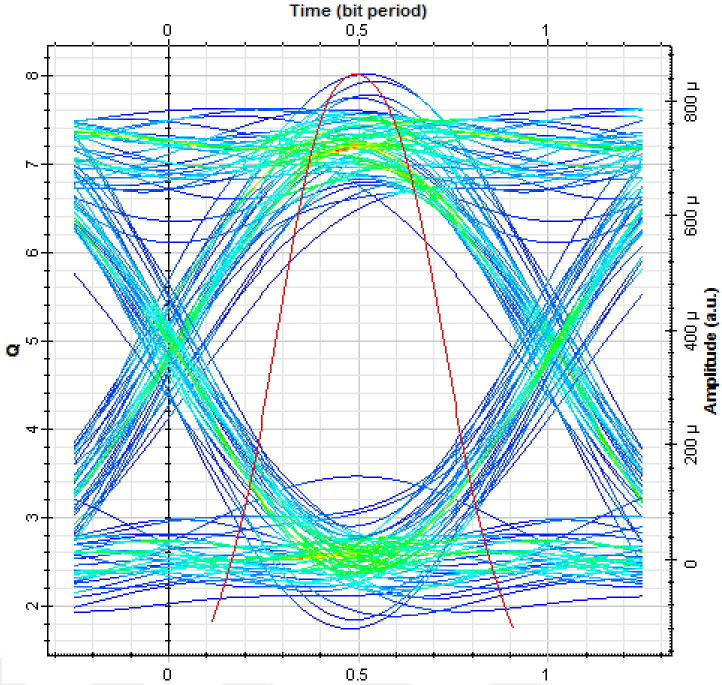


Figure 38 Eye diagram of output signal (193.1THz) with 750Mbps

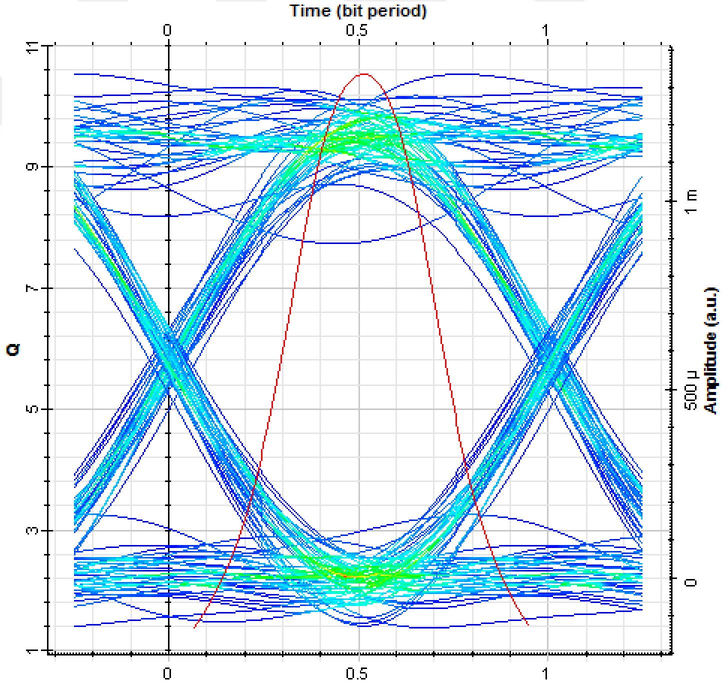


Figure 39 Eye diagram of output signal (193.2THz) with 750Mbps

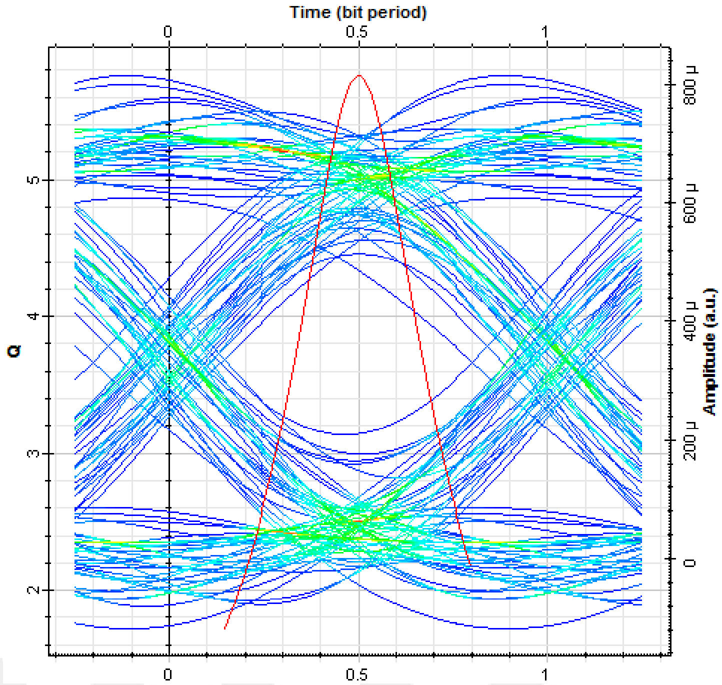


Figure 40 Eye diagram of output signal (193.1THz) with 1Gbps

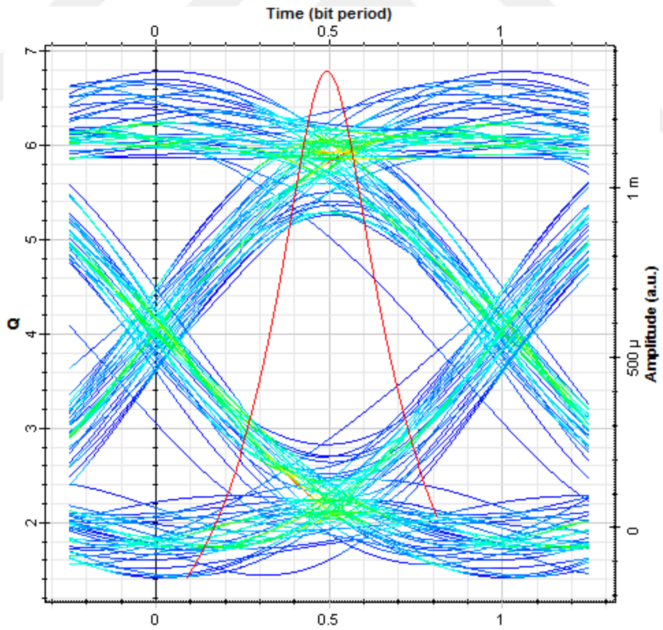


Figure 41 Eye diagram of output signal (193.2THz) with 1Gbps

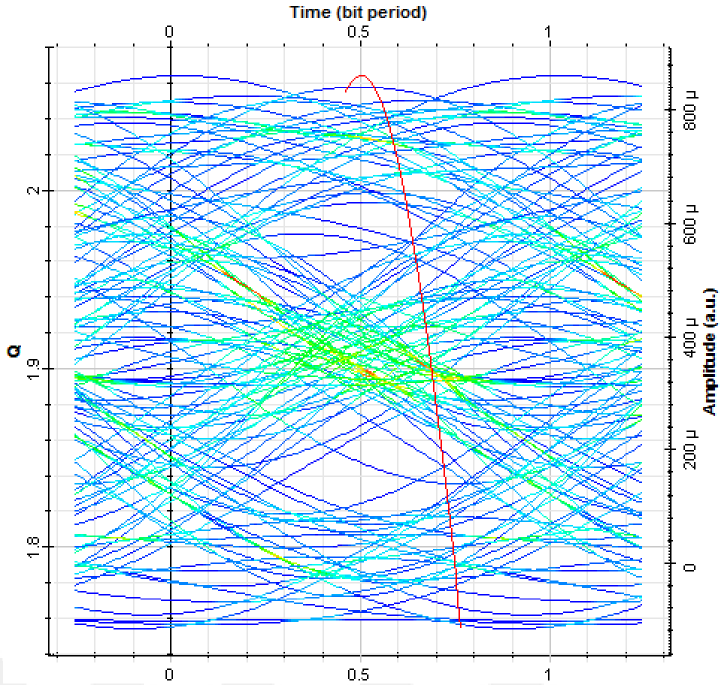


Figure 42 Eye diagram of output signal (193.1THz) with 1.5Gbps

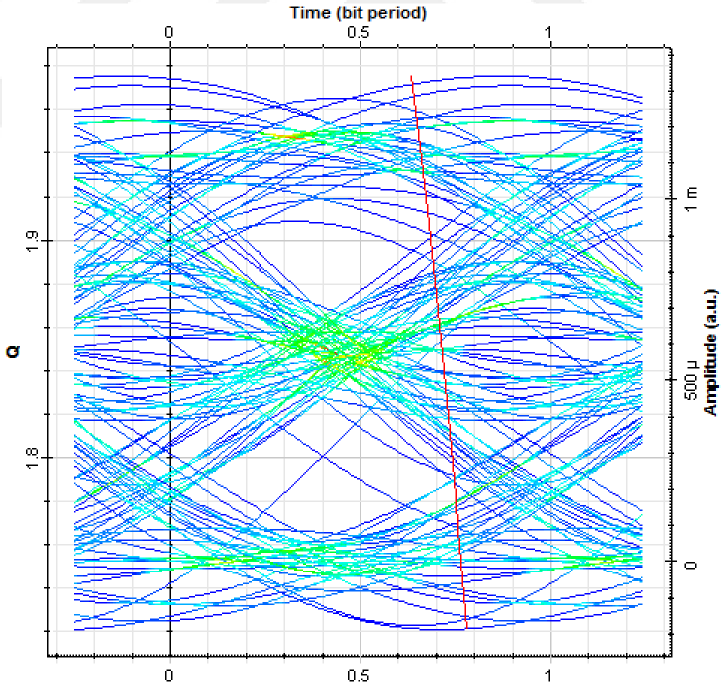


Figure 43 Eye diagram of output signal (193.2THz) with 1.5Gbps

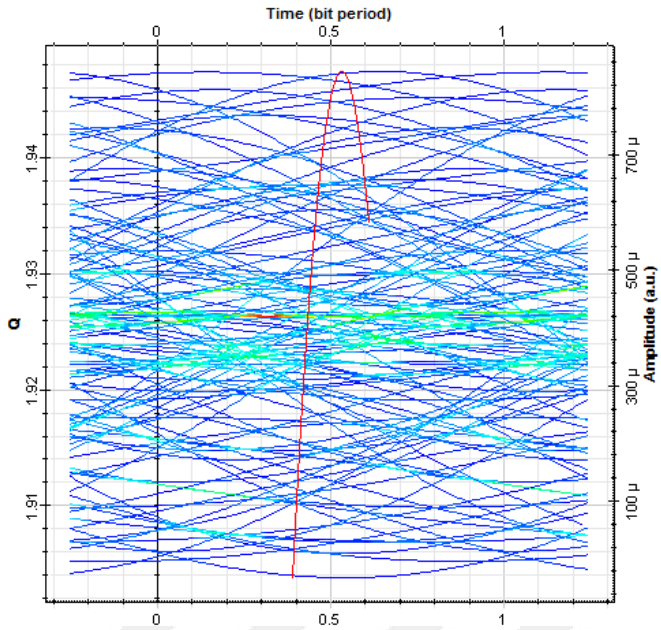


Figure 44 Eye diagram of output signal (193.1THz) with 2.5Gbps

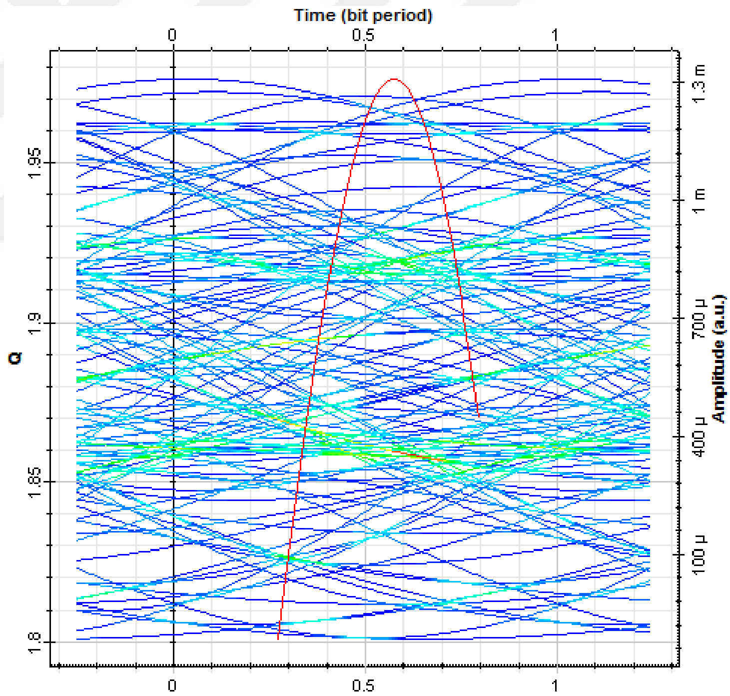


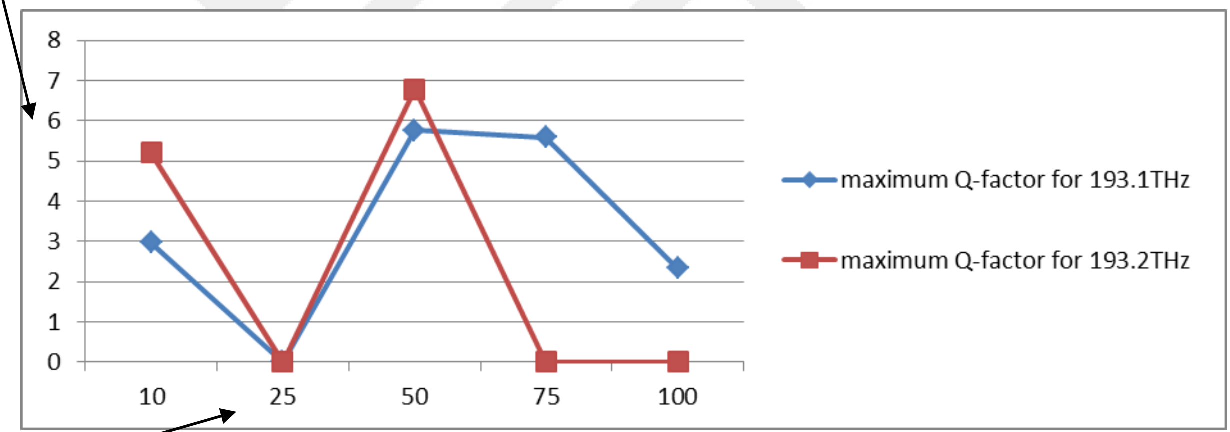
Figure 45 Eye diagram of output signal (193.2THz) with 2.5Gbps

Another analysis taken in second proposed experiment was a change in the length of the fiber and fixing the other parameters, as shown in Table 7. Results show us the effect on maximum Q-factor and minimum BER for two users. As seen from the table and the results chart in Figure 46, the best length of SMF is 50Km because it compatible with our design components and requirements, but the worse lengths are (25, 75, and 100KM), because we didn’t have getting acceptance values for (Maximum Q-Factor) at the output from BER analyzer, this is due to nonlinearities problems.

Table 7 Changing fiber length for two users

	SMF Optical Length (km)	193.1THz		193.2THz	
		maximum Q-factor	minimum BER	maximum Q-factor	minimum BER
1	10	2.97696	0.00143840884	5.2056	9.6437E-8
2	25	0	1	0	1
3	50	5.76130	4.17334e-9	6.782440296	5.9069e-12
4	75	5.58707	1.3899E-8	0	1
5	100	2.33304	0.008209	0	1

Maximum Q-factor



Fiber Length

Figure 46 Maximum Q-factor with variable fiber length

The other mesurments and result for second proposed can be seen from Fig. 47 to Fig. 51. All results seems to be satisfactory as following:

i. Fig. 47: views the input electrical signal for user 193.1THz, generated by (NRZ) pulse generator.

ii. Fig. 48: shows the output power vs. frequency of signal (193.1THz) after 50km-SMF, green color (noise), red color (signal).

iii. Fig. 49: shows the output power vs. frequency of signal (193.2THz) after 50km-SMF, green color (noise), red color (signal).

iv. Fig. 50: demonstrates the output signal (193.1THz) at the receiver side after AM demodulator.

v. Fig. 51: demonstrates the output signal (193.2THz) at the receiver side after AM demodulator.

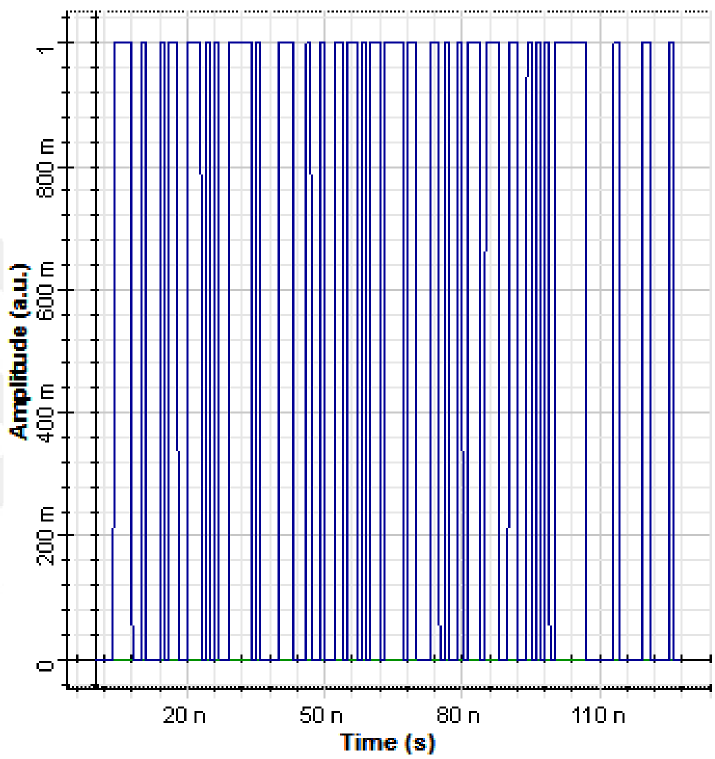


Figure 47 Input signal_1 generated by the NRZ pulse generator

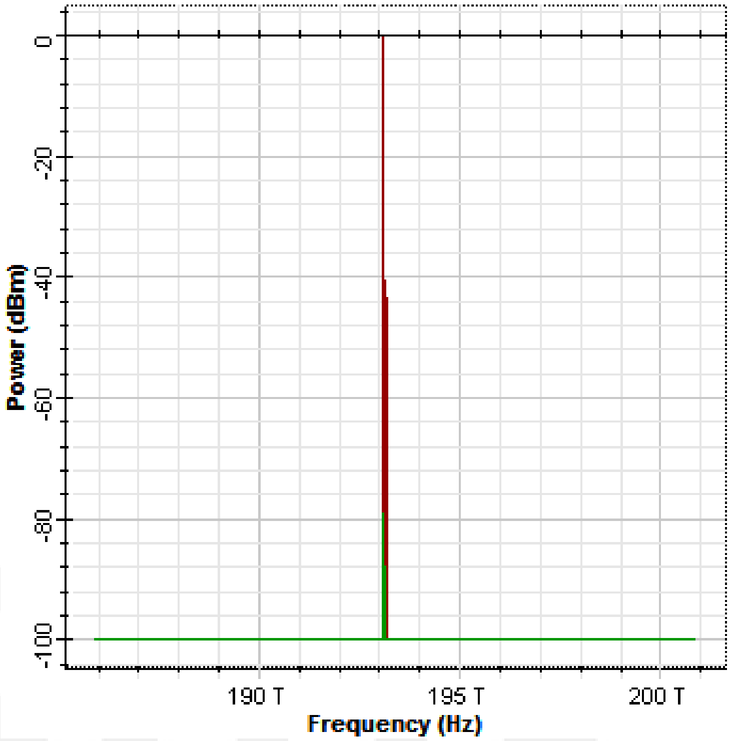


Figure 48 Output signal (193.1THz) after 50km SMF, green color (noise), red color (signal)

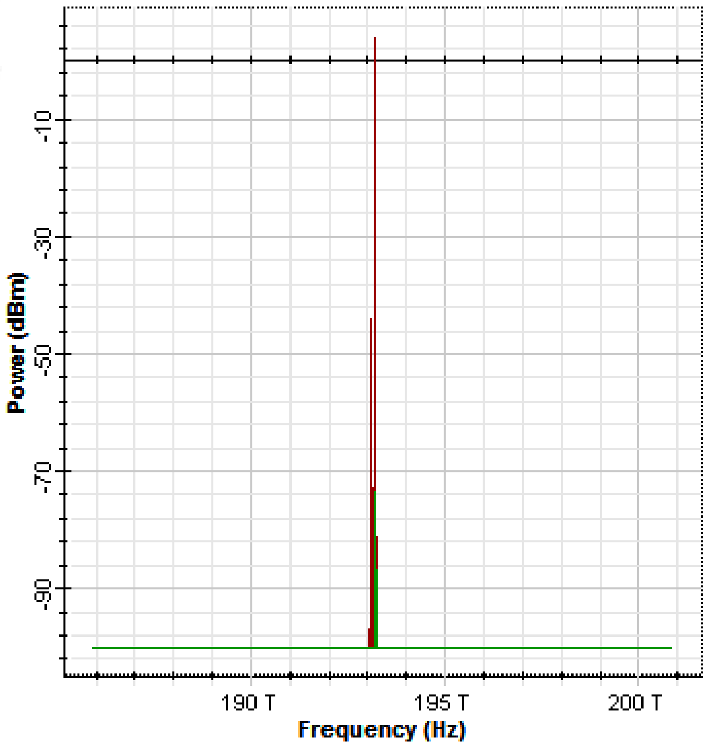


Figure 49 Output signal (193.2THz) after 50km SMF, green color (noise), red color (signal)

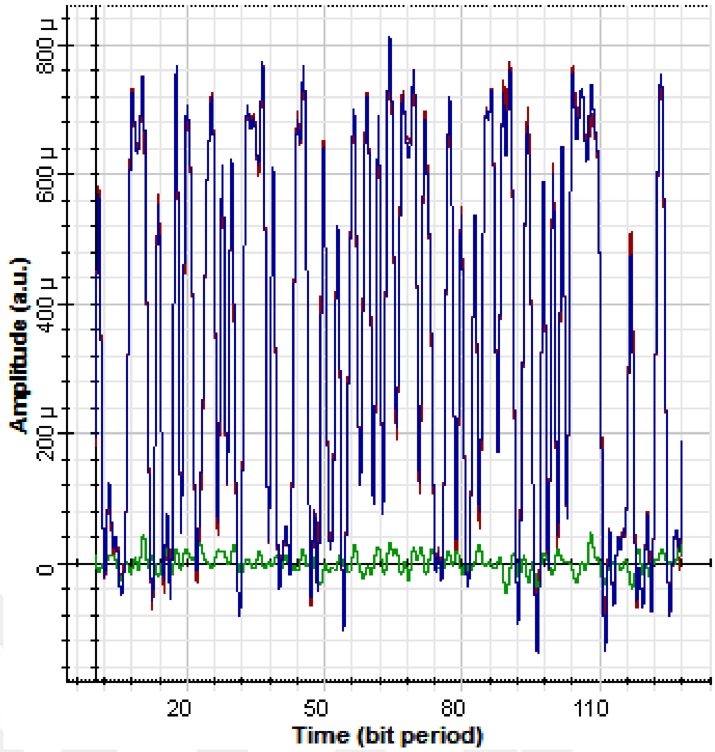


Figure 50 The output signal (193.1THz) after 50km SMF, and AM demodulator

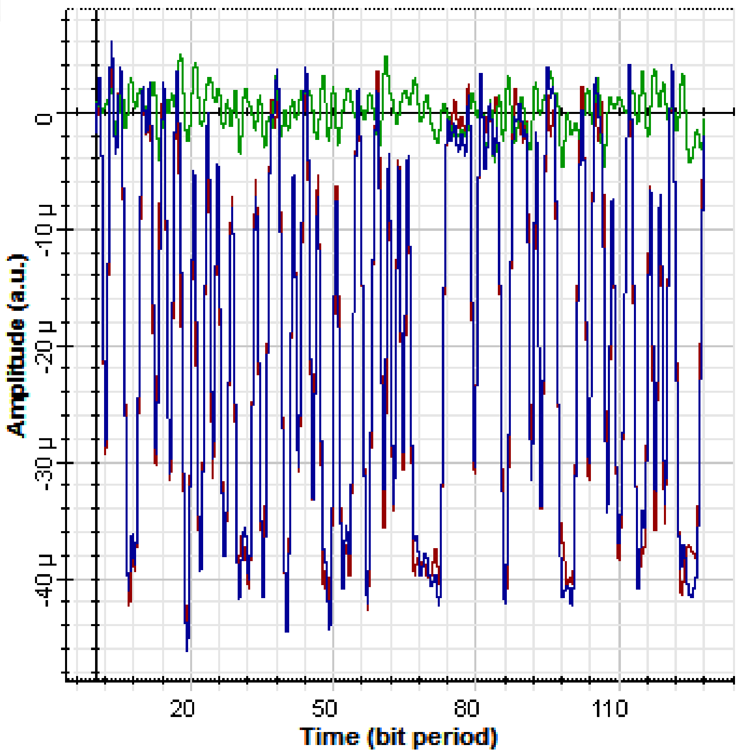


Figure 51 The output signal (193.2THz) after 50km SMF, and AM demodulator

The (maximum Q-factor=5.761301), and the (minimum BER =4.173345438e-9) for the signal (193.1THz), and (6.782440296) and (5.9069e-12) respectively for the signal (193.2THz). Meanwhile, The output signal power for two frequencies as (6.9 dBm), and the output optical signal to noise ratio (OSNR) is (52.09) have to be got. Meanwhile, referring to our simulation results that have been obtained from the two experiments considered acceptable, compared with previous studies, this is due to the selecting convenience components because they are given us a agreeable signal shape, multiple users, and scalability over ROF technology.

From the BER analyzer it’s clearly the degradation in power signal, and no eye diagram appears when increasing the bitrate and distance to critical value of our second proposed experiment as shown in figures 52, 53 with 2.5Gbps bandwidth and 100Km SSMF Length.

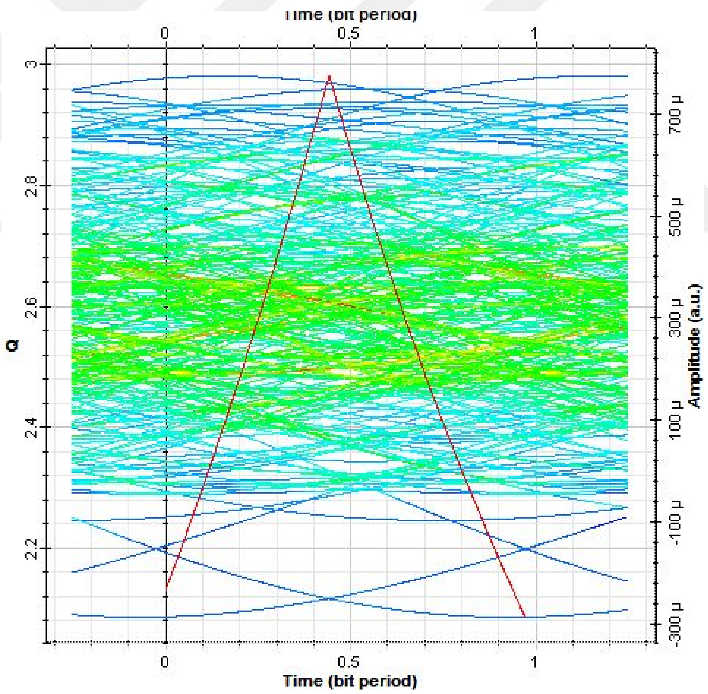


Figure 52 Eye diagram of output signal (193.1THz) with 100Km SMF

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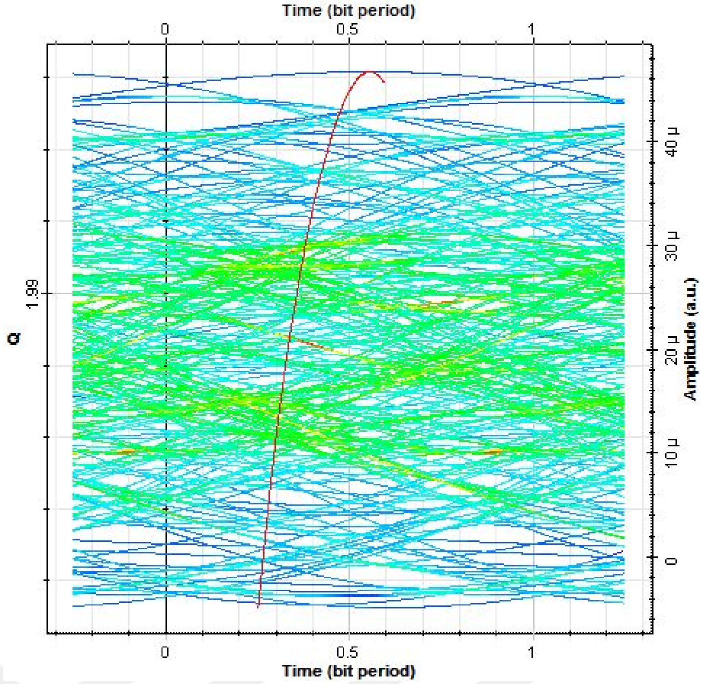

Figure 53 Eye diagram of output signal (193.2THz) with 100Km SMF

CHAPTER 4

CONCLUSION AND FEATURE WORKS

4.1 Conclusion

The system of RoF-based on hybrid SMF/MMF and WDM were be done to provide a cost efficiently, and easily implemented. The signals analyzed at the end of the receiver. It can be concluded from oscilloscope visualizer, and eye diagram visualizes at this moment the output signals are right. In the first experiment, the average total power for the three output signals is (13.333dBm), and for the second experiment the average Q-factor for two input signals is (6.0846), and the average of minimum BER is (3.7738E-10). The output signal power for two frequencies as (6.9 dBm), and the output optical signal to noise ratio (OSNR) is (52.09). There is limitation of degradation in signal along the whole networks and can support multiple users by using WDM, also with WDM could use an optical add-drop multiplexer (OADM). Finally, the ROF is very attractive for the last mile network backbone with the beneficiary of low power, good bandwidth, cost-effective, and scalability to upgrading the current infrastructure. On the other hand, with the presence of ROF system, the nonlinearities phenomena and improve access flexibility were overcomed in an efficient manner.

4.2 Future Works

For future work, to resource management in radio frequency networks based on cellular design include mobility management, load balancing, dynamic transmit power control, dynamic channel assignment, and so on are suggested.

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CURRICULUM VITAE

PERSONAL INFORMATION

Surname, Name: ALSHAYKHA, Ali Mustafa Ali

Date and Place of Birth: 11 July 1978, Salah Aldeen -Iraq

Marital Status: Married

Phone: +90 5313077789

Email: ali_rti@yahoo.com

EDUCATION

Degree	Institution	Year of Graduation
M.Sc.	Çankaya Univ., Computer Engineering	2017
B.Sc.	Musel University, Computer Engineering	2002
High School	Al-Sharqat High School – Salah Aldeen	1996

LANGUAGES

1. Mother Language (Arabic)
2. Advanced English

International Certificates

1. Certificate of CISCO: Regional CISCO academy in Iraq, as instructor in CCNA specialist 2009.
2. Certificate of IC3: CERTIPORT company in Iraq, as instructor in IC3 specialist 2/June/2010.

HOBBIES

Swimming, Chess, Books, Travel.