East West University

Project Title

A study of the effects of digital modulation and length of optical fiber in a Radio over Fiber (RoF) Communication System

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Declaration

We declare that we complete this thesis entitled **" A study of the effects of digital modulation and length of optical fiber in a Radio over Fiber (RoF) Communication System "** in the department of Electronics and communications Engineering, East West University, in partial requirement to fulfill the degree of B.sc. in Electronics and Telecommunication Engineering. We solemnly declare that to the best of our knowledge, no part of this report has been submitted elsewhere for award of a degree. All sources of knowledge use have been duly acknowledged.

Signature

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This is to certify that the project **" A study of the effects of digital modulation and length of optical fiber in a Radio over Fiber (RoF) Communication System "** has been submitted to the respective members of the Board of Examiners of the Faculty of Engineering department to fulfill the requirement for the degree of B.Sc. in Electronics and Telecommunication Engineering under complete supervision of the undersigned.

Signature

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Signature

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Abstract

Radio over fiber (RoF) transmission has extensively been studied as a means to realizing a fiber optic wireless distribution network that enables seamless integration of the optical and wireless network infrastructures. Emerging wireless communication networks that support new broadband services provide increased opportunities for photonics technologies to play a prominent role in the realization of the next generation integrated optical/wireless networks. In this thesis, we present a review of recent developments in radio over fiber technologies that can support the distribution of broadband wireless signals in a converged optical/wireless network. We also describe some of the challenges for the successful application of radio over fiber technologies in future wireless systems, such as 5G and 60GHz networks. We have also investigated the effects of order of QAM modulation, the length of the optical fiber and the operating RF frequency on the performance of RoF system. It was found that bit error rate (BER) become minimum at 60GHz with 64 QAM with optical fiber length of 12-14 km.

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Acronyms

AM-Amplitude Modulation

AP- Access Point

ASK-Amplitude Shift Keying

BB- Baseband

BBoF -Baseband Signal Over Fiber

BER- Bit Error Rate

BS- Base Station

BBoF -Baseband signal Over Fiber

CS-Central Site

DR-Dynamic Range

DSB- Double-Sideband

DWDM- Dense Wavelength Division Multiplexing

EDFA- Erbium-Doped Fiber Amplifier

E/O-Electrical to optical

FM-Frequency Modulation

FSK-Frequency-Shift Keying

GSM-Global System for Mobile Communications

HD-High Definition

ICI- Interface Control Information

IF- Intermediate frequency

IFoF- Intermediate Frequency over Fiber

IM-DD-Intensity Modulation with Direct Detection

ITU- International Telecommunication Union

LOS -Line of Sight

MU-Mobile User

MZM- Mach–Zehnder Modulator

NF-Noise Figure

O/E-Optical to electrical

OFDM-Orthogonal Frequency Division Multiplexing

PAPR- Peak-to-Average Power Ratio

PD- Photo Detector

PIN-PIN Diode

PM- Phase Modulation

PSK- Phase-Shift Keying

QAM-Quadrature Amplitude Modulation

RAP -Radio Access Points

RAUs -Remote Antenna Units

RF- Radio Frequency

RFoF -Radio Frequency over Fiber

RIN -Relative Intensity Noise

ROF -Radio over Fiber

SCM- Sub carrier multiplexing

SER- Symbol Error Rate

SMF -Single Mode Fibre

SNR- Signal-to-Noise Ratio

SSB- Single Sideband Modulation

UMTS- Universal Mobile Telecommunications service

WDM -Wavelength Division Multiplexing

WLAN -Wireless Local Area Network

Chapter 1

Introduction

1.1 Introduction

In today's era of omnipresent connectivity or "communication anytime, anywhere and with anything", the demand to have broadband capacity wirelessly has put pressure on wireless communication systems to enhance both their transmission capacity, as well as their coverage.

At present, users demand for services that provide rapid transmission and flexible solutions. Ways to enhance capacity of wireless communication systems may include deploying smaller cells or increasing the carrier frequencies, but a smaller cell size leads to a vast number of Base Stations(BS) or Radio Access Points(RAP) to get wider coverage required for pervasive communication systems [1].Therefore, the installation and maintenance costs of such systems are very high. Higher carrier frequencies may also cause increase in costs of radio front-ends in the BSs. Radio-over-fiber (RoF) technology can be the ultimate solution. Since it's validation for cordless or mobile telephone service in 1990[2], extensive research has been carried out to find out its limitation and explore new and high performance RoF technologies.

Conventional wireless communication that provides data speed up to few Mbps, is being used by voice and low speed data services, but with generation of high-speed internet and high definition (HD) video, high data speeds of Gbps has become a basic requirement to be provided by wireless systems. Large number of consumers at low frequencies causes overcrowd due to presence of limited frequency spectra, so higher carrier frequencies such as millimeter-waves are incumbent to ensure fast wireless communication [3].

RoF (Radio over Fiber) Technology is the integration of microwave and optical networks (Fig.1)[4].A broadband access network using an integrated intelligent system of radio-over-fiber and distributed antennas is developed by this technology. The working principle of it is to use light to modulate electrical signal (radio signal) and transmit it over an optical fiber link to distribute radio signals from a central location to the remote stations. RoF encrypts different types of wireless signals into a beam of light and sends them down a fiber-optic cable. At the fiber end, these signals are aired using a radio antenna, thus facilitating wireless access. For instance, 3G and Wi-Fi are accessed simultaneously from the same antenna. Radio-over-Fiber

(RoF) technology demands the use of optical fiber links to distribute RF signals from a central location (head-end) to Remote Antenna Units (RAUs). Hence, RoF centralize the RF signal processing functions in one shared location (head-end), and then to use optical fiber to distribute the RF signals to the RAUs, as shown in Figure 1. Optical fiber offers low signal loss (0.3dB/km for 1550 nm, and 0.5dB/km for 1310 nm wavelengths). Low signal loss creates a significant simplification in RAUs, as they are needed only to execute optoelectronic conversion and amplification functions. This centralization of RF signal processing functions allows dynamic allocation of resources, equipment sharing, and simplified system operation and maintenance. Such advantages will eventually result in ease and speed of installation as well as operational savings [5].

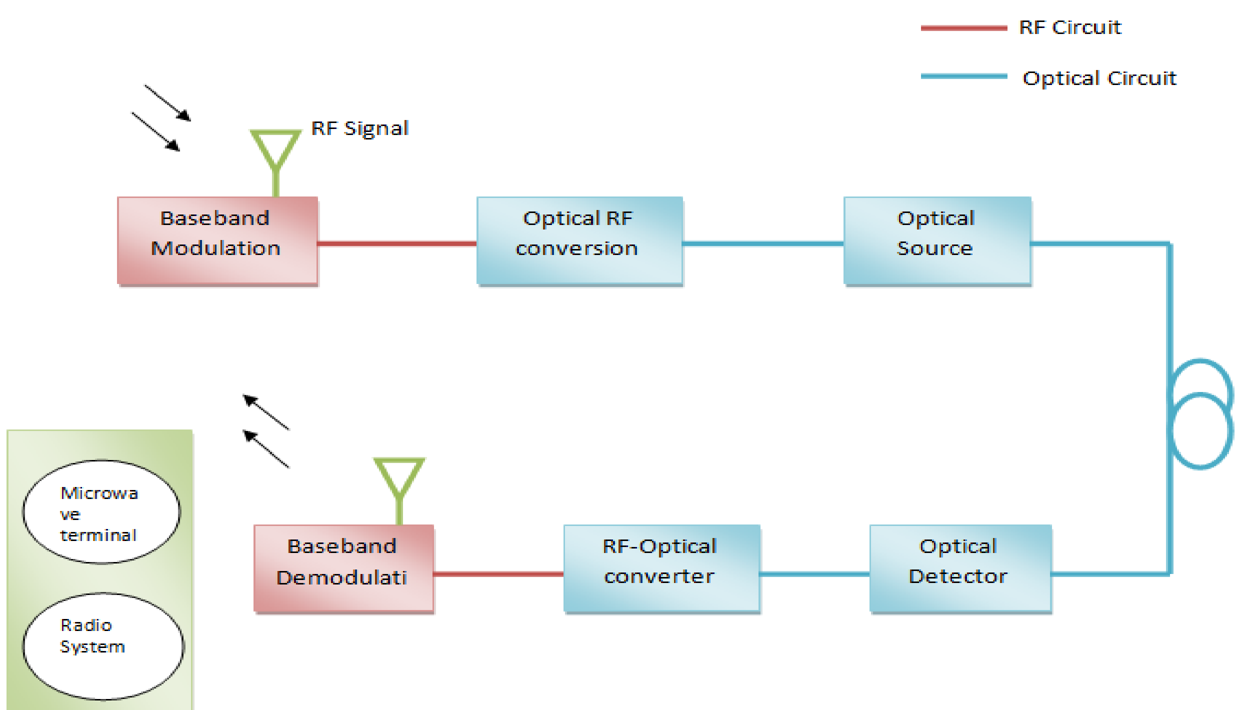

Fig. 1. Basic diagram of Radio over Fiber Technology

Present RoF systems, are designed in such a way that it can execute added radio system functionalities besides transportation and mobility functions. These functions include data modulation, signal processing, and frequency conversion (up and down). For a multifunctional RoF system, the required radio signal at the input of the RoF system depends on the RoF technology and the functionality desired. Figure 1 shows a typical RF signal (modulated by analog or digital modulation techniques) being transported by an analog fiber optic link. The RF signal may be baseband data, modulated IF, or the actual modulated RF signal to be distributed. The RF signal is used to modulate the optical source in transmitter. The resulting optical signal is launched into an optical fiber. At the other end of the fiber, we need an optical receiver that converts the optical signal to RF again. The generated electrical signal must meet the specifications. By delivering the radio signals directly, the optical fiber link does not even need to generate high frequency radio carriers at the antenna site. Because of antenna site's usually being remote from easy access, there is a lot to gain from such an arrangement. So a system should be chosen carefully which can provide a perfect amount of gain to ensure better transmission over the fiber with less error rate. [6]

The rest of the thesis is organized as follows:

Chapter 2 Motive of using QAM

Chapter 3 Radio over fiber technologies

Chapter 4the basic RoF system architecture

Chapter 5 Simulations

Chapter 6 Advantages and limitations associated with this technology

Chapter 7 Conclusion

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Chapter 2

Motivation of using QAM

2.1 Dependency of QAM, OFDM and WDM upon RoF

2.1.1 QAM

In the field of digital microwave radio, multistate modulation techniques such as 16, 64 and 256 QAM have been considered to be quite effective for their power and spectral efficiency. QAM is the technique in which two quadrature components of a continuous tone signal are combined and transmits the amplitude and the phase of the carrier signal. This procedure over SCM (sub carrier multiplexing) has many effective advantages that include error correction such as block convolutional and trellis which have advanced better noise immunity for multistate modulation system. Better interest in SCM system has been greatly contributed by wide-modulation-bandwidth laser. So this is very essential to know the dependency of or relationship between radio over fiber system and SCM system like QAM and OFDM.

SCM system uses semiconductor laser which shows nonlinear characteristic with decreased performance, but it is examined that when predistortion is implemented to laser intensity modulation, this results in decrease in distortion level significantly and creates system requirement in terms of carrier-to-noise ratio being met for FM and four levels QAM.

M-QAM has been widely accepted for terrestrial microwave communications and by using it, a simple interface of radio and fiber system is got. M-QAM modulation is mostly preferred for its combined power and bandwidth efficiency. In spite of fiber bands being very large, the available bandwidth is to be used very efficiently as this is very limited resource. However, multistate modulation techniques are using cyclic error correcting code which allows multiple error correction. This is done by using cyclic redundancy check error-detecting code embedded in the transmitted bit stream frame for synchronization purpose.

After examining the actions caused by M-QAM or different number of QAM responsible to transmit higher frequency in SCM system, the BER compared to SNR is detected and thus the performance efficiency for different type of QAM can be determined. The efficiency depends on the bandwidth of the optical fiber which is limited by the processing speed of electron too. So the performance measure of different QAM with different speed and efficiency can vary with the change of the using purpose [1].

2.1.2 OFDM

There are many situations in which OFDM modulated RF signals need to be transmitted over optical fiber, as in OFDM-ROF systems [2]. An OFDM-ROF system may be followed by wireless channel (in fiber-wireless systems) or copper wire (in some DSL or fiber-coaxial systems) [3].

In spite of OFDM's providing huge advantages, the higher peak to average power ratio (PAPR) is an important issue in OFDM systems that demands large linear range for the transmission channel. The radio-over-fiber links typically suffer from limited linear dynamic range. This happens because of the nonlinear distortion of the optical transmitter. The distortion caused by MZM/laser nonlinearity, increased average power requirement in intensity modulated optical systems, loss of orthogonally of subcarriers resulting in inter-carrier interference (ICI), increased hardware complexity are some issues of OFDM. This situation increased the need for more processing power. This sort of distortion due to Laser/optical channel could be a major limiting factor in high speed OFDM system involving thousands of subcarriers [4].

OFDM is used because it has increased robustness against frequency selective fading, narrow-band interference and it can be very effective against multipath delay spread [5]. Also symbol duration is increased through it. High data streams are splited into low data streams so they can be transmitted simultaneously and parallelly through the subcarriers. Multipath delay spread is lessened significantly in this procedure. OFDM uses multiple subcarriers which is modulated with different QAM and then carried on a high frequency microwave carrier [6].

2.1.3 WDM

Generally, information carried by a single fiber in one direction only (simplex) which means that we usually require two fibers for bi-directional (duplex) communication. However, the updated system of wavelength division multiplexing creates the way to use the same fiber for duplex communications using different wavelengths. WDM can be use to combine several wavelengths together to send them through a fiber optic network, greatly increasing the use of the available fiber bandwidth and maximizing total data throughput that in order to meet future wireless bandwidth.

2.2 Effectiveness of QAM in Radio over Fiber:

Radio-over-fiber system carries millimeter-wave signals and the chromatic dispersion-limited transmission distance can be enhanced by using optical single-sideband modulation technique. On the other hand, by using multilevel modulation techniques such as M-ary quadrature amplitude modulation (M-QAM) techniques, the radio-spectrum-limited capacity can be overcome. Integrated optical vector modulator (IOVM) is a basic usable method that has been proposed in coherent optical M-QAM systems. This is used to transport multigigabit/s data.

Moreover, traditional subcarrier multiplexed M-QAM system suffers from lack of modulation efficiency, dispersion tolerance, and receiver sensitivity, while conventional coherent system is economically non-beneficiary. In this case, M-QAM can be an effective solution. QAM can be very effective as it can do multiple error correction by using cyclic redundancy.QAM is preferred for its combined power and bandwidth and spectral efficiency which is very essential for high frequency or long distance communication. That is why it is widely accepted for terrestrial microwave communication. In this paper, the motto of using QAM is to determine if the performance of Radio over Fiber communication can be increased by using different QAM rather than any other modulating techniques which can be effective for faster transmission with reduced error as well as beneficiary economically.

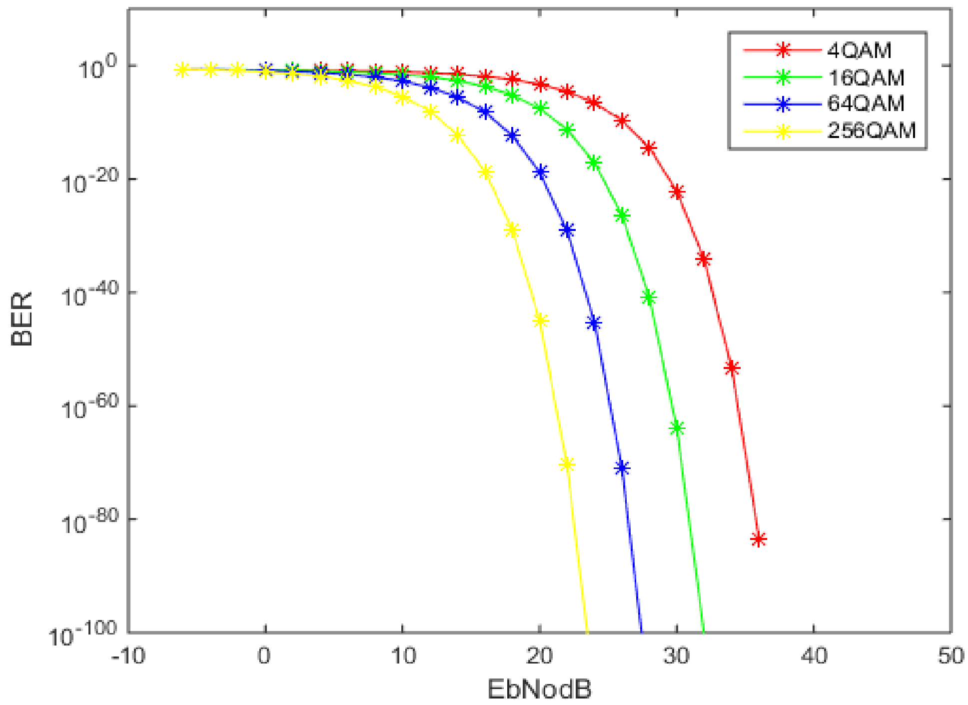

Fig 2: BER vs. EbNodB

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CHAPTER 3

Radio over Fiber Technologies

Wireless networks based on RoF technologies have been proposed as a promising cost-effective solution to meet ever increasing user bandwidth and wireless demands. In this network a CS is connected to numerous functionally simple BSs via an optical fiber. The main function of BS is to convert optical signal to wireless one and vice versa. Almost all processing including modulation, demodulation, coding, routing is performed at the CS. That means, RoF networks use highly linear optical fiber links to distribute RF signals between the CS and BSs.

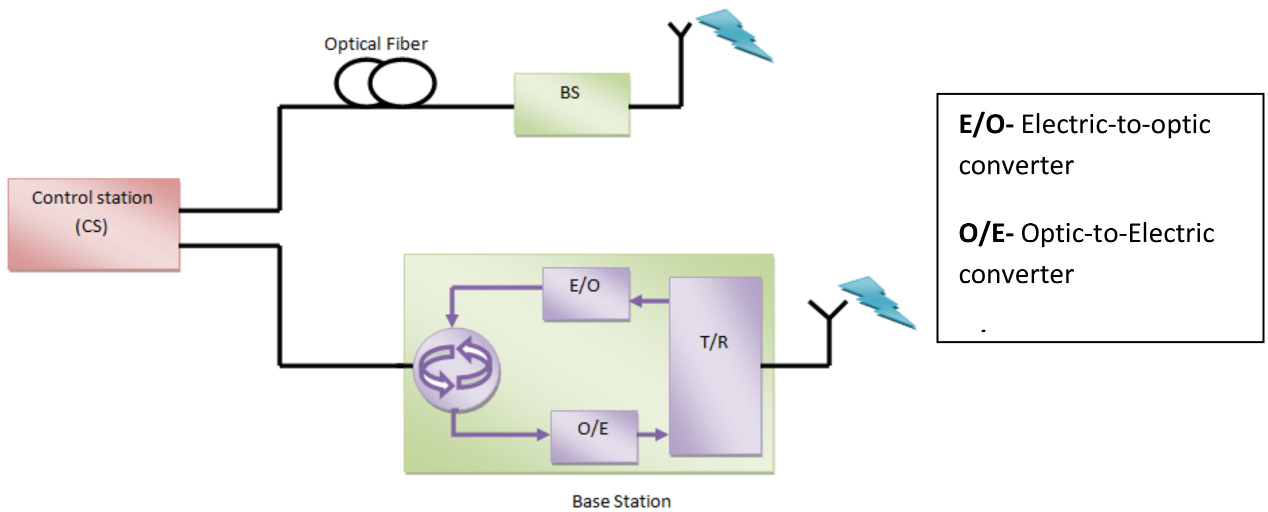

Figure 3: General radio over fiber system

3.1 Optical Transmission Link

A general optical transmission link is shown in Figure 4. We assume that a digital pulse signal is transmitted over optical fiber unless otherwise specified. The optical link consists of an optical fiber, transmitter, receiver and amplifier, each of which is dealt with in the subsequent subsections.

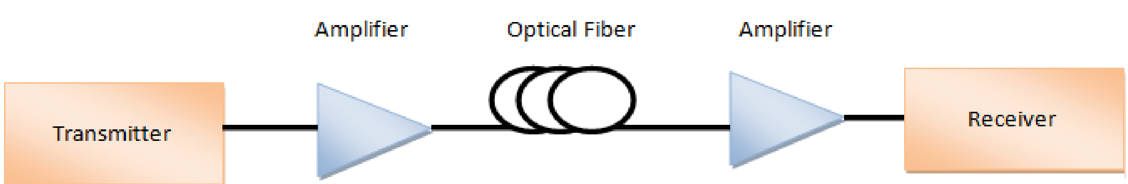

Figure 4: Optical transmission link

3.1.1 Optical Fiber

Optical fiber is a dielectric medium for carrying information from one point to another in the form of light. Unlike the copper form of transmission, the optical fiber is not electrical in nature. To be more specified, fiber is essentially a thin lament of glass that acts as a waveguide. A waveguide is a physical medium or path that allows the propagation of electromagnetic waves, such as light. Due to the physical phenomenon of total internal reflection, light can propagate following the length of a fiber with little loss. Optical fiber has two low-attenuation regions [1]. Centered at approximately 1300 nm is a range of 200 nm in which attenuation is less than 0.5 dB=km. The total bandwidth in this region is about 25 T Hz. Centered at 1550 nm is a region of similar size with attenuation as low as 0.2 dB=km. By using these large low-attenuation areas for data transmission, the signal loss for a set of one or more wavelengths can be made very small, thus reducing the number of amplifiers and repeaters actually needed. Besides its enormous bandwidth and low attenuation, fiber also offers low error rates. Communication systems using an optical fiber typically operate at BER's of less than 10^{11}. The small size and thickness of fiber allows more fiber to occupy the same physical space as copper, a property that is desirable when installing local networks in buildings. Fiber is flexible, reliable in corrosive environments, and deployable at short notice. Also, fiber transmission is immune to electromagnetic interference and does not cause interference.

3.1.1.1 Optical Transmission in Fiber

Light can travel through any transparent material, but the speed of light will be slower in the material than in a vacuum. The ratio of the speed of light in a vacuum to that in a material is known as the material's refractive index (n)and is given by$n=c = v$, where$c$is the speed in a vacuum and$v$is the speed inthe material. When light travels from one material of a given refractive index to another material of a different refractive index (i.e., when refraction occurs), the angle at which the light is transmitted in the second material depends on the refractive indices of the two materials as well as the angle at which light strikes the interface between the two materials. According to Snell's law, we have $n_a \sin\theta_a = n_b \sin\theta_b$, where n_a and n_b are the refractive indices of the first substance and the second substance, respectively; and $\theta_a$and θ_b are the angles from the normal of the incident and refracted lights, respectively. The angle of incidence for an incident ray in an optically denser medium for which the angle of refraction is 90 degrees is called critical angle and is given by θc,

$$\sin\theta c = \frac{n\ clad}{n\ core}$$

Here nclad and ncore are the refractive indices of cladding and core respectively. Thus, for a light to travel down a fiber, the light must be incident on the core-cladding surface at an angle greater than $\theta_{\mathbf{c}}$.

3.1.1.2 Multi-mode Fiber

In optical fiber technology, multimode fiber is optical fiber that is designed to carry multiple light rays or modes concurrently, each at a slightly different reflection angle within the optical fiber core. Multimode fiber transmission is used for relatively short distances because the modes tend to disperse over longer lengths (this is called modal dispersion). For longer distances, single mode fiber (sometimes called monomode) is used. Multimode fiber has a larger core than single mode.

3.1.1.3 Single-mode Fiber

In optical fiber technology, single mode fiber is optical fiber that is designed for the transmission of a single ray or mode of light as a carrier and is used for long-distance signal transmission. For short distances, multimode fiber is used. Single mode fiber has a much smaller core than multimode fiber.

3.1.1.4 Attenuation in Fiber

Attenuation in an optical fiber leads to a reduction of the signal power as the signal propagates over some distance. When determining the maximum distance that a signal can propagate for a given transmitter power and receiver sensitivity, one must consider attenuation. Let P(L) be the power of the optical pulse at distance L km from the transmitter and A be the attenuation constant of the fiber (in dB/km). Attenuation is characterized by

$$P\ (L) = 10^{\ \mathbf{AL=}10}P(0)$$

Where P(0) is the optical power at the transmitter

3.1.1.5 Dispersion in Fiber

Dispersion is the widening of pulse duration as it travels through a fiber. As a pulse widens, it can broaden enough to interfere with neighboring pulses (bits) on the fiber, leading to intersymbol interference. Dispersion can be divided into three parts.

- **Intermodal dispersion:** This is caused when multiple modes of the same signal propagate at different velocities along the fiber. Intermodal dispersion does not occur in a single-mode fiber.
- **Material or chromatic dispersion:** A type of dispersion that occurs in optical fiber due to the interaction of various wavelengths with the physical matter in the crystalline structure of the glass.[2]
- **Waveguide dispersion:** Waveguide dispersion is caused as the propagation of different wavelengths depends on waveguide characteristics such as the indices and shape of the fiber core and cladding.

3.1.1.6 Nonlinearities in Fiber

Nonlinear effects in fiber may potentially have a significant impact on the performance of WDM (Wavelength Division Multiplexing) optical communications systems. Nonlinearities in fiber may lead to attenuation, distortion, and cross-channel interference.

3.1.1.7 Couplers

A fiber optic coupler is an optical device capable of connecting one or more fiber ends in order to allow the transmission of light waves in multiple paths. The device is capable of combining two or more inputs into a single output and also dividing a single input into two or more outputs.

3.1.2 Optical Transmitters

3.1.2.1 How a Laser Works

Laser light is very different from normal light. Laser light has the following properties:

- **Monochromatic:** It contains one specific wavelength of light (one specific color). The wavelength of light is determined by the amount of energy released when the electron drops to a lower orbit.
- **Coherent**: It is “organized” -- each photon moves in step with the others. This means that all of the photons have wave fronts that launch in unison.
- **Directional**: A laser light has a very tight beam and is very strong and concentrated. A flashlight, on the other hand, releases light in many directions, and the light is very weak and diffuse.

To make these three properties occur takes something called stimulated emission. This does not occur in ordinary flashlight -- in a flashlight, all of the atoms release their photons randomly. In stimulated emission, photon emission is organized.

The photon that any atom releases has a certain wavelength that is dependent on the energy difference between the excited state and the ground state. If this photon (possessing a certain energy and phase) should encounter another atom that has an electron in the same excited state, stimulated emission can occur. The first photon can stimulate or induce atomic emission such that the subsequent emitted photon (from the second atom) vibrates with the same frequency and direction as the incoming photon.

The other key to a laser is a pair of mirrors, one at each end of the lasing medium. Photons, with a very specific wavelength and phase, reflect off the mirrors to travel back and forth through the lasing medium. In the process, they stimulate other electrons to make the downward energy jump and can cause the emission of more photons of the same wavelength and phase. A cascade effect occurs, and soon we have propagated many, many photons of the same wavelength and phase. The mirror at one end of the laser is "half-silvered," meaning it reflects some light and lets some light through. The light that makes it through is the laser light.

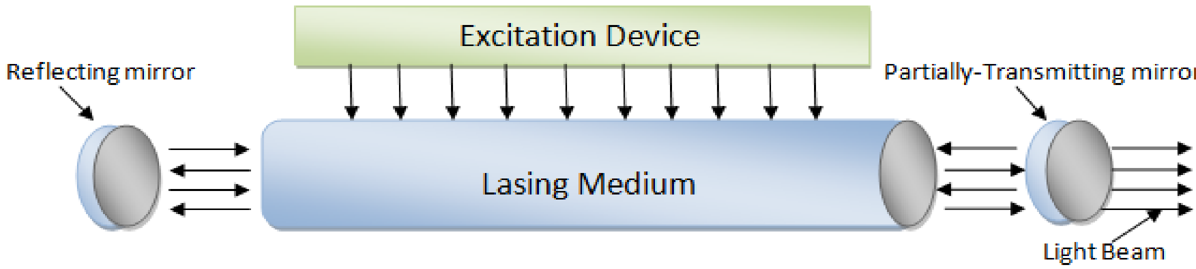

Figure 5: The general structure of a laser

3.1.2.2 Optical Modulation

To transmit data across an optical fiber, the information must first be encoded, or modulated, onto the laser signal. Analog techniques include amplitude modulation (AM), frequency modulation (FM), and phase modulation (PM). Digital techniques include amplitude shift keying (ASK), frequency shift keying (FSK), and phase shift keying (PSK). Of all these techniques, binary ASK currently is the preferred method of digital modulation because of its simplicity.

3.1.3 Optical Receiver

3.1.3.1 Photo detector

In receivers employing direct detection, a photodetector converts the incoming photonic stream into a stream of electrons. The electron stream is then amplified and passed through a threshold device. Whether a bit is a logical zero or one depends on whether the stream is above or below a certain threshold for a bit duration. In other words, the decision is made based on whether or not light is present during the bit duration. The basic detection devices for direct–detection optical networks are the PN photodiode (a p-n junction) and the PIN photodiode (an intrinsic material is placed between p- and n- type material).

3.1.3.2 Optical Amplifier

Optical amplifiers are devices that amplify an optical signal without converting it into an electric signal. Optical amplifiers are of two kinds: laser amplifiers and feedback amplifiers. Laser amplifiers do not have an optical cavity, while the feedback amplifiers consist of a suppressed cavity. Optical amplifiers are classified based on the mechanism that is incorporated for amplification of the signal. Optical amplifiers are useful in long distance communication that requires minimum attenuation loss. This datasheet will elaborate on the construction, working principle and the applications of the various types of optical amplifiers.

3.1.3.3 Doped-Fiber Amplifier

Optical doped-fiber amplifiers are lengths of fiber doped with an element (rare earth) that can amplify light. The most common doping element is erbium, which provides gain for wavelengths of 1525–1560 nm. At the end of the length of fiber, a laser transmits a strong signal at a lower wavelength back up the fiber. This pump signal excites the dopant atoms into a higher energy level. This allows the data signal to stimulate the excited atoms to release photons. Most erbium-doped fiber amplifiers (EDFA's) are pumped by lasers with a wavelength of either 980 or 1480 nm.

A limitation to optical amplification is the unequal gain spectrum of optical amplifiers. While an optical amplifier may provide gain across a range of wavelengths, it will not necessarily amplify all wavelengths equally. This characteristic – accompanied by the fact that optical amplifiers amplify noise as well as signal and the fact that the active region of the amplifier can spontaneously emit photons, which also cause noise – limits the performance of optical amplifiers. Thus, a multi wavelength optical signal passing through a series of amplifiers will eventually result in the power of the wavelengths' being uneven.

3.2 Radio over Fiber Optical Links

3.2.1 Introduction to RoF Analog Optical Links

Unlike conventional optical networks where digital signal is mainly transmitted, RoF is fundamentally an analog transmission system because it distributes the radio waveform, directly at the radio carrier frequency, from a CS to a BS. Actually, the analog signal that is transmitted over the optical fiber can either be RF signal, IF signal or baseband (BB) signal. The transmission of analog signals puts certain requirements on the linearity and dynamic range of the optical link. These demands are different and more exact than requirements on digital transmission systems [2].

3.2.2 Basic Radio Signal Generation and Transportation Methods

Virtually all of the optical links transmitting microwave/mm-wave signals ap-ply intensity modulation of light [3]. Essentially, three different methods exist for the transmission of microwave/mm-wave signals over optical links with intensity modulation:

- **Direct intensity modulation:** In direct intensity modulation an electrical parameter of the light source is modulated by the information-bearing RF signal. In practical links, this is the current of the laser diode, serving as the optical transmitter.
- **External modulation:** This method is used in an unmodulated light source and an external light intensity modulator.
- **Remote heterodyning:** is a method in which more than one optical signal is generated by the light source, one of which is modulated by the information-bearing signal and these are mixed or heterodyned by the photodetector or by an external mixer to form the output RF signal.

3.2.3 RoF Link Configurations

In this section we discuss a typical RoF link configuration, which is classified based on the kinds of frequency bands (baseband (BB), IF, RF bands) transmitted over an optical fiber link. Representative RoF link configurations are schematically shown in Figure 4 [4]. Here, we assume that a BS has its own light source for explanation purpose.

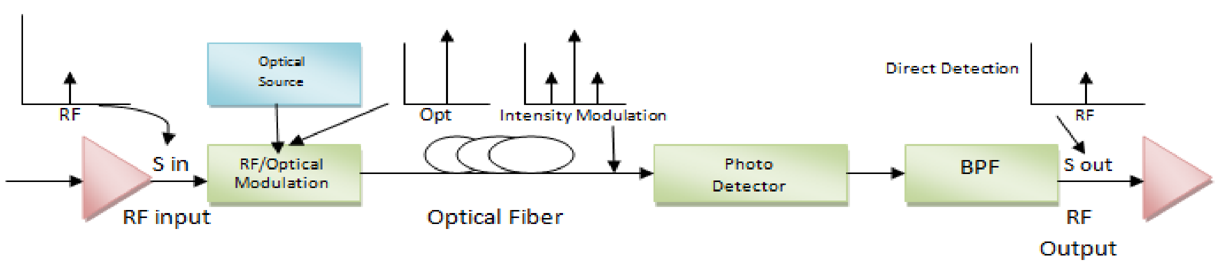

Figure 6: Intensity-modulation direct-detection (IMDD) analog optical link

3.3 RoF and Wavelength Division Multiplexing (WDM)

The application of WDM in RoF networks has many advantages including simplification of the network topology by allocating different wavelengths to individual BSs, enabling easier network and service upgrades and providing simpler network management. A schematic arrangement is illustrated in Figure 5, where for simplicity, only downlink transmission is depicted. Optical mm-wave signals from multiple sources are multiplexed and the composite signal is optically amplified, transported over a single fiber, and demultiplexed to address each BS. Though a large number of wavelengths is available in the modern DWDM technologies, since mm-wave bands RoF networks may require even more BSs wavelength resources should be efficiently utilized.

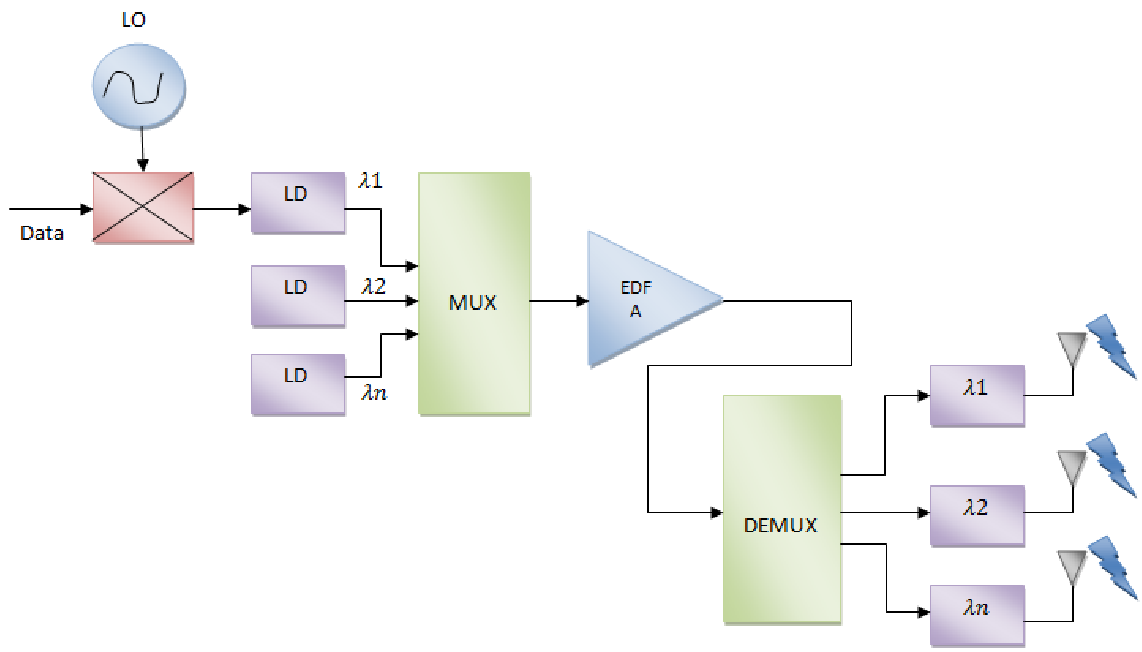

Figure7: Schematic illustration of a combination of DWDM and RoF transmission.

A challenging issue is that the optical spectral width of a single optical mm-wave source may approach or exceed WDM channel spacing. For example, Figure 8 shows an optical spectrum of DWDM mm-wave RoF signals with optical DSB modulation (a) and SSB modulation (b), where we assume that the carrier frequency of the mm-wave signal is 60 GHz. Fig. 8(a) indicates that to transmit single data channel at 60 GHz band, more than 120 GHz bandwidth is necessary for DSB modulation. In addition, from a viewpoint of cost reduction, it is preferable to use the channel allocation in accordance with ITU grid because of the availability of optical components. Then, the minimum channel spacing in this case is 200 GHz [6]. In case of SSB modulation, this is 100 GHz as shown in Fig. 8(b). To increase the spectral efficiency of the system, the concept of optical frequency interleaving has been proposed [5][6].

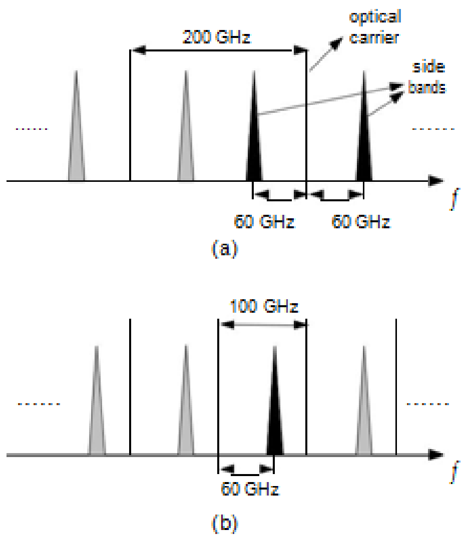

Figure 8: Optical spectra of DWDM mm-wave RoF signals of conventional optical (a) DSB and (b) SSB.

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CHAPTER 4

Basic RoF system architecture

A basic RoF system is shown in Figure 9. In the downlink transmission, the laser diode in the Central Site (CS) is directly modulated by RF signal, and the resulting intensity modulated optical signal is subsequently transmitted through an optical fiber to the base station (BS). At the BS, the signals are demodulated directly by using a PIN photo detector or any other photodiode and thus the RF signals are recovered. Moreover, they are then amplified and radiated by an antenna. The uplink signal from the MU is transmitted from the RAU to the head-end in the same way. This technique of transporting RF signals over the fiber is called Intensity Modulation with Direct Detection (IM-DD) [1], and is the simplest form of the RoF link. The reverse process is carried out at the BS, where the RF signals from the antenna directly modulate the laser diode and then the resultant optical signals are transferred through an optical fiber to the CS. At the CS, the intensity modulated optical signals are directly demodulated by employing a photodiode and thus the RF signals are recovered. Then the signals are amplified and further processed. The optical carrier's wavelength is usually selected to match with either the 1.3 µm window, in which a standard single-mode fiber has least dispersion, or the 1.55 µm window, when its attenuation is the smallest. The basic configuration of RoF link system consists of a central station and a remote access unit (RAU) connected by a single mode fiber[2].

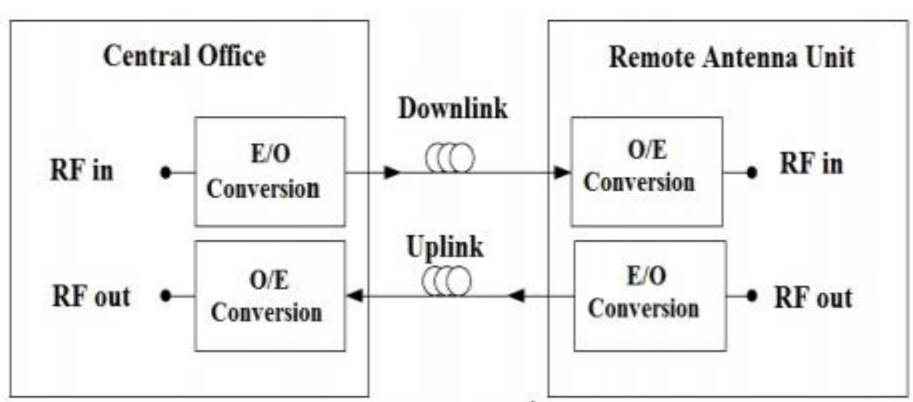

Fig 9: Radio over Fiber System Architecture

RoF systems are classified into three main categories

1. RFoF (Radio Frequency over Fiber)

2. IFoF (Intermediate Frequency over Fiber)

3. BBoF (Baseband signal over Fiber)

In RF-over-Fiber architecture, an RF signal (analog waveform) with high frequency (greater than 10 GHz with baseband data embedded in it) can be modulated with light waves.

In IFoF architecture, a data carrying RF signal with frequency (less than 10 GHz) are modulated with light wave using either direct or external modulation before transmission over the optical link. Therefore, before radiation, through the air at the remote base station this signal from IF frequency needs to be up-converted to RF level before transmitting them wirelessly through RAUs. IFoF scheme has exhibited a 2dB better sensitivity than RFoF scheme [3]

In BBoF scheme a baseband signal is modulated with light wave and transmitted over optical fiber. Then, at the receiver end this baseband signal is detected and up-converted to RF level by up-conversion techniques. BBoF scheme exhibits better sensitivity than an IFoF scheme by 4dB [3]. A general architecture of radio over fiber architecture is shown in [figure 3], optical fiber is used to transmit data between central office and remote base station. Optical fiber is used for both downlink and uplink operations because it offers anenormous bandwidth. During the downlink operation in the central office, electrical to optical (E/O) conversion takes place, whereas in the remote base station optical to electrical (O/E) conversion is done using a photo-detector. Similarly, during uplink transmission E/O conversion takes place in remote base station

using an external modulator and O/E conversion happens in the Central office where this signal is further processed to receive the base band data.

References

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Chapter 5

Simulation

5.1 Simulation Components

5.1.1 90 degree hybrid coupler

In a 3 dB, 90° hybrid coupler , there is a four-port device which is used either to equally split an input signal with a resultant 90° phase shift between output ports or to merge two signal at the time of maintaining high isolation between the ports.

When power is introduced at the **IN** port, half the power (3dB) flows to the **0**°port and the other half is coupled (in the opposite direction) to the 90° port. Reflections from mismatches sent back to the output port.

5.1.2 Duel port dual drive MZ Modulator Absorption-phase:

A Mach-Zehnder modulator can control the amplitude of an optical wave. In this modulator, the input waveguide is split up into two waveguide interferometer arms. When a signal propagates across one of the arms, a phase shift is induced for the wave passing through that arm. At the recombination of the two arms, the phase difference between the two waves is converted to an amplitude modulation.

5.1.3 EDFA

Erbium-doped fiber amplifiers are so far the most important fiber amplifiers for long-range optical fiber communications. They can efficiently amplify light in the 1.5-μm wavelength region, where telecom fibers have their loss minimum.

5.1.4 QAM sequence generator

Data transmission basically needs to be done in the form of binary bits. Here the optical power is used to represent binary bits where power is only an aspect of electric field and the phase can also be modulated. The logical step to modulate the amplitude and the phase at the same time is known as Quadrature Amplitude Modulation (QAM).

5.1.5 VCSEL laser input

This is used as the main light source used in radio over fiber communication. The light is modulated with the digitalized signal in QAM generator. This is a semiconductor based laser diode that emits highly efficient optical beam, vertically from its top surface. A bias generator is used as the power source of the light input of RoF.

5.1.6 Optical receiver

This is the receiving end where the output of the entire process is got. There is an APD (avalanche photodiode) which converts an optical information signal back into an electrical signal. There is also an optical amplifier to amplify the laser, which do not have optical cavity and also a feedback cavity having a suppressed cavity. This amplification is done before the conversion of optical signal to electrical signal.

5.2 Design of the simulation

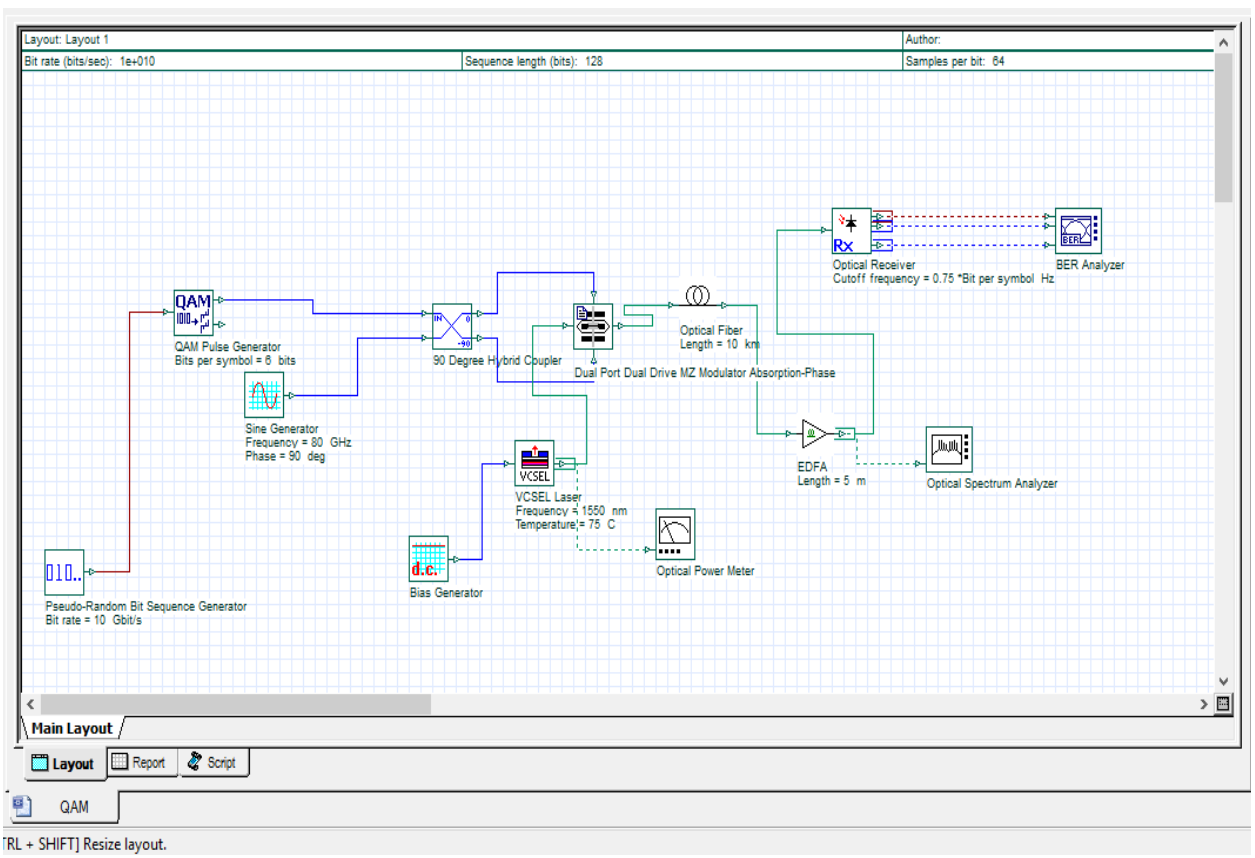

Figure 10.1 : Simulation of the system done using OPTYSYSTEM

Radio over fiber technology can be implemented with different type of modulation system. In this thesis, QAM has been used as a modulation technique. As shown in fig 10, a bit sequence generator is used within a QAM generator as a input signal and combined with a signal of radio frequency which is generated by a sine generator. This combination of bit ensures the signal to be digital. From this software, the frequency rate and number of QAM can be changed or controlled. Then these two outputs is given to the 90 degree hybrid coupler which is used so that the implementation of QAM is matched over the system. This creates a phase difference in between the inputs. The outputs of the coupler are sent to the MZM where VCSEL laser generated by a bias generator, is also combined with the given signal. This laser works as an optical input for the system. There is a optical power meter which can determine the quantity of optical signal to be used. Then this signal is sent as optical signal from the MZM within the optical fiber with different length. EDFA (erbium doped fiber amplifier) is used to amplify the signal after a certain distance. There is an optical system analyzer which determines the accuracy of the system. This optical signal is received in the optical receiver where the signal is converted into the radio signal with the help of APD (avalanche photodiode). There is a BER analyzer connected to the optical receiver to determine the BER for different parameters. Finally after decoding the analog input signal is retrieved.

5.3 Distance VS Q-factor

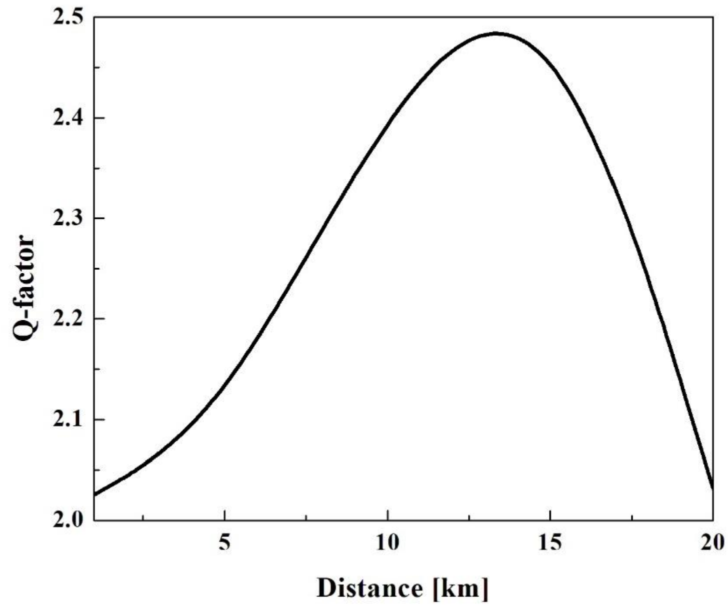

Figure 10.2: Distance vs Q-factor

The distance VS Q-factor shows the change of efficiency of the procedure for different length of optical fiber where 64 QAM is used. Here it is clearly seen that the Q-factor of the optical fiber increases with the increase in the length of the optical fiber. This situation continues until it reaches to the length of 14.5 km (approximately). Basically the Q-factor reaches to the peak point in the curve at 12.5-14.5 km, which means in 64-QAM at the length of 12.5-14.5 km of optical fiber can be considered as a standard length where the system acts most efficiently.

5.4 Distance VS BER

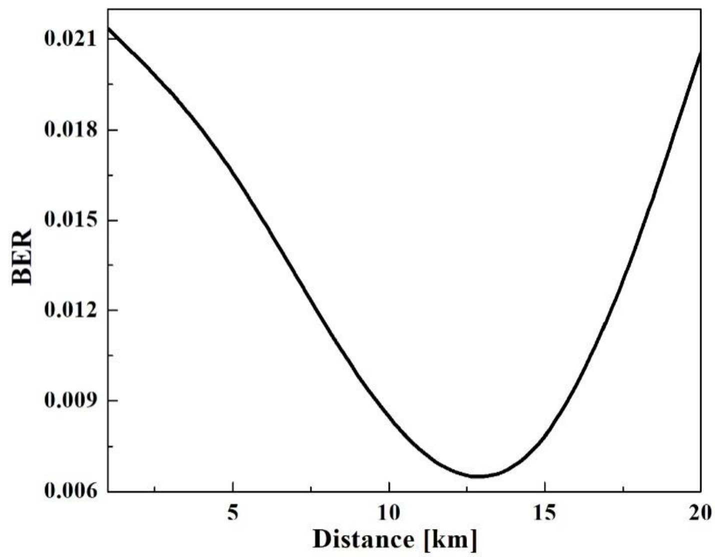

Figure 10.3 : Distance vs BER

Distance VS BER curve represents the change of bit error rate for different length at 64-QAM. Here the curve shows the gradual decrease of bit error rate with the increase of the length of the optical fiber. As we can see until the length of 14.5 km, the bit error rate decreases gradually. After this, the rate of error increases again. So this can be state that at the length of 12.5 to 14.5 km the system shows better performance. On the other hand, from the previous graph we have seen that the length of 12.5-14.5 km range shows better performance for the Q-factor of the system. So this range of length of optical fiber can be considered for a better radio over fiber system with 64-QAM.

5.5 Frequency VS Q-factor

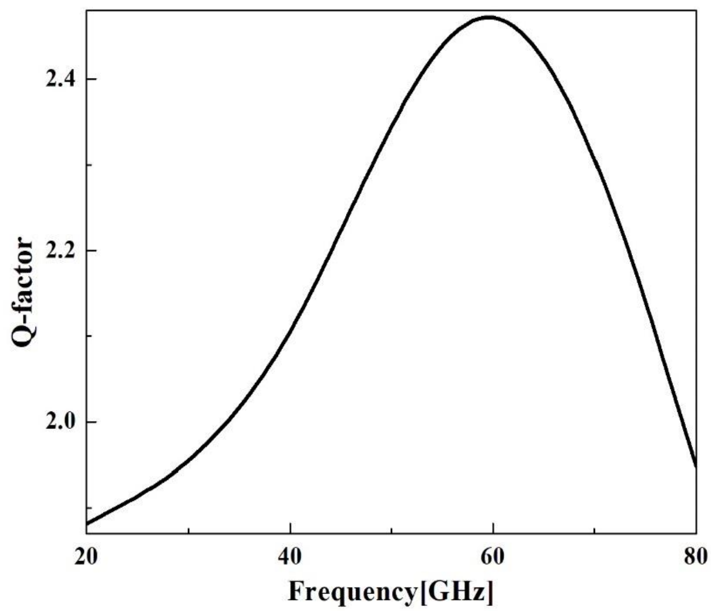

Figure 10.4: Frequency vs Q-factor

In this curve we can see that with the increasing number of frequency, the Q-factor or the efficiency of the system increases. The gradual increase of the curve happens until the frequency reaches to 60 Ghz and after that the Q-factor begins to decrease with the increase of frequency. So this can be estimated that approximately at 60 Ghz the system shows better efficiency when 64-QAM is used.

5.6 Frequency VS BER

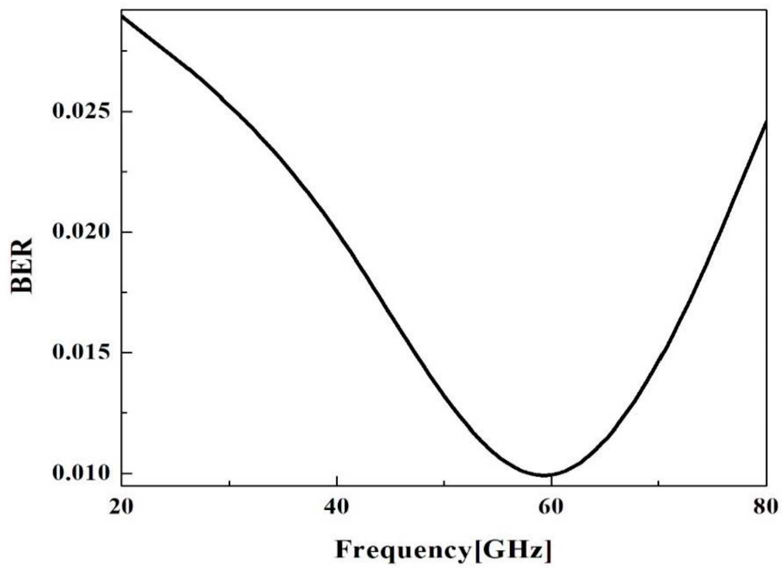

Figure 10.5 : Frequency vs BER

In this curve, the change of performance for different frequency is represented. As long as the frequency increases up to 60 Ghz, the bit error rate decreases gradually. After 60 Ghz , whenever the frequency increases the bit error rate increases gradually which is not expected for a better efficient system. To achieve better performance, bit error rate must be minimized which is possible at 60 Ghz frequency in 64-QAM. On the other hand, from the previous graph we have seen that 60 Ghz frequency shows better performance for the Q-factor of the system. So this frequency can be considered for a better radio over fiber system with 64-QAM.

5.7 Discussion

From the experiment and the simulation, we have found that for faster and better communication 64-QAM shows the best performance. For the generalize communication system 64-QAM can fulfill all the requirements for faster and better transmission. Considering this fact we have used 64-QAM in our thesis. The change of other parameters like length of optical fiber and frequency of the input signal can cause the change in performance. we have seen that in ROF system of 64-QAM , using radio signal of 60 Ghz frequency and 12.5-14.5 km optimal length of optical fiber can be mostly effective for the system to show better performance as the minimum BER and maximum Q-factor is achieved with these two parameters in the given range.

Chapter 6

Conclusion

In this thesis, we have analyzed the entire procedure that has been used for Radio over Fiber communications previously. Analyzing those, we have learnt the different purpose of this technology and the implementation of it over the future communication system. The future generation and increasing population needs faster data transmission and better performance that can be ensured for a large number of populations. Radio over fiber communication can fulfill this requirement as huge amount of data can be transmitted over it. Huge distance can be covered by this procedure so this system is very efficient for better area coverage.

In our thesis, we have used different QAM to modulate the input with radio frequency. The different QAM gives different outputs. Moreover, the length of optical fiber and different frequency of signal may cause the variation in Q-factor and bit error rate (BER) which determines the efficiency of a system. 64- QAM is here considered to be the most efficient modulation technique as it provides very less bit error rate and increased Q-factor rather than other QAMs such as 4-QAM, 16-QAM, 128-QAM etc.

From the simulation results, the performance of the system is shown and compared. In figure 6.1 the distance VS Q-factor graph with respect to 64 QAM, shows that the Q-factor of ROF reaches at the peak increasingly up to a certain distance which is approximately 12-14 km. Then the rate of Q-factor begins to degrade. On the other hand, the distance VS BER graph (figure 6.2) shows that the bit error rate (BER) reaches almost at the bottom at the same distance of 12-14 km. After degrading to this distance range, the BER starts to increase again. So this range of distance can be considered to be a standard length for the fiber optic.

Again, in the frequency VS Q-factor graph (figure 6.3), it is found that the Q-factor of the system with 64-QAM increases with the increase of frequency up to 60 GHz, which means 60 GHz attains the top most Q-factor for this system. Similarly, the frequency VS BER graph (figure 6.4) shows the decreasing amount of BER with the increasing frequency up to 60 GHZ. At this bottom point, the BER is lower most so the efficiency is higher. After this point, the BER begins to increase. So this point of frequency is considered to be a factor o an efficient ROF system.

There are several number of QAM which are used for different purpose in communications system with different criteria. In our thesis, our basic goal has been to reach at a decision where we can get better performance of a Radio over Fiber system which ensures less bit rate error, better area coverage or transmission distance and high rate of data transmission with increased Q-factor. With the lower number of QAM such as 4-QAM, 8-QAM, 16-QAM the BER may be decreased but the Q-factor becomes low which is bad for better performance. On the other hand, the higher number of QAM such as 128-QAM, 256-QAM have better rate of data transmission but the bit rate error is higher and using those can be non-beneficiary considering the criteria.

Analyzing these results, we have found 64-QAM with signal of 60 GHz transmitting within the cable with length of 12-14 km is considered to be the best set of design that can be used for future radio over fiber communications system. The analysis basing on the output determines this set to perform better rather than any combination of equipment. This can be considered to be effective for faster transmission with better spectral efficiency with less error and wide range coverage.

Appendix

MATLab Code of SNR vs BER curve for different QAM:

1.

Snr vs BER

```
EbNodB=6:2:36

EbNo=10.^(EbNodB/10);

k=8;

M=2^k;

x=sqrt(3*k*EbNo/(M-1));

Pb=(4/k)*(1-1/sqrt(M))*(1/2)*erfc(x/sqrt(2));

semilogy(EbNodB,Pb,'r-*')

hold on

EbNodB=6:2:36

EbNo=10.^(EbNodB/10);

k=6;

M=2^k;

x=sqrt(3*k*EbNo/(M-1));

Pb=(4/k)*(1-1/sqrt(M))*(1/2)*erfc(x/sqrt(2));

semilogy(EbNodB,Pb,'g-*')

hold on



EbNodB=6:2:36

EbNo=10.^(EbNodB/10);

k=4;

M=2^k;
```

```
x=sqrt(3*k*EbNo/(M-1));
Pb=(4/k)*(1-1/sqrt(M))*(1/2)*erfc(x/sqrt(2));
semilogy(EbNodB,Pb,'b-*')
hold on
EbNodB=6:2:36
EbNo=10.^(EbNodB/10);
k=2;
M=2^k;
x=sqrt(3*k*EbNo/(M-1));
Pb=(4/k)*(1-1/sqrt(M))*(1/2)*erfc(x/sqrt(2));
semilogy(EbNodB,Pb,'y-*')
axis([-10 50 10^-100 10^10])
hold on
xlabel('EbNodB')
ylabel('BER')
legend('256QAM','64QAM','16QAM','4QAM')
```