Estimation and Analysis of Free Space Optics Link Margin for Quality Based Network Routing

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Estimation and Analysis of Free Space Optics Link Margin for Quality Based Network Routing

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by

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under the guidance

of

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June, 2015.

Dedicated to

My inspiring Parents and Brother

Declaration

I certify that

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c. I have followed the guidelines provided by the Institute in preparing the thesis.
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This is to certify that the work in the thesis entitled " ***Estimation and Analysis of Free Space Optics Link Margin for Quality Based Network Routing***" submitted by ***Kappala Vinod Kiran*** is a record of an original research work carried out by him under our supervision and guidance in partial fulfillment of the requirements for the award of the degree of Master of Technology in Department of Electronics and Communication, National Institute of Technology, Rourkela. Neither this thesis nor any part of it has been submitted for any degree or academic award elsewhere.

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Abstract

Free space optics (FSO) is a revolution in communication technology which uses light in free space for transmission. FSO systems are used for high data rate communication between two remote sites over distances up to several kilometers. It solves the problem between the client/user and fiber-optic back-haul solving the last−mile problem. They are appealing for abroad application areas such as, fiber back-up, local area network (LAN)-to-LAN connectivity, disaster recovery, backhaul for wireless cellular networks, high definition TV and wireless video surveillance/monitoring etc. The link reliability particularly in long range communication is limited mainly due to atmospheric turbulence-induced fading and sensitivity to weather conditions. The main consideration in the FSO design is the availability of link for different atmospheric conditions and providing a reliable quality of transmission (QoT) to the end user. An FSO network with distance based routing and wavelength assignment (RWA) technique does not provide any information about the current state of network, leading to a non-reliable communication. Based on the above the following analysis is been proposed:

- This work deals with the estimation of FSO link in different parts of India using Link Margin (LM). Here the meteorological data of various cities has been collected which evaluates the availability of the link for different attenuations in channel.

- FSO network with an adaptive routing and wavelength assignment (RWA) technique based on LM is proposed which selects the connection with higher availability rather than shortest distance. The overall network performance is being evaluated in terms of blocking probability (BP) based on network load and available link wavelengths. The estimated results can provide more knowledge about the reliability and deployment of FSO network.

  In short, this thesis work estimates the Free space optics LM for Quality based network routing.

Keywords: FSO, last-mile, attenuations, Link margin, RWA, network load, blocking probability

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CHAPTER 1

Introduction

Free-space optical system (FSO) refers to the transmission of modulated visible or infrared, IR beams through the atmosphere to achieve broadband communications. The theory of FSO is exactly the same as that of the fiber optical transmission system. The difference is that the energy beam is collimated and sent through clear air or space from the source to the destination, rather than guided through an optical fiber [1]. It has drawn attention in telecommunication industry, due to its cost effectiveness easy installation, quick establishment of communication link especially in the disaster management scenario, high bandwidth provisioning and wide range of applications. With FSO communication, maximum data transfer rates up to 2.5 Gbps is possible, unlike the maximum data transfer rates of 622Mbps offered by RF communication systems [2]. Another appealing characters are, the optical spectrum is unlicensed and a modulation technique like on-off keying which is simple in implementation finds much importance in high bandwidth and in physical layer connection where there is protocol transparency [3]. The main limitation of FSO link is due to atmospheric attenuations (i.e., rain, fog, snow). Attenuation created by rain plays a major role and reduces the power level at the receiver limiting the FSO link availability over a distance. The availability of FSO link is estimated based on the threshold value of LM .For telecommunication (carrier class) applications, the link availability is generally considered to be 99.999% while for the LAN applications (enterprise class) it is over 99% [4]. The estimation of LM in different places for different distances based on the statistical data of rain fall distribution and for different attenuations is been evaluated. An FSO network is considered with an adaptive LM based RWA Technique is proposed for maximum Link reliability even for the worst scenarios. The network performance metrics have been calculated for different conditions.

1.1 Organisation of Chapter

The remaining chapter is organized as follows. Motivation behind the research work is discussed in Section 1.3. Problem definition is mentioned in Section 1.4. The Scope of the thesis are explained in Section 1.5. Finally, the Organization of the thesis is mentioned in Section 1.6.

1.2 Motivation behind the Research Work

As of India is planning for the smart cities, where it requires a high end digital needs with a large bandwidth requirements. In metropolitan areas, an approximate of 95 percent buildings are within few kilometer range of fiber-optic back-bone, and they are unable to get access due to street trenching, digging and are expensive, which cause traffic jams and displaces the trees. Providing the last mile connectivity is extremely difficult and expensive. This results in the imbalance leading to "last mile bottleneck." FSO provides a viable solution but the deployment of FSO link depends on different conditions and should provide the Link availability even for the worse conditions .Also an FSO network routing based on distance does not provide the information about the link availability leading to unreliable communication and the overall network performance degrades. Above factors motivated us to provide a Quality of transmission (QoT) to the end user based on LM .This mechanism evaluates the LM of FSO based on the meteorological data and establishes the link even for the adverse scenario .In an FSO network the LM is being calculated for all connections and among all depending upon the QoT the best connection is being selected. The goal of the thesis is to design a FSO network with adaptive selection based on LM.

1.3 Problem Definition

Estimate the availability of FSO link for different conditions based on LM. Given a FSO network,considering a NSFNet topology the objective is to analyze the quality of transmission in all possible set of connections and select an appropriate connection subjected to the following conditions:

- Obtain the all possible connections for minimum LM

- Satisfy the required LM or highest quality of Transmission based on the client
- Availability and assignment of appropriate wavelength based on LM and
- Minimal blocking probability

1.4 Scope of the Thesis

The objective of this research work is to Estimate and Analyze the FSO link margin for the Quality based Network routing. The techniques are listed as under

- Deployment of FSO link for different atmospheric conditions based on LM
- Deployment of an FSO network based on LM
- RWA technique based on LM
- Estimation of network blocking performance based on LM

1.5 Organization of the Thesis

Following this introduction, the remaining part of the thesis is organized into following chapters: Chapter 2: This chapter describes the overview of FSO technology and availability of FSO link based on LM and related discussions. Chapter 3: This chapter describes the RWA technique based on LM and blocking performance of the FSO network for different network resources. Chapter 4: This chapter deals with the conclusion and future directions of the work.

CHAPTER 2

Estimation of FSO Link Margin

The rest of the chapter is organized as follows. The theoretical background of Design of FSO system model is explained in Section 2.3. Estimation of FSO link margin related to our research work is explained in Section 2.4 and Section 2.5 gives the Analytical simulation and Discussion.

2.1 Introduction

Optical communication without fibers is so called free space optics (FSO). It provides a very high bandwidth digital data transmission between remote sites and provides a key solution to the last hundred meters of broadband problem. Implementation of FSO technology mainly depends on the atmospheric conditions. The most important thing in the deployment of FSO link is determined by Link Margin. It is the parameter which analyzes the acceptable power level at the receiver for reliable communication.

2.2 Organization of the Chapter

The rest of the chapter is organized as follows. The theoretical background of Design of FSO system model is explained in Section 2.3. Estimation of FSO link margin related to our research work is explained in Section 2.4 and Section 2.5 gives the analytical simulation and Discussion

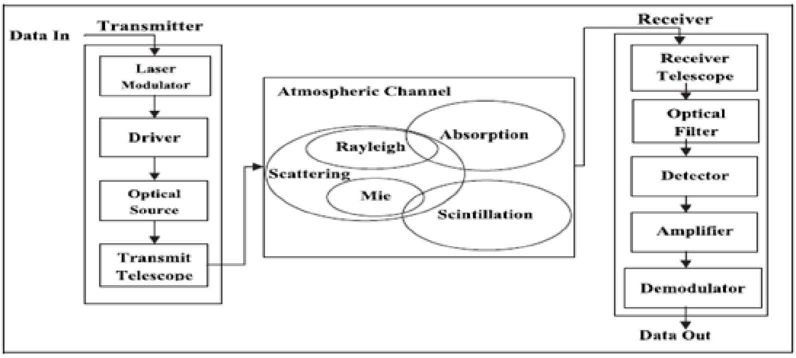

Figure 2.1: Block Diagram of FSO System

2.3 Design of FSO system

FSO is a technology that uses line of sight to transmit laser beam for a very high bandwidth data transfer from one point to another in free space. It can be obtained by modulating a narrow beam of laser launched from a transmission station to transmit it through atmosphere and receives correspondingly at the receiver station. The general block diagram of FSO system is shown in Figure 2.1 it consists of transmitter section, channel and a receiver section [2].

2.3.1 Transmitter

Transmitter section converts the electrical pulses to an optical signal which corresponds to modulation of a laser beam for transmission of data, which is to be collected at the receiver through the free space channel. The transmitter can be divided into four parts i.e., modulator, driver circuit, optical source and transmit telescope.

Laser modulator

Modulation is carried by the laser beam which modulates the data using a laser modulator. The modulation methods can be roadly clasified as: internal modulation and external modulation [2].

power consumption

Generating a laser beam which is highly coherent is impractical. The neodbymium (Nd:YAG) laser and the the popular helium-neon (He-Ne) laser are less efficient due to poor interfacing with electronic circuitry, but has a high power compared to other.Fortunately, semiconductor lasers, which are very efficient usually made of a direct band gap materials

which converts electrical current to corresponding photons, are very efficient and can be easily integrable to electronic circuits
In comparison, power amplifiers for the Very Low Frequency (VLF) up to the High Frequency (HF) bands are highly efficient, with conversion efficiencies from 85 to 90 percent. However, Microwave amplifier biasing arrangements have typical conversion efficiencies of only between 10 and 20 percent. Therefore, while microwave amplifiers are much more efficient than the Nd:YAG and He-Ne lasers, they are generally less efficient than semiconductor lasers.

Modulation

Modulation can be obtained usually inside the laser resonator and it relies on the change produced by the components which are added like the directional couplers which varies the light intensity of the laser in accordance to the baseband signal.

The simplest modulation technique adopted is amplitude-shift keying (ASK). It is also referred as on-off keying (OOK).This form of modulation scheme is also known as NRZ (non-return-to-zero) OOK. It is an intensity modulation scheme where the light source (carrier) is used to turned on when a logic one is transmitted and turned off when a logic zero is transmited. Apart from NRZ there exist other coding formats. The most common one is the RZ (return- to- zero) line coding, RZ has the main advantages in comparision to NRZ are its higher sensitivity and the clock frequency used generally lies within the range of modulation spectrum.NRZ and RZ,unfortunately suffers from clock synchronization, i.e,. if a series of long strings of ones or zeros are transmitted the line coding deviates from clock synchronization of the digital signal. Manchester coding overcomes the above problem but at the cost of sacrificing twice the bandwidth of NRZ in order to fulfil the NyquistShannon criteria.

The receiver on the other side is used to detect the optical pulse and compares its power level with an optimum threshold level. Coherent modulation schemes can also be employed in optical communications. A binary coherent modulation, binary phase shift keying (BPSK) can be used where the phase of the laser is varied between two states. Coherent detection depends on the received light in coherence with local oscillator tuned to the transmitting beam. Apart from the local oscillator, which can have synchronization problem is eliminated using self-homodyne. It is employed in differential phase shift keyeing (DPSK) systems, which are less sensitive than the BPSK. The sensitivity of coherent receiver implementations is better than the sensitivity of OOK systems but at the cost of system complexity and additional sensitivity to phase distortions of the received beam [5].

Driver

A Driver circuit is used to transform an electrical pulse into an optical signal with variation in current flow of the optical source.

Optical source

Laser diode (LD), light emitting diode (LED) fall under the category of optical sources. These sources converts the electrical signal to corresponding optical signal. A laser diode produces radiation by stimulated emission of radiation.Here photons are emitted from atoms by population inversion, which have been excited from a ground level state to a higher energy level. The light emitted by a laser source is highly directional and monochromatic, which has a narrow spectral width and a small beam divergence angle. There are two basic sorts of laser diode: Nd:YAG solid state laser and fabry-perot and distributed-feedback laser (FP and DFB) [2].

Wavelength

Wavelength selection for a FSO system depends on several factors, such as transmission distance, components availability, eye safety considerations, cost. The availability of components is light sources and detectors [6]. Eye safety is an important issue in consideration for designing the FSO system. Lasers sources of higher power can be used more safely with wavelength 1550nm systems rather than with 850nm and 780nm systems, since this wavelength is lesser compared to 1400 nm which is focused on the human cornea forms a concentrated spot falling on the retina which can cause damage to eye.

Transmitter telescope

The transmitter section is equipped with a telescope which collects and directs the light beam on to the receiver telescope at the other side of the channel.

2.3.2 FSO channel

FSO links uses atmosphere as the medium for the propagation. The atmosphere can be considered as series of layers around the earth with concentric gas. Three basic at-

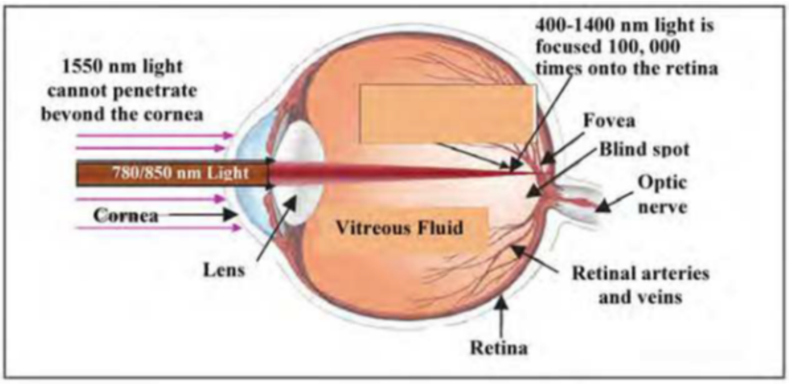

Figure 2.2: Penetration of Light into Eyeball

mospheric layers for consideration are the homosphere, the troposphere, stratosphere and mesosphere. These layers are different from each other based on their temperature gradient with respect to the altitude. Troposphere region plays a key role, because this is the region where the weather phenomena predominates and FSO links operate at the lower part of this layer. Also, there are small particles that contribute to the composition of the atmosphere, that includes particles (aerosols) such as haze, fog, dust, and soil. Propagation characteristics of FSO communication through atmosphere changes according to the environmental effects created mainly due to weather condition. The received signal power fluctuates within the atmosphere and attenuates the power reaching at the other end. The attenuation is due to the atmospheric conditions such as rain, fog, haze and turbulence in the propagation channel. The effects on free sspace optics communication are mainly due to absorption, scattering, and scintillation [7].

2.3.3 Receiver

The receiver system which receives the optical power and determines the data consists of five parts as shown in Figure 2.2 i.e., receiver telescope, optical filter, detector, amplifier and detector.

Receiver telescope

Optical light from the transmitter is collected and focused using the receiver telescope on to the photo detector. It should be noted that a large receiver telescope capture area is desirable to collects multiple uncorrelated radiation and focuses their average on the photo detector [2].

Optical filter

Optical filters are mainly used to allow energy at the wavelength of interest to impinge on the detector and reject the unwanted wavelengths, with this the effect of solar illumination can be significantly minimized [2].

Detector

The detector section consists of device which should be capable to provide a proportional electric current from the received photon energy. Photodiode (PD) is a semiconductor devices which converts the photon energy of light into an electrical signal by releasing and accelerating current conducting carriers within the semiconductors. Photodiodes operate based on the principle of photoconductivity.The diode operates in reverse-biased and capacitive charged.The two most commonly used photodiodes are the pin photodiode and the avalanche photodiode (APD).These have good quantum efficiency and are made of semiconductors that are widely available. [8].

The sensitivity of the receiver is the performance characteristic which indicates the minimum light energy it can detect.Selection of a particular detector depends on the application. To understand the descriptions of detector performance and to be able to pick a detector for a specific application, one should understand these detector characteristics. In general, the following properties are needed:

- A high response at the wavelength to be detected
- A small value for the additional noise is introduced by the detector
- Sufficient speed of response

2.4 Estimation of FSO LM

In the design of FSO links, several effects must be considered including the losses due to atmospheric attenuations created due to absorption, scattering, turbulence,link misalignment and link distance. An important parameter in the FSO system design is the link margin, Mlink(dB), which can be expressed as [8].

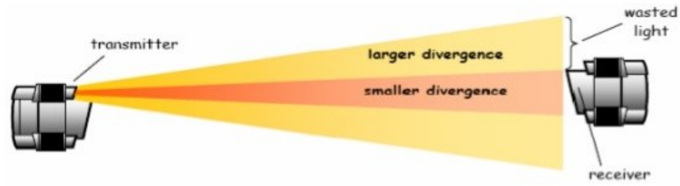

Figure 2.3: Beam Spreading due to Geometrical Attenuation

$$LM_{link} = P_e - S_r - \alpha_{tgeo} - \alpha_{atmo} - \alpha_{syst} \tag{2.1}$$

where, P_e is the transmitter power, S_r is the receiver sensitivity, α_{tgeo} is geometrical attenuation of link, α_{atmo} is atmospheric attenuation, and A_{syst} is internal losses.

2.4.1 Geometrical attenuation

As the beam travels over a large distance it diverges, and a very less amount of power is collected at the receiver due to small capture area, this leads to geometrical attenuation. It is fixed for a particular distance and is expressed as [9].

$$\alpha_{tgeo} = \frac{S_t}{S_c} = \frac{\frac{\pi}{4}(d\theta)^2}{S_c} \tag{2.2}$$

where, S_t is the area of illumination at a distance d, θ is the divergence angle of the light beam, d accounts for the distance between transmitter section and receiver section and S_c is the receiver capture area. The following Figure 2.3 explains the loss due to spreading of beam.

2.4.2 Atmospheric Attenuations

There are different attenuations due to varied atmospheric environment such as rain, fog ,snow, haze and scintillation, a few of these attenuations are as explained below:

Fog attenuation

Fog Attenuation is mainly caused due to mie-scateering [4]. It predicts the size of fog droplets accurately and the attenuation coefficient caused due to scattering was proposed by Kim [8] . This is dependent on the visibility (V) obtained from the meteorological data, wavelength (λ) and also on distribution of diffusing particles size q. Specific attenuation due to fog is given by [10].

$$\alpha_{fog}(\lambda) = \frac{3.91}{V}(\frac{\lambda}{550nm})^{-q} \tag{2.3}$$

where,

$$q = \begin{cases} 1.6, & \text{if V} > \text{50km.} \\ 1.3, & \text{if 6km} < \text{V} < \text{50km.} \\ 0.16, & \text{if 1km} < \text{V} < \text{6km.} \\ \text{V} - 0, & \text{if 0.5km} < \text{V} < \text{1km.} \\ 0, & \text{if 0.5km} < \text{V.} \end{cases}$$

Rain attenuation

Rain attenuation has significant role in determining the Link Margin. It is subjected to be major impairment of FSO link. Attenuation due to rain is a function of precipitation intensity R(mm/hr) and independent of wavelength with unit distance is expressed by the Carbonneau model [10] as

$$\alpha_{rain} = 1.076 \times R^{0.67} \tag{2.4}$$

Link Margin

A more precise FSO link margin considering geometrical attenuation, rain attenuation and system losses as the major factors, based on equation [2.1, 2.2, 2.3, 2.4] can be expressed as

$$LM_{link}(dB) = P_t + |S_r| - [10log_{10}\alpha_{tgeo}] - [\alpha_{rain} \times d]$$

$$-\alpha_{sys} \tag{2.5}$$

Where, P_t is the power from the source, d is the distance between the transmitter and receiver, system losses α_{sys} of 10 dB .

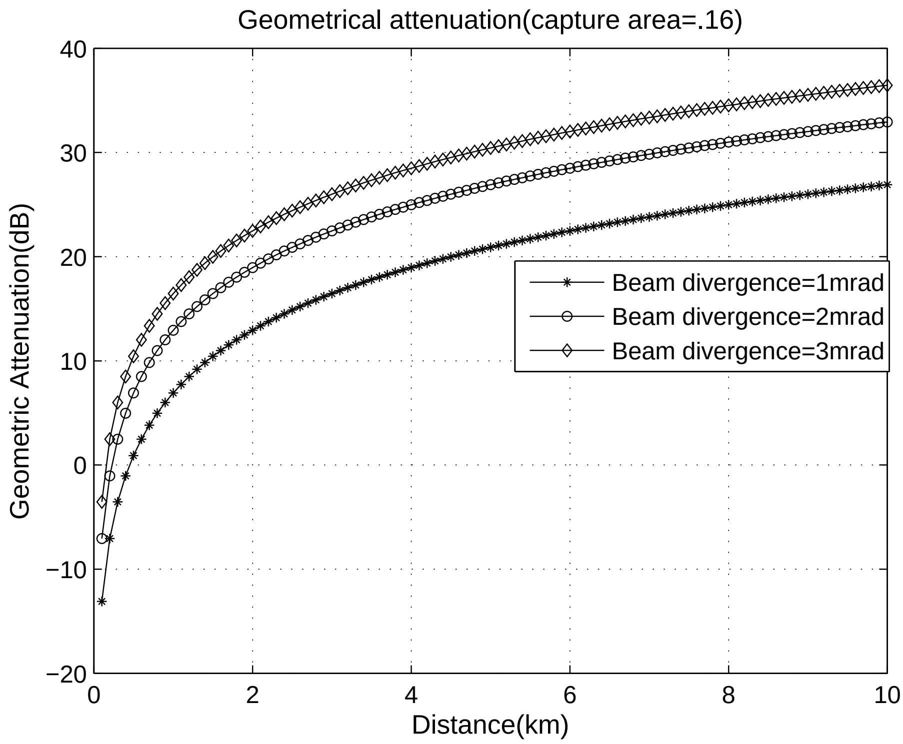

Figure 2.4: Geometrical Attenuation (dB)

Considering fog attenuation equation 5 can be expressed as

$$LM_{link}(dB) = P_t + |S_r| - [10log_{10}\alpha_{tgeo}] - [\alpha_{fog} \times d]$$

$$-\alpha_{sys} \quad (2.6)$$

2.5 Analytical Simulation and Discussion

Here we have evaluated the designing steps of FSO link based on geometrical attenuation, rain attenuation and system losses as the major factors. The following Figure 2.4, 2.5, and Figure 2.6 are plotted for the analysis of individual factors. Geometrical attenuation for different light beam divergence angles with varying link distance is as shown in Fig. 5. Attenuation due to rain with varying rainfall rate is as shown in Figure 2.5 and Kim model for different wavelength as a function of visibility is as shown in Figure 2.6 for fog attenuation.

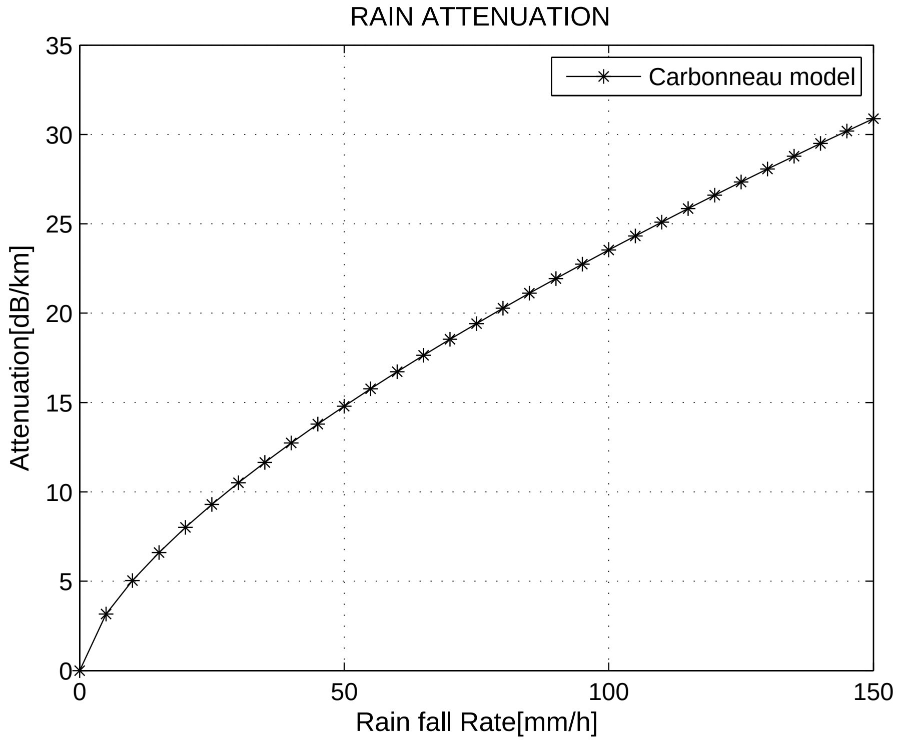

Figure 2.5: Rain attenuation (dB/km)

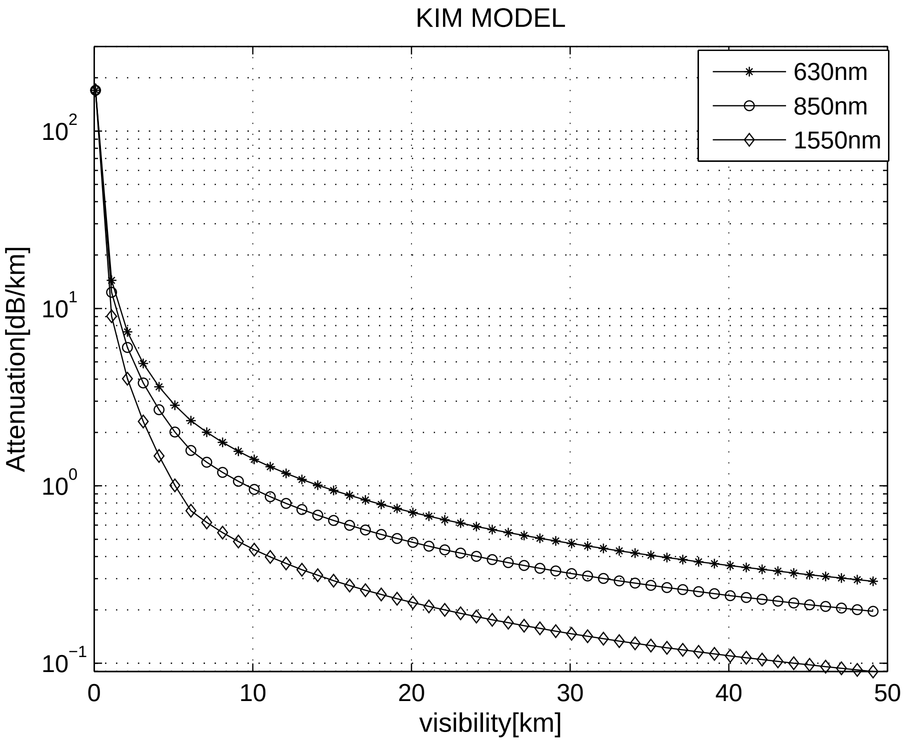

Figure 2.6: Fog Attenuation (dB/km)

Table 2.1: Equipment Rarameter

Parameters	FSO A	FSO B
d	1km	2km
P_t	14.47dBm	16.98dBm
S_r	−34dBm	−31dBm
S_c	$0.16m^2$	
θ	3mrad	
λ	1550nm	

Table 2.2: Estimation of average rainfall(ARF) and rainfall rate(RFR) from Indian Meteorological Department.

State	District	ARF (mm/4 months)	RFR rate(mm/hr)
Uttar Pradesh	Allahabad	184.2714	1.53
Rajasthan	Ajmer	103.975	0.866
Andhra Pradesh	Visakhapatnam	165.4375	1.37
Maharashtra	Aurangabad	165.9929	1.37
Tamil Nadu	Chennai	105.5286	0.871
Delhi	Delhi	131.275	1.093
Karnataka	Tumkur	110.9464	0.924
Goa	Goa	760.6179	6.33
Gujarat	Rajkot	204.5286	1.7044
Haryana	Gurgoan	121	1.008
Orissa	Cuttack	85.964	2.899
Tamil Nadu	Coimbatore	85.964	0.716
West Bengal	Howrah	297.74	2.481

The above observations are considered for designing two FSO transceivers (FSO A and FSO B) with distances of range 1km and 2km each. Various equipment parameters used in the research are as shown in the Table 2.1

For this design statistical data of rainfall for various cities has been collected from Indian Meteorological Department [11]. In India the overall rainfall is much during the period from June-September. The annual distribution of rainfall for the case of four months and four hours a day is considered, and mentioned in Table 2.2.

The maximum distance and Link margin (i.e., the received power above the receiver sensitivity) of an FSO link can be determined by substituting the calculated rainfall rate (RFR) in equation 2.5. The resulted maximum link (LD) distance and LM are as tabulated in Table 2.3

The above observations results that FSO A and FSO B links work properly for the given

Table 2.3: Resulted Link Distance and LM

District	RFR (mm/hh)	LD for 2km	LD for 1km	LM for 2km	LM for 1km
Allahabad	1.53	5.12	5.28	12.64	20.58
Ajmer	0.866	6.04	6.24	13.55	20.68
Visakhapatnam	1.37	5.3	5.45	12.84	20.68
Aurangabad	1.38	5.28	5.45	12.83	20.68
Chennai	0.871	6.03	6.23	13.54	21.03
Delhi	1.093	5.66	5.84	13.22	20.87
Tumkur	0.924	5.93	6.13	13.46	20.99
Goa	6.33	3.13	3.2	8.067	18.31
Rajkot	1.7044	4.95	5.1	12.43	20.47
Gurgoan	1.008	5.79	5.38	13.34	20.93
Cuttack	2.899	4.16	4.27	11.11	19.82
Coimbatore	0.716	6.35	6.57	13.78	21.15
Howrah	2.481	4.38	4.51	11.55	20.03

link distance (LD). LM is been estimated which determines that Indian rainy weather does not affect the FSO performance and the link is available even for the worst atmospheric condition as shown in Figure 2.7 and Figure 2.8.

Considering a heavy precipitation intensity of 24.8 mm/hr using equation 5. For a 2km link i.e. FSO is available even for the heaviest rainfall scenario and the link is stable, the same is simulated using OptiSystem 7.0 [12] as shown in Figure 2.9.

2.6 Conclusion

This chapter has discussed the motivation and the estimation of FSO link availability due to different attenuations. Here the statistical data of rainfall distribution has been collected and two FSO links has been taken into consideration for deployment in different parts of India. Link margin of each link under different atmospheric conditions and other attenuations has been analyzed. The evaluated LM is found to be above the threshold value providing the availability of link even for the varied conditions. This LM is used for the FSO network for quality based routing and wavelength assignment.

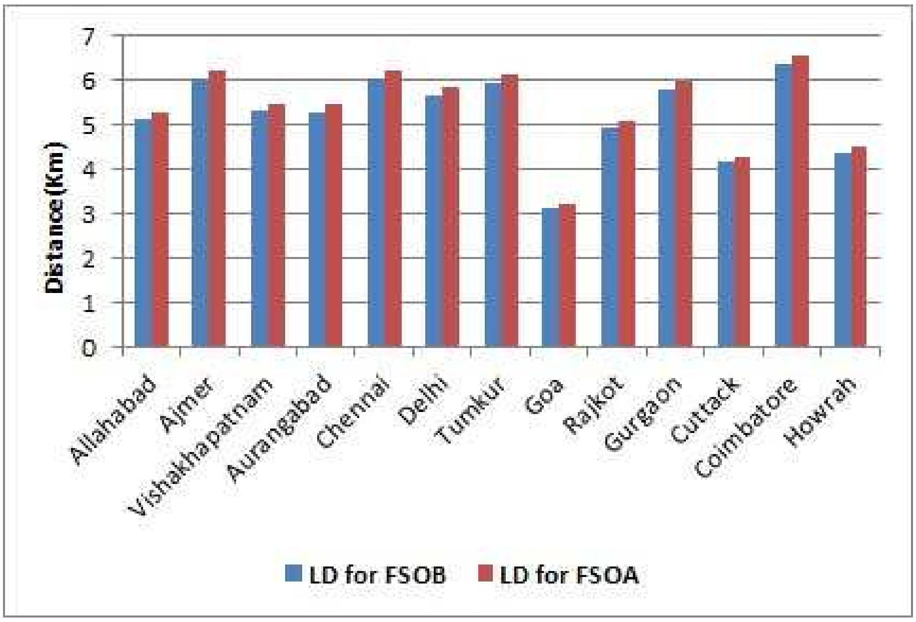

Figure 2.7: Maximum LD for FSO A and FSO B

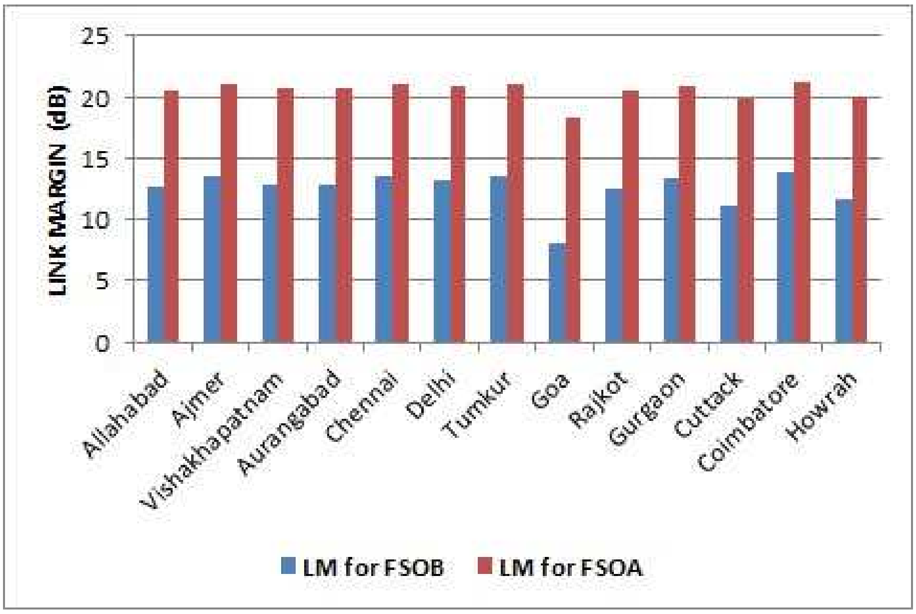

Figure 2.8: LM for FSO A and FSO B

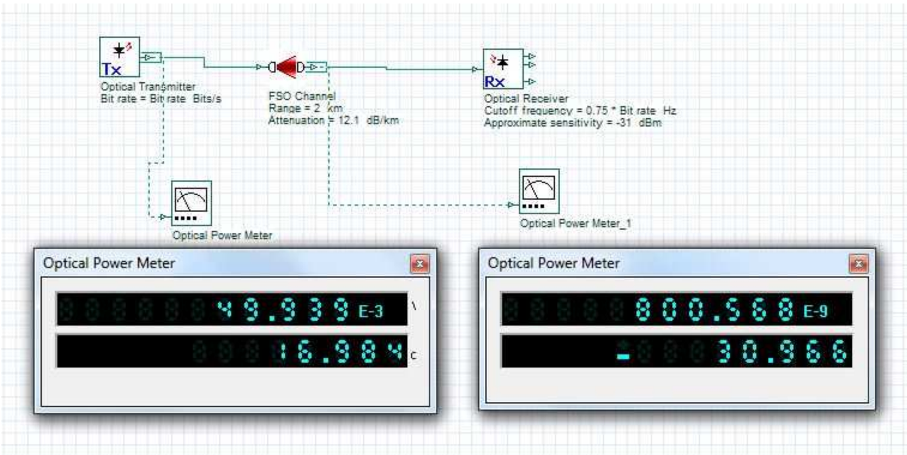

Figure 2.9: Simulation for the heaviest rainfall 24.8 mm/hr OptiSystem 7.0

CHAPTER 3

LM Based QoS for Network Routing

3.1 Introduction

In an FSO network routing and wavelength assignment technique plays a prominent role in determining the QoS to the end user. There are various paradigms for implementing these techniques. Call blocking probability is one of the important performance metric in QoS-WDM network. If there is no path available from the source to destination nodes with a wavelength available in every link of the route, the request for connection is blocked. A novel adaptive method based on the system current condition i.e., based on LM provides a more insight to the network performance.

3.1.1 Organization of the Chapter

The rest of the chapter is organized as follows. The theoretical background of Routing and Wavelength Assignment (RWA) technique is explained in Section 3.2. Blocking Probability (BP) related to our research work is explained in Section 3.3.Algorithms and Flowchart of our research are explained in Section 3.4. and Section 3.5 gives the Simulation results and Discussion.

3.2 Routing and Wavelength Assignment

RWA is a key feature of optical network where the process of data path selection i.e., selection of a path for a particular connection request with specified source and destination edge nodes and then allocating one designated wavelength for the selected path occurs [13], [14]. It is generally addressed by a two-step approach: first finding a connection for a source-destination pair using a routing technique, and second, selection of a free wavelength on the chosen connection by using wavelength assignment (WA) algorithm. For establishing a connection, we consider both selection of data path i.e. routing and wavelength assignment for the selected path.

3.2.1 Routing Technique

Selection of a path for a particular connection request with specified source and destination edge nodes is Routing. There are typically three paradigms of routing for dynamic routing they are:

- Fixed routing (FR)
- Fixed-alternate routing (FAR)
- Adaptive routing (AR)

Fixed routing (FR)

Here, there is a single fixed route for each pair of network nodes [15]. This fixed route is precomputed off-line, and any connection between a pair of source and destination nodes uses the same fixed route, which imposes a strict restriction on route selection. If there is a link failure on the shortest-path route, a connection from node a to node d will be disrupted and blocked as shown in Figure 3.1.

Fixed-alternate routing

In Fixed-alternate routing, there is a set of alternate routes for each pair of network nodes [16], [?]. The actual path for a connection request can be choosen from the available alternate paths, which also imposes a restriction on route selection. These alternate routes are precomputed off-line and are stored in an ordered manner within the routing table maintained by the network controller. A couple of routes alternate to the original, from node a to d are as shown in Figure 3.2.

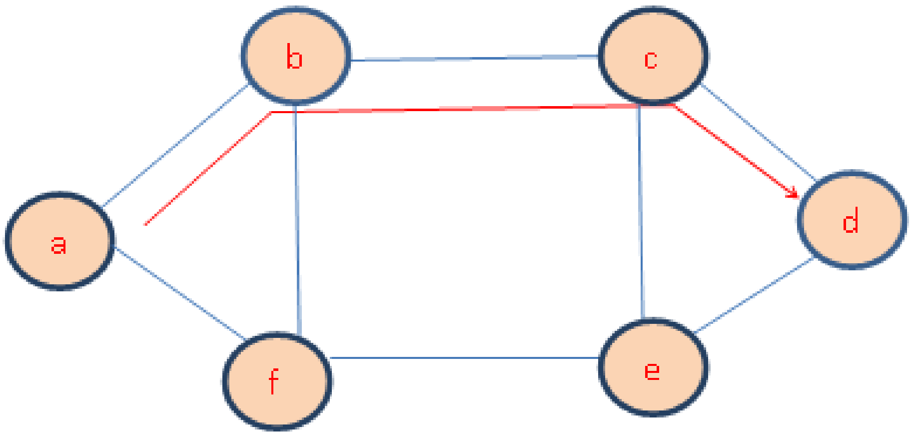

Figure 3.1: A Network of Fixed Routing

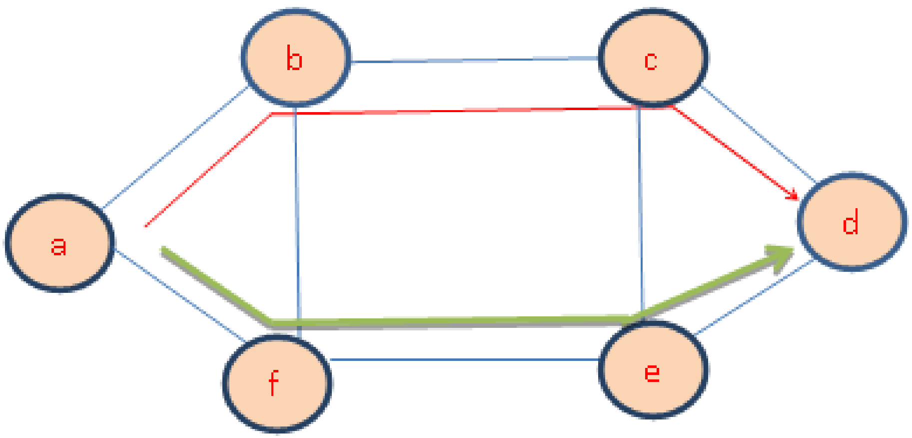

Figure 3.2: A Network of Fixed-Alternate Routing

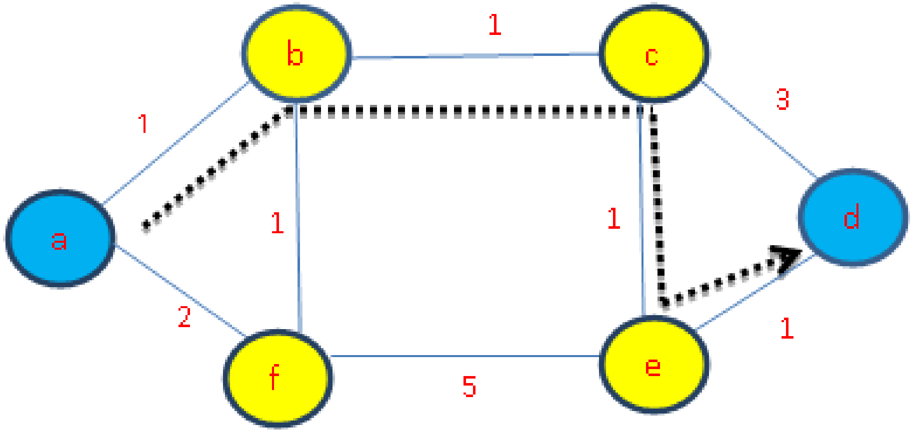

Figure 3.3: A Network of Adaptive Routing

Adaptive routing

In adaptive routing there is no restriction on route selection. Any possible route between a pair of source and destination nodes can be chosen as an actual route for a connection. The choice of route is based on the current network state information as well as a path-selection policy, such as the least-cost path first or the least-congested path first [17]. A least cost route from node a to node where the label on each link presents the cost for using that link as shown in Figure 3.3.

This is the most efficient routing technique for dynamic systems like FSO, so we have taken this for consideration in our thesis work.

3.2.2 Wavelength Assignment (WA)

The WA task is to assign wavelength to each link on the selected connections. If there is no path available from a source to destination nodes with a wavelength available in every link of the route, the connection request is blocked [18].
The RWA problem is subjected to various constraints such as wavelength continuity, wavelength distinct, physical layer impairment and traffic engineering.

Wavelength Continuity Constraint (WCC) In this scheme, all links on a connection is assigned with the same wavelength. The WCC differentiates the wavelength continuous network from a circuit switched network. The calls are blocked when there is no capacity along any of the links in the connection assigned from the request. This type of network suffers from blocking in comparison to the circuit switched network. This degraded performance can be overcome by wavelength conversion techniques [19].

Wavelength Distinct Constraint (WDC) In this scheme, the links on the connection may be assigned with different wavelengths. Here, signal arriving at one wavelength is converted to another wavelength at an intermediate optical router and then forwarding the signal through another link. This technique is almost used in all WDM/DWDM network and is known as wavelength conversion method for WA. In wavelength convertible network, optical routers are capable of wavelength conversion and work similar to a circuit switched network, that blocks the connection request when there is no available links carrying the capacity to forward the data [20]. In WDC, the effective resources i.e. the total effective connection for routing is more, hence the probability of blocking for incoming connection request is lower.

Physical Layer Impairment Constraint (PLIC) This constraint concerns how to select a wavelength and/or connection that guarantees the required level of signal quality.

Traffic engineering constraints (TECs) This aims to improve resource-usage efficiency and reduce connection blocking probability.

A few of the existing WA algorithms are explained below. These algorithms use WCC, WDC, PLIC or TEC depending on the type of network architecture.

Random WA In this scheme, a wavelength is assigned randomly from a set of wavelengths which are available in a WDM/DWDM link. Generally a random number generator is used and wavelengths are assigned to the numbers. In our work we used this WA based on LM.

First-Fit WA (FFWA) In FFWA method, a wavelength matrix is designed by arranging all wavelengths in ascending order. Then the wavelengths are numbered and the least numbered wavelengths are assigned for the first lightpath connection. Higher priority is assigned to the lower numbered wavelengths. Computation cost of this scheme is lower since it is not required to search for all wavelengths. The performance in terms of blocking probability, fairness and computation complexity is generally low [20]. In a wavelength-routed network, the traffic may be static or dynamic. In a static pattern, a set of connection requests are provisioned at a time and it remains for certain period of time, where the respective lightpaths are established simultaneously. In dynamic pattern, each lightpath is established as the connection request arrives and is released after certain period of time. This method considers the current traffic state of the network and lightpath provisioning is done accordingly. As the communication system grows, the bandwidth demand also increases leading to shortage of resources. For satisfying this, dynamic lightpath provisioning or on-demand lightpath established is preferred over static methods. In general, the RWA block is responsible for lightpath set up and RWA function is done either in two stages or in a single stage (integrated).

3.3 Blocking Probability (BP)

A connection request is established based on the routing and wavelength assignment (RWA) protocol. It sets up a light path connection between the source and destination nodes, if there is no route from the source to destination nodes with a wavelength available in every link of the route, the connection request is blocked [21].

As a result, the blocking probability serves to be an important parameter in the evaluation of network performance under different scenarios.

We apply this model into WDM systems from the point of giving relatively separated blocking likelihood to different traffic classes. A purposeful blocking calculation is applied to execute this model at the wavelength assignment level. So BP serves as an important parameter for network performance evaluation. BP is estimated by investigating individual link and node [22] analysis in a network. If the computation of all possible paths (routes) in the network is represented by a n x n matrix T along with network load $\mu_n et$, then the corresponding load matrix, L can be expressed as [18].

$$\mathbf{L} = \frac{\mu_{net}}{\sum_{i=1}^{n}\sum_{j=1}^{n}\mathbf{T}(i,j)}\mathbf{T} \tag{3.1}$$

where, n represents the no. of nodes in the network. $\mathbf{T}$(i, j) gives the supported paths by each link within nodes i and j.The BP matrix, B_p(i,j) with $\mathbf{L}$ can be calculated for all the links using the ErlangB formula as [**?**]

$$\mathbf{B_p}(i,j) = \frac{\frac{\mathbf{L}(i,j)^{A(i,j)}}{A(i,j)!}}{\sum_{c=0}^{A(i,j)} \mathbf{L}(i,j)^c} \tag{3.2}$$

where, A(i, j) is a wavelength matrix on each link between nodes i and j. Now, the overall network BP, $\mathbf{B}_{pnet}$ can be directly obtained from equation 8 and expressed as and expressed as where, $\mathbf{A}$(i, j) is a wavelength matrix with no. of wavelengths supported on each link between nodes i and j.

$$\mathbf{B_{pnet}} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} \mathbf{B_p}(i,j).\mathbf{T}(i,j)}{\sum_{i=1}^{n}\sum_{j=1}^{n} \mathbf{T}(i,j)} \tag{3.3}$$

Also the BP on each nodes, $\mathbf{B_{pnode}}$ can be approximated as [18].

$$\mathbf{B_{pnode}} = \frac{\sum_{j=1}^{n} \mathbf{B}(i,j).\mathbf{T}(i.j)}{\sum_{j=1}^{n} \mathbf{T}(i,j)} \tag{3.4}$$

3.4 Algorithm and Flow Chart

Algorithm 3.1 provides the steps for computations of paths (routes) based on LM. At first for each (s, d) pair all possible paths are computed and of each route, the minimum LM is obtained. Algorithm 3.2 provides the wavelength assignment technique by selecting the number of paths based on threshold LM. Corresponding network performance metrics are computed for different LM. figure 3.4shows the flow chart of RWA and blocking performance computation.

3.5 Simulation Results and Discussion

The proposed QoS estimation technique is validated by simulation studies. An NSFNet topology with 10 nodes and 16 links is considered for the analysis of a FSO network with different distances and LM is shown in Figure 3.5. We have used the RWA to assess the network performance based on distance and LM.

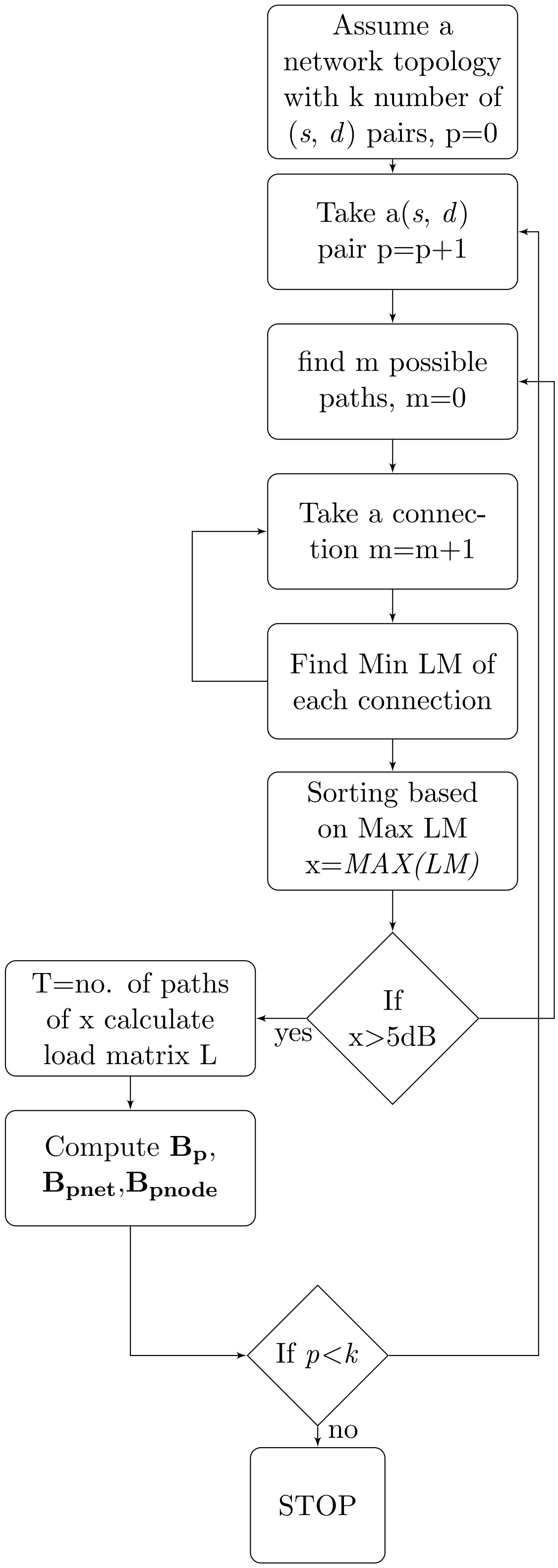

Figure 3.4: Flow Chart for RWA technique and BP computation

Algorithm 3.1: LM based path computation

{Compute all possible path, Initailization val-temp = 100 }
for $i = 1$ to n **do**
  for $j = 1$ to m **do**
    Calculate Link Margin for each path
  end for
  Calculate Minimum Link Margin for each path
end for
NM = Minimum Link Margin
N(number of paths) = length(paths)
for $i = 1$ to $(N - 1)$ **do**
  for $k = 1$ to $((N + 1) - i)$ **do**
    if $K \neq ((N + 1) - i)$ **then**
      if $LM(k, 1) \leq LM(k + 1, 1)$ **then**
        temp1 =LM(k,1)
        LM(k,1) = LM(k+1,1)
        LM(k+1,1) = temp1
      end if
    end if
  end for
end for
Maximum Link Margin of path = LM

Algorithm 3.2: BP computation

{Compute T (based on distance, LM),n,A }
for $i = 1$ to n **do**
  for $j = 1$ to m **do**
    for $y = 1$ to $A((i, j) + 1)$ **do**
      $x(i, j) = x(i, j) + (((L(i, j))^{(}y - 1))/(y - 1)!)$
    end for
  end for
end for
for $i = 1$ to n **do**
  for $j = 1$ to m **do**
    $B(i1, j1) = ((L(i, j))^{(}A(i, j)))/(A(i, j)!)/x(i, j)$
  end for
end for
for $i = 1$ to n **do**
  $B_{node}(i) = (sum(B(i).T(i)))/sum(T(i))$
  for $j = 1$ to m **do**
    $B_{net}(i, j) = (sum(B(i).T(i)))/sum(sum(T(i, j)))$
  end for
end for

3.5.1 Computation of all possible paths

Computation of all possible paths is as shown in Figure 3.6. For example a pair of source-destination (2-3) has 21 all possible paths. A fixed shortest path based routing

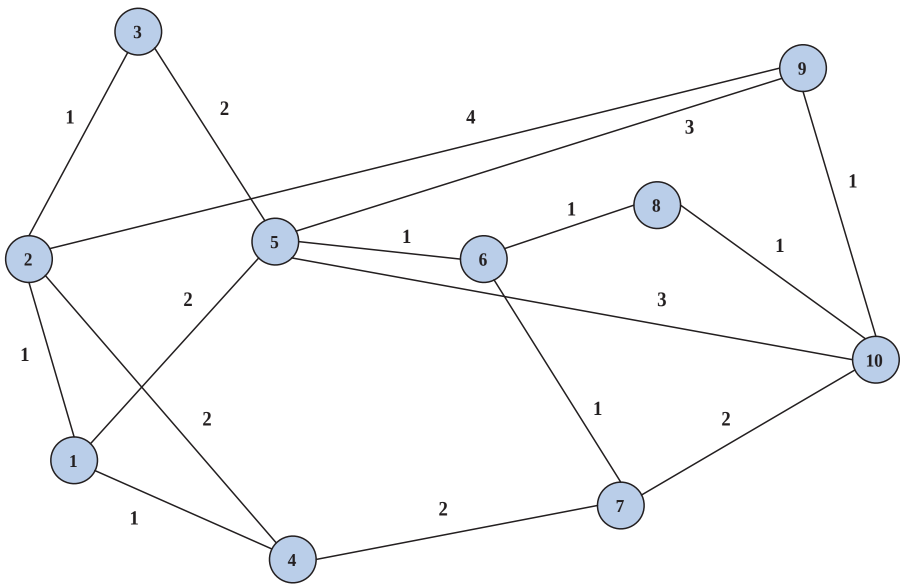

Figure 3.5: An NSFNet topology with 1 span=2km, LM of 1 span=5dB

technique does not provide any information on the current network status. The link may be down or failed due to different attenuations and as the network is not aware of it, so routing performed based on the shortest path distance leads to a non-reliable communication system. Hence a path is to be selected using the current scenario of the network. The proposed all possible path technique is an efficient and more reliable adaptive routing algorithm based on the LM as the cost factor providing the path with maximum availability even for adverse atmospheric affects.

3.5.2 LM based path computation

The steps followed for path selection based on LM i.e., all possible paths are computed and the minimum LM offered by the particular path is being calculated as shown in algorithm 1. Out of the all possible paths, the path with maximum LM is being selected as the best path for availability. Corresponding simulation results of the LM for all the paths from source-destination pair (2, 3) is as shown in Figure 3.7 and the Maximum LM paths are as shown in Figure 3.8.

3.5.3 Analysis of network traffic load

Considering all topology nodes as edge nodes, supported routes due to shortest distance path and LM based for the adopted topology are as shown in Figure 3.6, 3.9, and

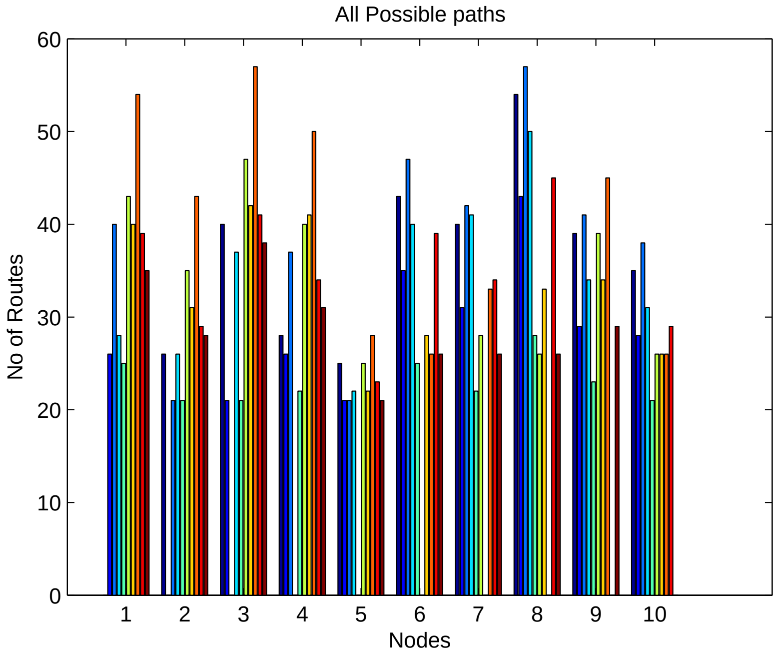

Figure 3.6: All possible paths from each node to destination node

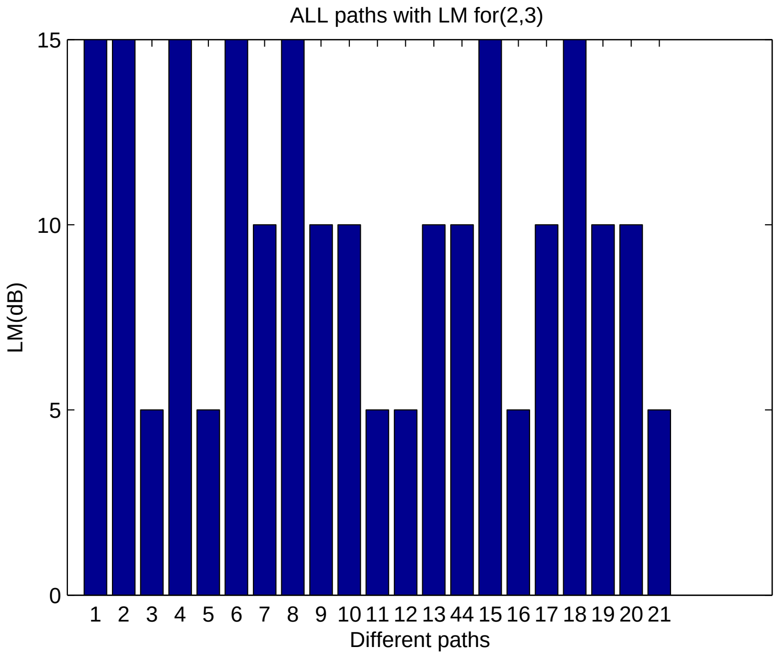

Figure 3.7: All paths with LM for source node 2 to destination node 3

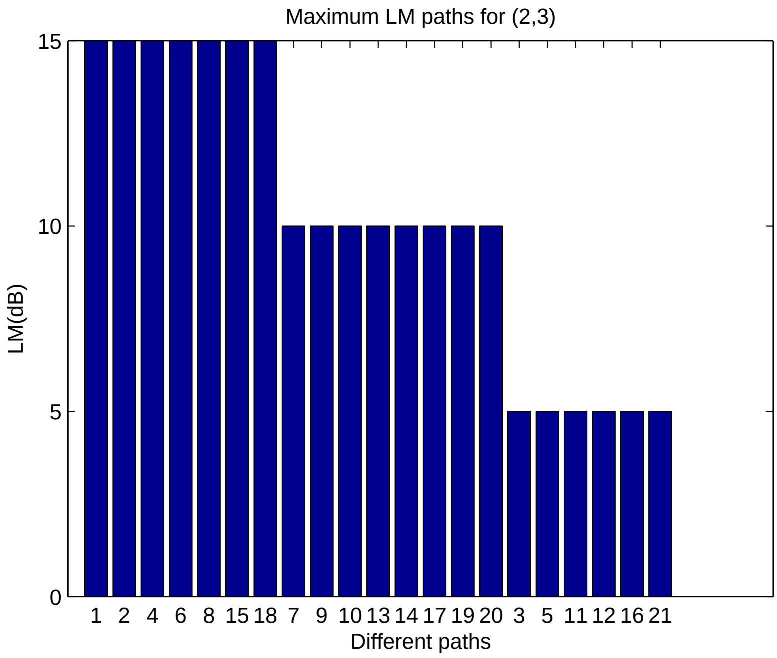

Figure 3.8: All paths with maximum LM for source node 2 to destination node 3

Figure 3.10. It can be observed that, some links support more paths and also as LM increases, the number of supported routes decreases. A constant number of wavelengths per link with network load net is varied from 1 to 200E (Erlang). Figure 3.11, and Figure 3.12 presents the node blocking probabilities in a network for a LM> 5dB with 8 number of wavelengths (λ=8) and with two values of loads μ_{net}. It can be seen that, node 5 is providing the least BP among all the nodes. Also as network load increases the BP on each node increases. Here Figure 3.13, and Figure 3.14 shows the results of network performance which depends on the number of wavelengths per link under the network load. It can be observed that for a given LM > 5dB, as the available wavelengths increases, BP decreases. Also as network load increases, BP increases irrespective of wavelengths. Figure 3.15 shows the network blocking performance for different algorithms (i.e., distance base and LM based). It can be viewed that, the proposed LM based routing in RWA decreases the BP and as higher the LM, better is the performance.

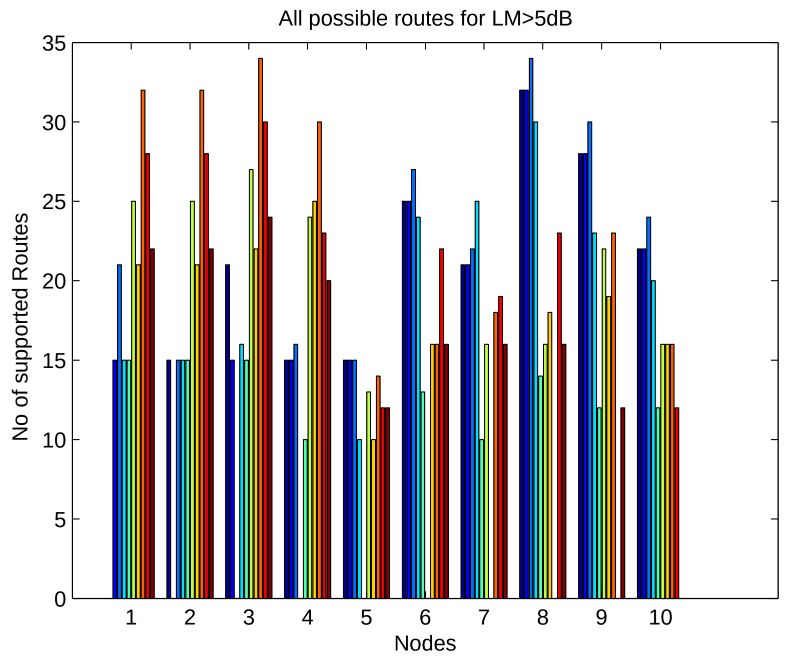

Figure 3.9: Distribution of possible paths (based on LM > 5dB)

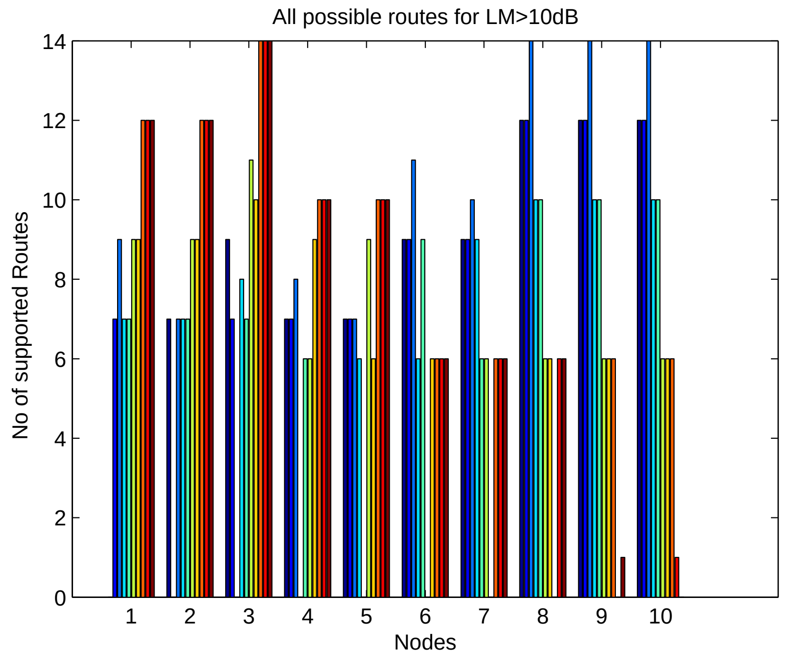

Figure 3.10: Distribution of possible paths for LM > 10dB)

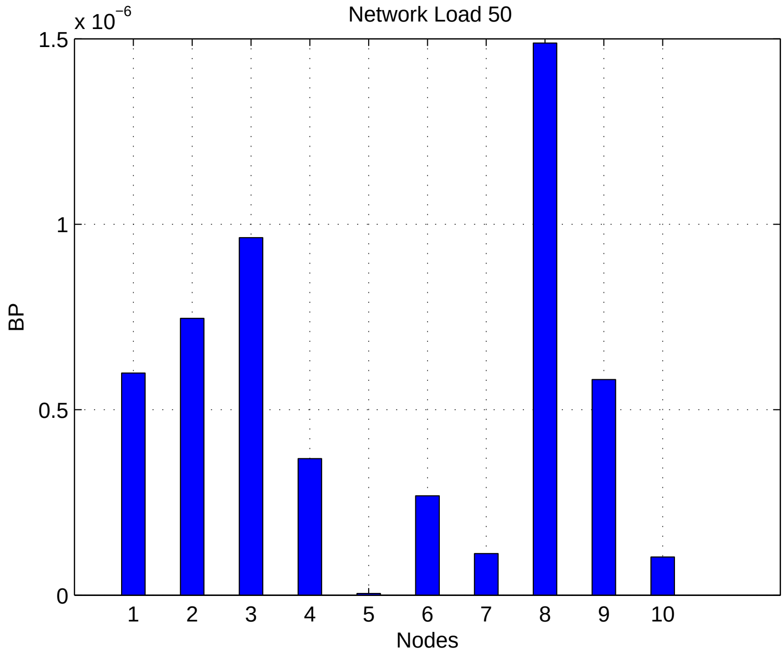

Figure 3.11: Node BP, number of wavelengths: 8 and with network load 50E

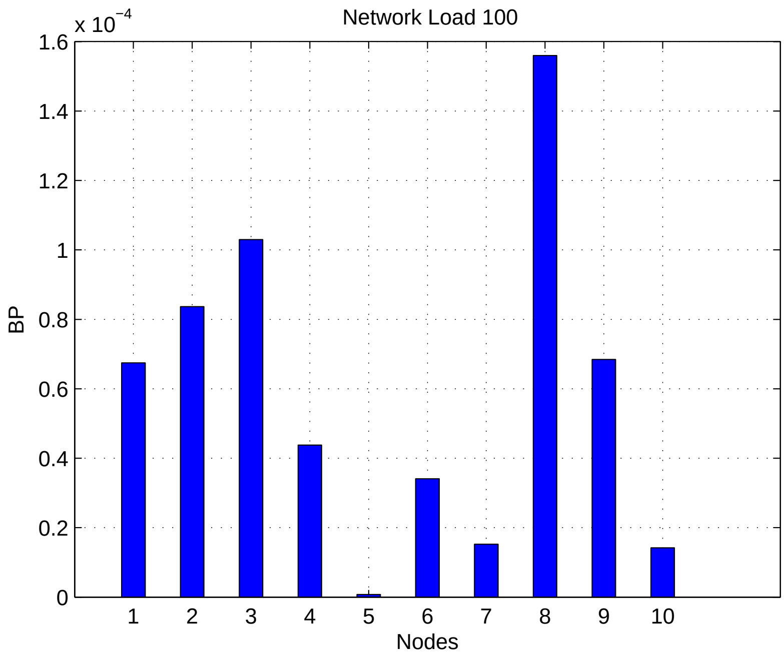

Figure 3.12: Node BP, number of wavelengths: 8 and with network load 100E

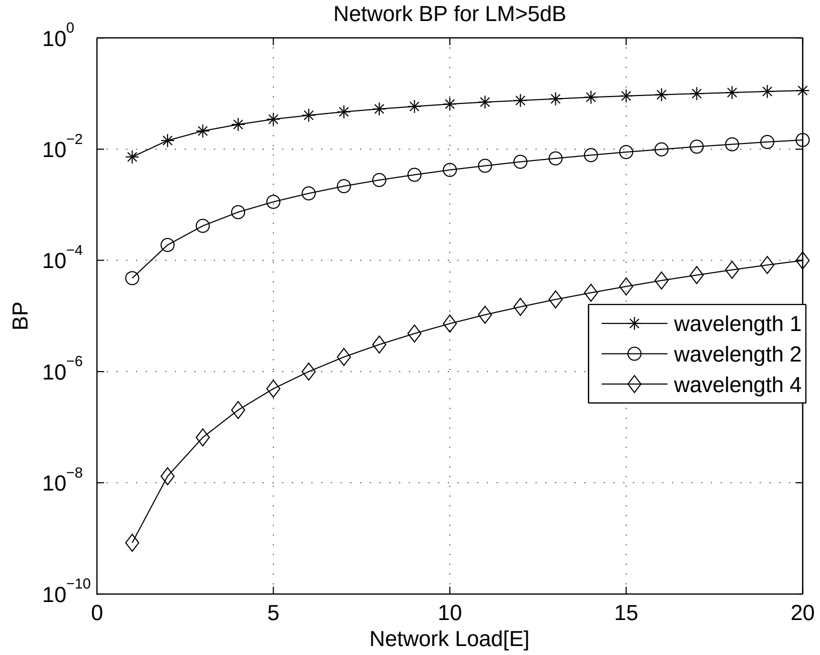

Figure 3.13: Network BP for different number of wavelengths and load (1 to 20)

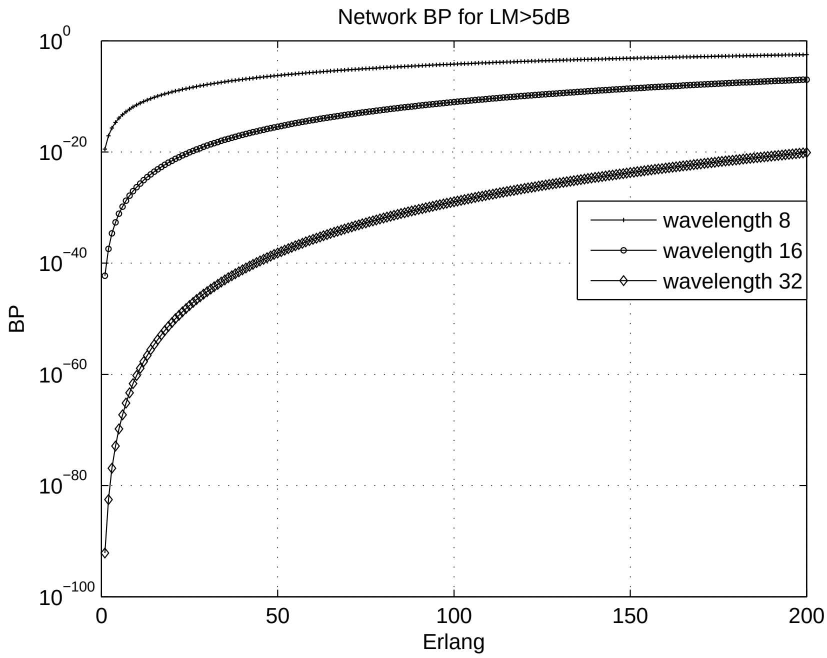

Figure 3.14: Network BP for different number of wavelengths and load (1 to 200)

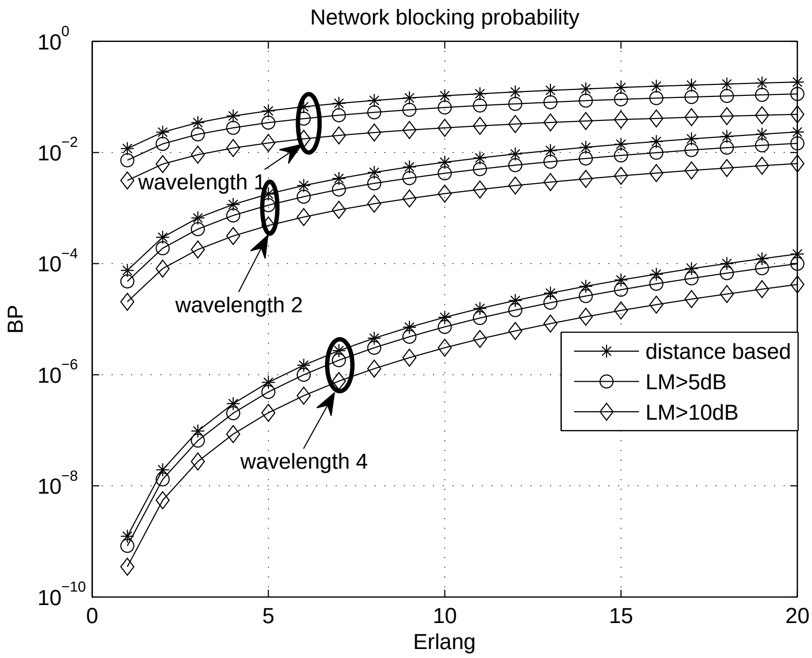

Figure 3.15: Comparison of network BP for distance based and LM based algorithms.

CHAPTER 4

Conclusions, Limitations and Future Works

4.1 Concluding Remarks

As FSO network provides a wide range of applications comparable to optical communication, these carry high amount of traffic, maintaining a threshold level of LM with guaranteed QoS is an important parameter for consideration. It is required to analyze and maintain the LM as per the QoT requirements to the end user. The demand of various application being deployed across the public Internet today are increasingly mission-critical, owing to which business success can be paralyzed by poor quality of the network. It does not account how attractive and potentially lucrative the applications are if the network does not provide the guaranteed quality consistently to the client .The choices for the selection of suitable connection with required quality and availability of the link can be provided by the service provider network to the client.

This thesis addresses the QoS estimation techniques for the selection of connection with required LM under dynamic traffic demand. We have developed the availability of FSO link under different channel conditions by collecting statistical data and determining the LM for a particular distance. Also an FSO network with adaptive routing based on LM is developed. Wavelength assignment is been considered based on LM and the entire network performance is evaluated for available wavelengths and different traffic conditions.

Blocking performance of each individual node is also been evaluated for varied network traffic. The outcome of the global computation will be a new decision criterion for the selection of FSO link connection along with wavelength assignment. In the following section, we have detailed the contributions made in this thesis to address the LM based path selection with QoS requirements.

4.2 Contributions

The contributions from this thesis can be listed as follows

- Estimation of FSO link for different channel conditions. The deployment FSO link for a particular distance depends on different factors of the channel and can be estimated based on LM of the link. A detailed study for different places in India under different atmospheric conditions is been evaluated and corresponding LM is calculated, providing the establishment of FSO link.

- FSO network with LM based RWA technique for better QoS. A FSO network with an adaptive LM based routing provides a higher QoS to the client providing the longer availability of connection even in adverse scenario. A better wavelength assignment strategy based on LM is proposed providing a better performance compared to conventional models.

4.3 Limitations of the Work

Following are some of the limitations of our work.

- The practical implementations of the proposed work has not been done.

- The attenuations due to other atmospheric conditions are not considered.

- The path restoration techniques have not been considered during link failure.

- This thesis considered uniform traffic pattern in all cases. It is expected that similar result will apply when the traffic pattern changes.

4.4 Future Directions

Based on the above limitations of the work and the work reported here, following are some of the possible directions for future research.

- The calculation of LM considering all the attenuations can provide a more precise knowledge of the FSO link.
- A path restoration technique when the link fails can provide a better performance.
- An optimization based on distance and LM can improve the overall QoS.
- Performance of network for dynamic traffic conditions can be considered to provide a better performance to the work.

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