Estimation of Link Margin for Performance Analysis of FSO Network

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Abstract. In a high-speed optical network, the primary considerations for data communication is the sustainability of free space optical (FSO) link on various atmospheric conditions, which provides a reliable connectivity to the end user. This paper focuses on the estimation of FSO link margin (LM) based on meteorological data collected at various smart cities due to atmospheric conditions. The availability of link is evaluated in terms of LM, also it is used to establish a quality based network route for data transmission. The network performance of the proposed scheme has been analyzed in terms of blocking probability (BP).

Keywords: FSO, Atmospheric attenuation, Link Margin, Blocking probability, Routing and Wavelength Assignment

1 Introduction

Optical communication without fiber media is termed as FSO. It is an alternative solution to commonly deployed fiber optic and wireless radio-frequency links. FSO is the technology, which is capable of providing high bandwidth communication links between remote sites. It solves the last-mile problem in broadband. The range of frequencies over which it operates makes FSO communication free from licensing [1]. There has been a tremendous increase in digital needs across the globe. In context to developing country like India, there is a need for high-speed data transfer systems. FSO suits the need and provides a viable solution. An FSO system with a clear line of sight (LOS) is workable over distances for several kilometers between the source and the destination [2]. The main limitation to FSO link is the different attenuations created by atmospheric conditions such as rain, fog, snow, and haze. Among all, rain has a significant role that effects the optical power intensity at the receiver. This limits the FSO link availability over a given transmission range. LM is used to determine the availability of an FSO link, the availability of link is considered to be 99.999% for telecommunication (carrier class), and is about 99% for the LAN applications (enterprise class) [3]. In [4], the authors used a cumulative distribution function (CDF) of meteorological data to estimate the availability of a given link. In [5] the author compares the cumulative distribution of meteorological data and experimental

data in a broadband network. If any of the links fails, then there is no provision to provide an alternative connection. Here we estimated the LM based on the statistical analysis of meteorological data of rainfall for different cities over several years to determine the availability of FSO link. This paper emphasizes an intelligent routing technique based on LM for high availability in an FSO network.
This paper has been organized as, following to introduction, Section 2 presents the system model for the estimation of LM. In Section 3, LM based routing technique is proposed. In Section 4, explains the flowchart of routing technique. In Section 5, analytical simulation and discussion compares the performance. Finally, Section 6, concludes the work.

2 System Model

In FSO link, several effects are considered such as the losses due to atmospheric absorption, scattering, turbulence, microclimate environment, localized effects, link distance and link misalignment. A typical FSO system is as shown in Fig. 1 with transmitter T_{xi} and receiver R_{xj}. It consists of transmitter power, receiver sensitivity, beam divergence angle and atmospheric attenuation due to the atmospheric channel. A key quality parameter in FSO link is the link margin, $LM(i,j)$, which is expressed as [6],

$$LM(i,j) = P_e(i) - S_r(j) - \alpha_{tgeo}(i,j) - \alpha_{atmo}(i,j) - \alpha_{sys}(i,j) \tag{1}$$

where, $P_e(i)$ is the i^{th} transmitter power; $S_r(j)$ is the j^{th} receiver sensitivity; $\alpha_{tgeo}(i,j)$ is geometrical attenuation between link (i,j); $\alpha_{atmo}(i,j)$ is atmospheric attenuation; $\alpha_{sys}(i,j)$ is system losses. These parameters are further explained as follows.

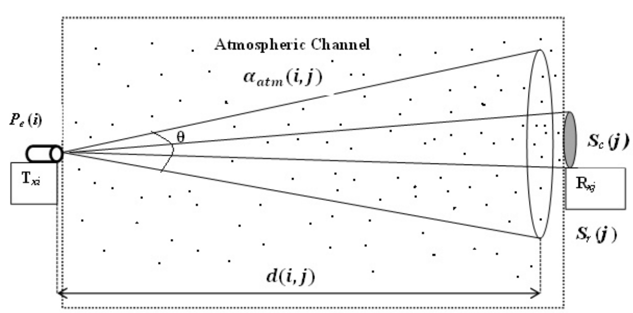

Fig. 1. A Typical FSO System

2.1 Geometrical attenuation

The light beam diverges as it travels a long distance due to small receiver capture area, a very less amount of power is consumed. This problem corresponds to geometrical attenuation (GA), $\alpha_{tgeo}(i,j)$ is expressed as [6],

$$\alpha_{tgeo}(i,j) = \frac{S_t(i)}{S_c(i)} \tag{2}$$

where, $S_t(i) = \frac{\pi}{4}(d(i,j)\theta)^2$ it is the area of illumination; θ is the light beam divergence angle, $d(i,\ j)$ is the distance from the transmitter (i) to receiver (j) and $S_c(i)$ is the capture area of the receiver.

2.2 Atmospheric Attenuation

There are different types of attenuation occurring due to variation in atmospheric conditions (i.e., rain, fog, snow, haze, and scintillation). Rain is considered to be the major impairment for an FSO link. It has a significant role in determining the LM. Atmospheric attenuation, $\alpha_{atmo}(i,j)$ due to rain is expressed as per unit distance. Using the Carbonneau model [7], it can be expressed as,

$$\alpha_{rain}(i,j) = 1.076 \times R^{0.67} \tag{3}$$

where, R is the precipitation intensity in mm/hr. Now, based on (2) and (3), a more precise FSO link margin, $LM(i,j)$ in effect to GA, rain attenuation, and system losses can be expressed as,

$$LM(i,j) = P_t(i)+|S_r(j)|-[10log_{10}\alpha_{tgeo}(i,j)]-[\alpha_{rain}(i,j)\times d(i,j)]-\alpha_{sys}(i,j) \tag{4}$$

where, $\alpha_{atmo}(i,j) = \alpha_{rain}(i,j) \times d(i,j)$.
The next section explains routing technique based on LM.

3 Link Margin based Routing Technique

RWA refers to the process of establishing the connection with wavelength assignment between a source−destination pair [8], [9]. It is a two-step approach such as routing technique and wavelength assignment. The process of connection establishment is known as routing technique. It is to find a route as per the connection request with given source−destination pair. There are typically three types of routing techniques used, which are called fixed routing (FR), fixed-alternative routing (FAR) and adaptive routing (AR) [10], [11], [12], [13]. In general, a FAR based on shortest distance can be selected from all possible routes for any source−destination pair $(s,\ d)$ [14]. In AR, the route can be selected based on the dynamic change of the link quality.
Once the route is selected, a particular wavelength is assigned to it. There are different wavelength assignment (WA) techniques used, which is called first-fit

WA, random WA, least-fit WA *etc.* If there is no route or wavelength is available for a (s, d) pair, then the request for connection is to be blocked [15]. BP serves a key role in the evaluation of network performance. This is evaluated by investigating individual node and link in an FSO network [16]. The primary step in the analysis is the computation of all available routes in a given FSO network based on the distance or LM. As proposed in [14], all available routes are computed based on LM is represented by a n x n matrix, **T**. The network load in the network is represented as, μ_{net}. The corresponding load matrix **L**, represents the load carried at each link, that can be expressed as [17],

$$L(i,j) = \frac{\mu_{net}}{\sum_{i=1}^{n}\sum_{j=1}^{n} T(i,j)}\mathbf{T} \tag{5}$$

where, n is the number of nodes; $T(i,\ j)$ is the no. of supported routes for link $(i,\ j)$ belongs to **T**, $L(i,j)$ belongs to **L**.
The BP matrix, $\boldsymbol{B_p}(i,j)$, for each link with L$(i,\ j)$ can be expressed by using the Erlang−B formula as [18],

$$\boldsymbol{B_p}(i,j) = \frac{\frac{L(i,j)^{A(i,j)}}{A(i,j)!}}{\sum_{c=0}^{A(i,j)} L(i,j)^c} \tag{6}$$

where, $A(i,\ j)$ is the number of wavelengths on link L$(i,\ j)$. The overall network BP, $\boldsymbol{B_{pnet}}$, can be expressed as,

$$\boldsymbol{B_{pnet}} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} B_p(i,j) \times T(i,j)}{\sum_{i=1}^{n}\sum_{j=1}^{n} T(i,j)} \tag{7}$$

The BP on each node, B_{pnode}, is approximated as follows [17],

$$\boldsymbol{B_{pnode}} = \frac{\sum_{j=1}^{n} B(i,j) \times T(i,j)}{\sum_{j=1}^{n} T(i,j)} \tag{8}$$

4 Flow chart of LM based Routing and BP computation

The flow chart for LM based routing and the evaluation of blocking performance is shown in Fig. 2. Initially, all available paths are estimated with the corresponding LM of each link. The available paths are then sorted in descending order based on the LM. Among the sorted order, paths above the threshold are accepted and form a new all available paths matrix, T. Corresponding blocking probabilities are computed for performance analysis.

5 Analytical Simulation and Discussion

Parameters considered for the simulation are shown in Table 1. Simulations are performed using MATLAB and Optisystem 7.0 [19] software. The performance is analyzed based on link level and FSO network. These are further explained as follows.

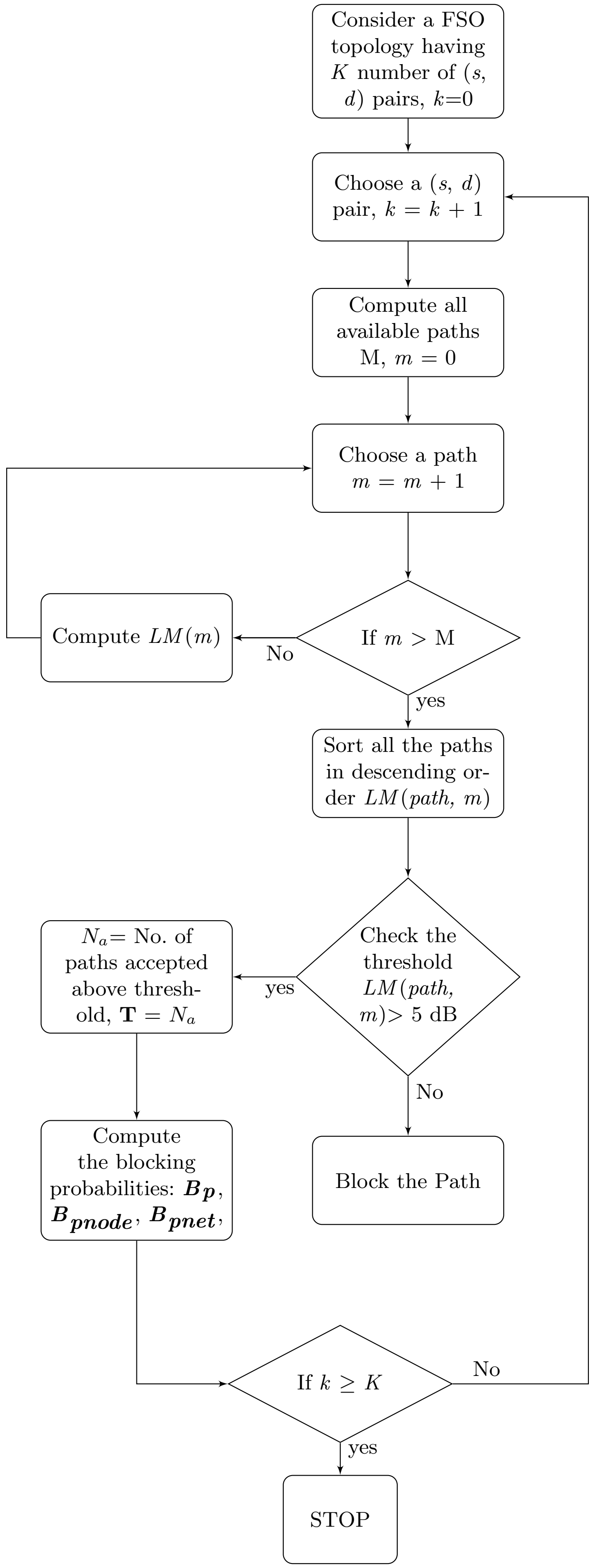

Fig. 2. Flow chart of LM based Routing and BP

5.1 Performance Analysis of FSO link

The availability of FSO link is evaluated based on GA, rain attenuation, and system losses. Fig. 3 shows the GA for different beam divergence angles of light as a function of link distance. It is observed, as the distance increases the attenuation increases considerably. Fig. 4 represents the attenuation due to varying precipitation intensity of the rain. Two FSO links (i.e., FSOA and FSOB) of range 1km and 2km are considered for the deployment in different parts of India. To analyze the performance of the links, a comprehensive statistical data of rainfall is collected from Indian meteorological department [20] for various smart cities. A period from June-September is focused in our estimation since much of the rainfall is during this session. A case study of the annual distribution of rainfall for 30 days with 4hr/day is considered. Rainfall Rate(RFR) is calculated (i.e for Allahabad, 184.2714/4x30=1.53), which is shown in Table 2. The maximum distance link can operate, and LM (i.e., the minimum received power that is above the receiver sensitivity) of an FSO link can be computed with RFR using (5). Table 3 represents the maximum FSO link distance (LD) and LM. It is observed from the results that, the two transceivers link work properly within a given distances. LM forms an important quality parameter for link status, Fig. 5 and Fig. 6 signifies that attenuation due to rain does not have much effect on the FSO link. As the precipitation increased, i.e., for a heavy rainfall of 25 mm/hr and using (5), the availability of FSO link for a 2km is simulated using OptiSystem as shown in Fig. 7, which represents that even for the worst case scenario the link remains stable. An eye diagram is shown in Fig. 8 which signifies that it has very fewer amplitude variations with eye height of 58428e-006 for a 2km link.
This is not the case if there is a cloud burst or any other atmospheric calamity which drastically leads to a link failure. The following section addresses the problem by using a multi-link network topology with intelligent routing, based on the atmospheric conditions.

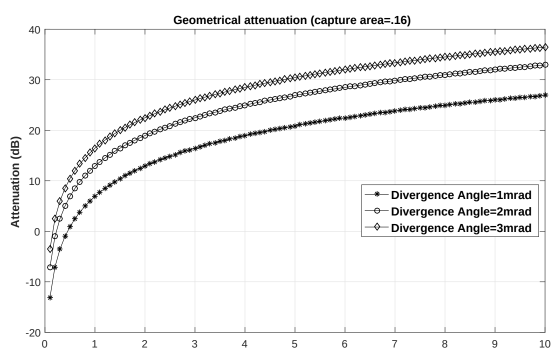

Fig. 3. Geometrical Attenuation (dB)

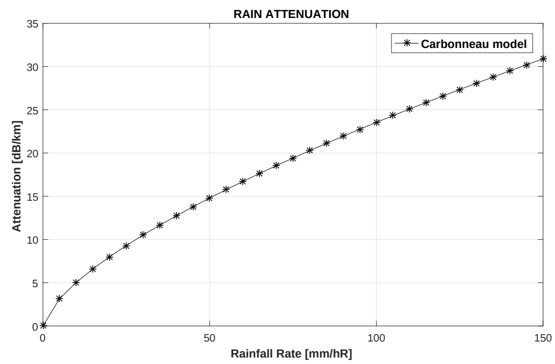

Fig. 4. Rain attenuation (dB/km)

Table 1. FSO Transceiver

Parameters	FSOA	FSOB
d	1 km	2 km
P_t	14.47 dBm	16.98 dBm
S_r	-34 dBm	-31 dBm
S_c	$0.16m^2$	
θ	2mrad	
λ	1550nm	
α_{sys}	10dB	

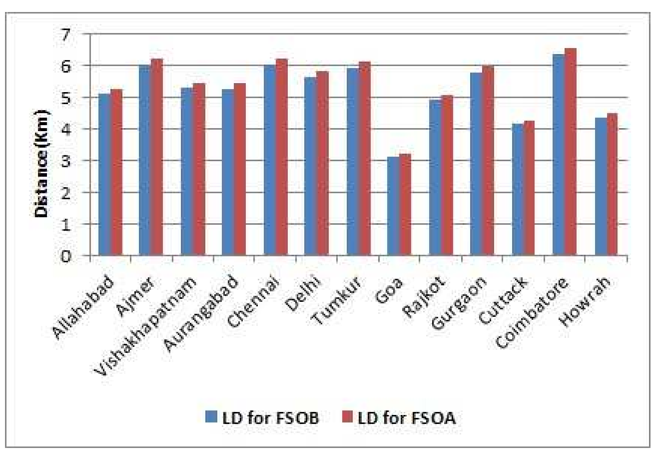

Fig. 5. Maximum Operating Link Distance for FSOA and FSOB

Table 2. Estimation of rainfall rate(RFR) from average rainfall(ARF) [20]

District	**ARF (mm/4 months)**	**RFR (mm/hr)**
Delhi	131.275	1.093
Visakhapatnam	165.4375	1.37
Ajmer	103.975	0.866
Chennai	105.5286	0.871
Aurangabad	165.9929	1.37
Goa	760.6179	6.33
Gurgoan	121	1.008
Tumkur	110.9464	0.924
Cuttack	85.964	2.899
Rajkot	204.5286	1.7044
Allahabad	184.2714	1.53
Howrah	297.74	2.481
Coimbatore	85.964	0.716

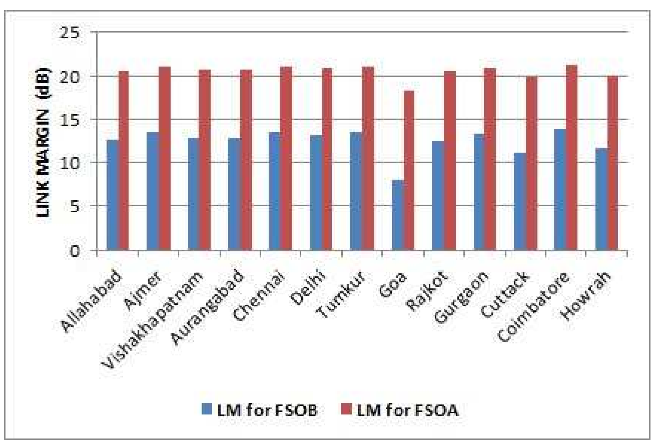

Fig. 6. LM for FSO A and FSO B

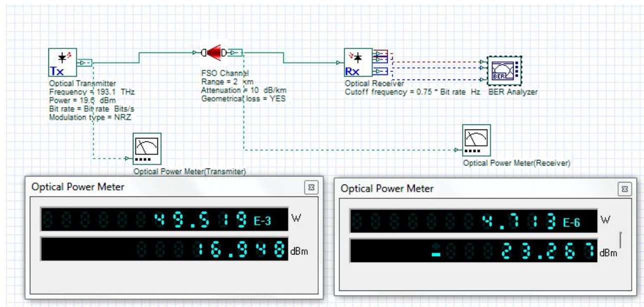

Fig. 7. Simulation for the heaviest rainfall rate of 25 mm/hr OptiSystem 7.0

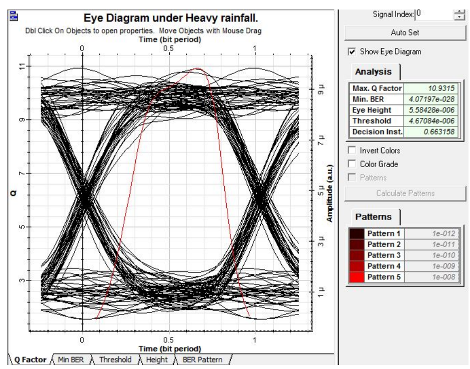

Fig. 8. Eye Diagram at 1Gbps for 2Km FSO Link

5.2 Performance Analysis using FSO Network topology

Consider an FSO network with 10 nodes and 16 links similar to NSFNet topology as shown in Fig. 9. FSO link with 1 span is equal to a transmission distance of 1km with LM of 5dB. Initially, all possible paths are computed based on distance and for different LM (i.e, LM $>$ 5dB and LM $>$ 10dB) are shown in Figs. 10, 11 and 12. The vertical bar represents a number of possible routes from each source node to the other nodes, i.e., a source−destination pair (2, 3) has 21 paths based on distance, where as 15 paths for LM $>$ 5dB and 7 paths for LM $>$ 10dB. It is observed that as the LM threshold increased the number of supported paths decreased, but this trade-off increases the link reliability. Conventional routing technique such as shortest path algorithm does not include the link status, rather finds the route based on distance. There are situations where the shortest link may suffer from high atmospheric attenuation. The topology is controlled by selecting a path using the current scenario of the network. An intelligent routing algorithm with LM as the quality parameter for routing is explained below.

Table 3. Maximum LM with Link Distance (LD) for FSOA and FSOB

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

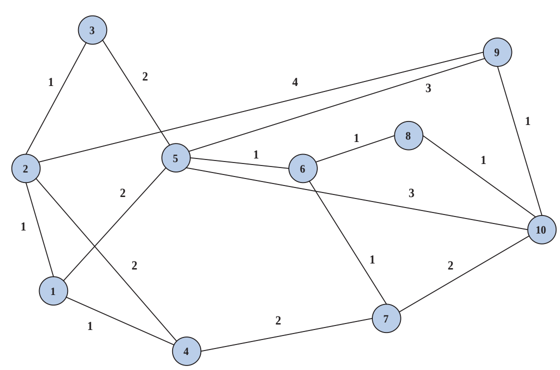

Fig. 9. An FSO Network topology with 1 span=2km or LM = 5dB

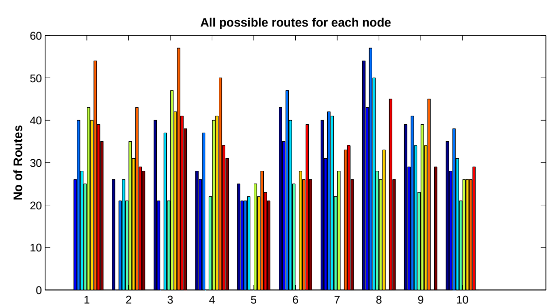

Fig. 10. Computation of all available routes from each node to destination node for LM > 0dB

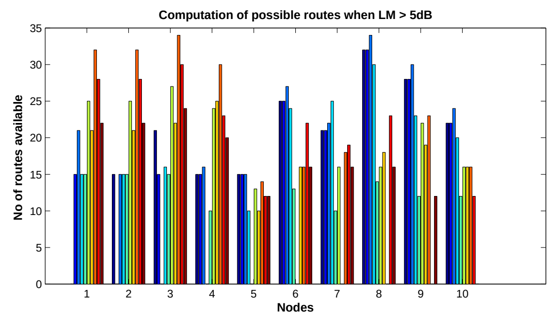

Fig. 11. Computation of available routes, when LM > 5dB

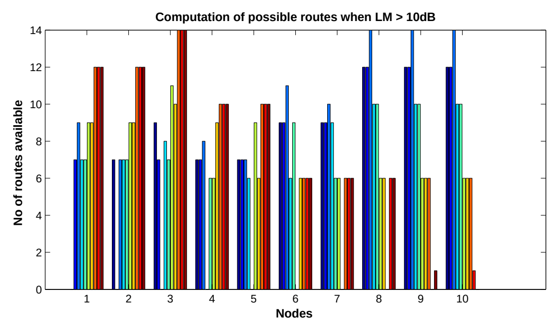

Fig. 12. Computation of available routes, when LM > 10dB

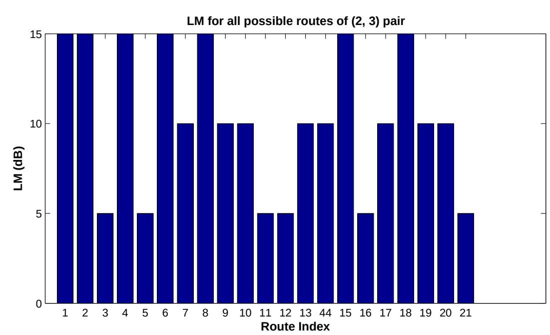

Fig. 13. LM plot for all possible routes of source−destination pair (2, 3)

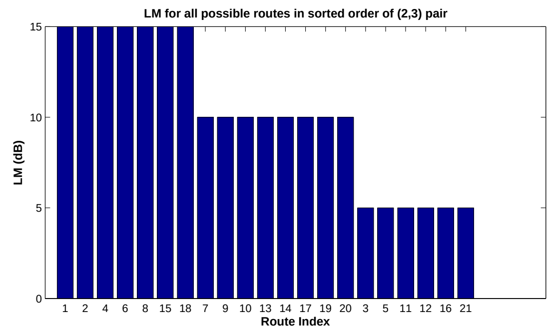

Fig. 14. LM plot for all possible routes of source−destination pair (2, 3) in sorted order

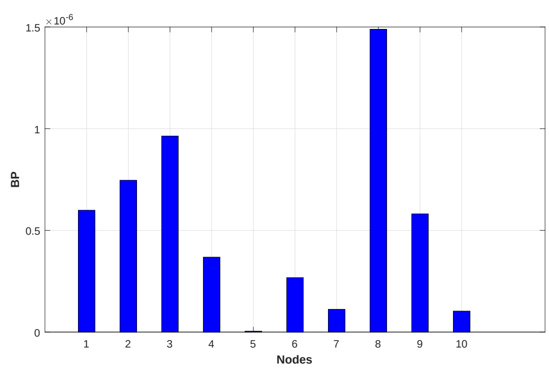

Fig. 15. BP computation for each Node with wavelengths = 8 and network traffic = 50E

- **Path computation based on LM**
  Following are the steps for path computation based on LM:

  i Computation of LM for each link of the entire network.
  ii Compute all available paths with the minimum LM for the connection setup i.e., a source - destination pair (2, 3) has 21 paths for LM > 0dB as shown in Fig. 13.
  iii Sort the paths based on highest LM as shown in Fig. 14 for a source - destination pair (2, 3).

  Now, the paths with threshold LM is selected.
- **Analysis of network traffic load**
  The number of supported routes due to LM for the different threshold is shown in Fig. 10, 11 and 12. This result represents that as LM threshold is increased it consequently relates to less number of supported routes, but provides a higher reliable connection. The analysis is performed for LM > 5dB with network load, μ_{net} and fixed number of wavelengths. Fig. 15 and Fig. 16 represents the blocking probabilities at each node with different network load, μ_{net} as 50E and 100E. It is observed the least BP is provided by node 5 among all the nodes, which signifies a route with node 5 has less probability of link failure. Fig. 17 represents the overall network performance depending on the wavelengths used per link and traffic. It is observed that as the number of wavelengths increased corresponding BP decreases. Fig. 18 shows the network blocking performance for distance and LM based algorithms, it is observed as the LM increased the BP has decreased leading to a high availability of the links. Also, the proposed algorithm outperforms the existing distance based algorithm.

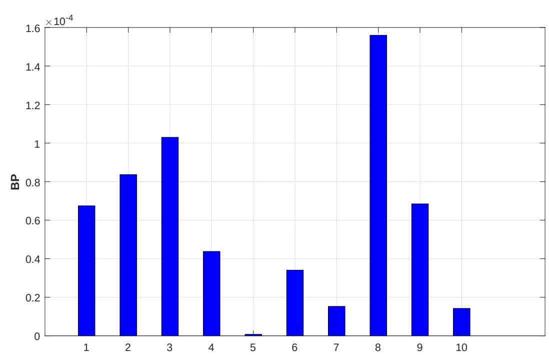

Fig. 16. BP computation for each Node with wavelengths = 8 and network traffic = 100E

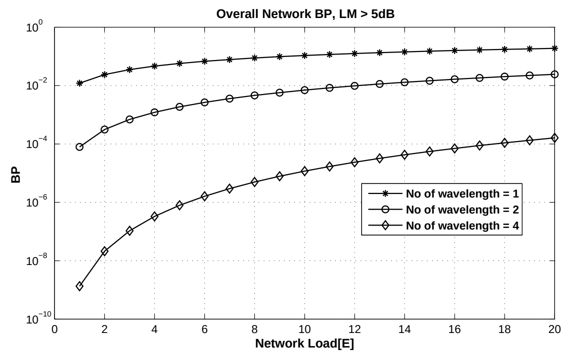

Fig. 17. BP computations of Overall network with wavelengths and network traffic (1E to 20E)

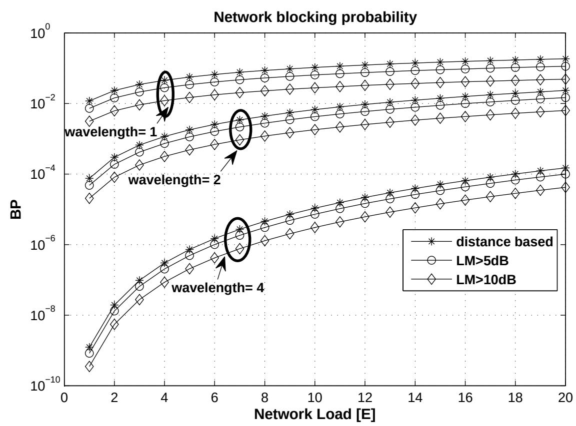

Fig. 18. BP for distance and LM based algorithms

6 Conclusion

The primary goal of this work is to determine the availability of FSO link under rainy weather conditions from the data collected at various smart cities of India. Also, the proposed routing technique for FSO network based on link margin provides a high reliable communication even on adverse conditions. Performance analysis of the network under different traffic conditions and network resources based on LM is done, which comprises the quality in network routing. This work can be extended for different atmospheric attenuation condition, and an optimization based on different factors can give a deeper insight analyzing network quality. This forms a basis for future link design in an FSO network.

7 Acknowledgments

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