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# COST ESTIMATION OF PASSIVE OPTICAL NETWORK (PON) FOR SUB OPTIMAL DEPLOYMENT WITH APPLICATION OF PATH MINIMIZATION TECHNIQUE AND WAVELENGTH ALLOCATION BASED OF BIT ERROR RATE (BER) PERFORMANCE

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## ABSTRACT
A basic criterion for PON network planning is to design fiber path. This criterion may be satisfied with some practical restrictions such as length of fiber paths, split ratios, splitter positions, the presence of obstacles on the deployment path etc. After finalizing any possible path, the BER performance of the finalized path also needs to be verified. Here we propose the algorithm that not only reduces deployment costs of PON system by maintaining the strategy of lowering distance limits, avoiding obstacles in the route but also have facility to evaluate BER performance and calculate approximate deployment costs of the path.

## INTRODUCTION
Passive Optical Network (PON) is used in modern high speed broadband communication system with various types like Ethernet PON, Gigabit-PON (G-PON) or WDM PON etc. PON network actually act as an access network that carries information between the CO(s) to the end users unit. In recent years, many PON studies have focused on areas such as dynamic bandwidth allocation (DBA), upgrade the data frame format to achieve higher PON data rate etc but still there are less focus on cost-effective design technique of PON system. This fact drives our interest on this subject topic and here we proposed the technique which would help to define an optimal point-to-multipoint network that can be used to connect each customer (ONU) with their respective CO through splitters with the total fiber length as less as possible. If the location of the central office (CO), the end user, the location of the optical splitter is given, we can use this technique as key strategies for developing a network map or the probable minimized route. Further when the probable path is realized, there may lay some restrictions for which the shortest connections between two points become impractical.

In specific, due to the presence of obstacles along the way that may not traversed by any means (impassable obstacles)[1]. In addition, by applying the impedance avoiding technique described here, we can avoid the obstacle present on the path of the optical fiber and complete the searching process of the possible route through which fiber line may be installed. The BER performance of probable path may be computed. Optical fiber communication line is possible to connect using various topologies like ring topology, bus topology, tree topology, etc. But the tree topology is mostly used in practice. So here we also worked with tree topologies.

## OPTIMIZATION PROCESS FOR OPTICAL PATH

### Network Diagram using K-nearest neighbour algorithm
The K-nearest neighbour (KNN) algorithm is a very strong tool which is vital to the algorithmic study of geometric problems [9]. Let we presume that **N** points ($\mathbf{p_1, p_2, \ldots, p_N}$), are randomly generated, in a two-dimensional plane to mark the ONU. The ONU are located at remote node end, and if all the **N** points are distributed in the same plane along with **M** number of points which indicates the location of splitters ($\mathbf{s_1, s_2, \ldots, s_M}$) where the position of CO is predefined, such that each **N** will be connected with CO through their nearest **M** point by single fiber path for which the total Euclidean distance among all N points with the CO becomes minimum,. Then that result in partition of the plane into **M**-areas (where **M**<**N**). As here we use

tree topology, so in most of the case the position of the splitter will be located almost very close to the centre of each region. In nearest neighbour techniques variants for multi-label classification, regression, and semi supervised learning settings allow its application to classification of Remote Nodes (RNs) located at different distance over a two dimensional geometric plane.

## Introduction to Classification and KNN

This is the problem to predict discrete class labels for unlabeled pattern or different remote nodes based on observations. Let $\{(x_1, y_1),..., (x_N, y_N)\}$ be the set of observations of q-dimensional patterns $X = \{x_i\}^N_i = (1/Rq)$, and the corresponding set of labels or location of splitter is $Y = \{yi\}^N_i = (1/Rd)$. The goal of classification is to calculate a functional model **'f'** that allows a reasonable prediction of class label **y'** for an unknown pattern or distribution of remote nodes **x'.** Remote Nodes without labels should be assigned to labels[10].

## KNN Classifier

Nearest neighbour classification which is also known as K-nearest neighbours (KNN), is based on the idea that the nearest patterns of RN to a target pattern or distribution of remote node **x'**, by this we seek the label, which deliver useful label information. KNN assigns the class label of the majority of the K-nearest remote node in data. By this, we would be able to define a similarity measure in data space. In **Rq**, it is reasonable to employ the Minkowski metric (p-norm)

$$||x' - x_j||^p = \left( \sum_{i=1}^{q} |(x_i)' - (x_i)_j|^p \right)^{1/p} \quad (1)$$

The Euclidean distance for p = 2.In the case of binary classification, the label set **Y**= {1, −1} is employed, and KNN is defined as:

$$f_{KNN}(x') = +1 \text{ if } \sum_{i \in Nk(x')} yi \geq 0; \text{ otherwise -}$$
$$f_{KNN}(x') = -1 \text{ if } \sum_{i \in Nk(x')} yi \leq 0 \quad (2)$$

With neighbourhood size defined as **K** and with the set of indices defined as **Nk**(**x'**) of the K-nearest patterns. The choice of **K** defines the locality of KNN.

## The Proposed Algorithm

Most of the time, two end points of optical fiber link connectivity are limited by the PSC location, available network resources, obstacles (both traversable and impenetrable such as streets, green field territories, etc. With all above network planners need to design a PON line with the goal of the total fiber length to be minimum as much as possible.

This problem can be represented as an insignificant network design problem in a given graph G(N, M), where G is a collection of nodes N and the location point of splitter are M which are utilized to determine the ONU region. In addition, the network organizer must consider into account the splitting ratio of the optical N splitter and the maximum allowable length of the aerial lead-in line $L_{max}$ connecting the optical splitter and ONU. Better communication depends on the length of the fiber or distance of the communication line and here the maximum limit is considered as $L_{max}$. Therefore, these parameters are also included. The input parameters of the proposed algorithm are listed in Table I

Table I: Input parameters to the proposed algorithm

| Parameter | Description |
|---|---|
| G (N,M) | Set of ONU points and set of probable location of splitters. |
| k | This number decides how many neighbours (where neighbours are defined based on the distance metric) influence the classification. This is usually an odd number if the number of classes is 2. If k=1, then the algorithm is simply called the nearest neighbour algorithm. |
| N splitter | The splitting ratio of the optical splitter. |
| L max | The maximum allowable length of an optical fiber /aerial lead-in line. |

The main challenge here is obstacle avoidance (if any) located on the fiber-optic deployment path, which can be accomplished by following the Obstacle Avoidance technique described as follows.

Obstacle Avoidance

A larger proportion of the operational network installation needs to be transported through a highly populated area where the shortest route connections may not be feasible due to the presence of specific obstacles that can't be traversed or can be tracked at a higher cost compared with the standard set-up cost of another optical fiber link. These obstacles must be considered when looking for the shortest connecting path associated with two self-defining nodes on a two dimensional map. To get started, the designer need to build a networking map that contains various goals. Barriers can exist there between the shortest path of any two or more than points on the map. Identify the obstacles from the map (Figure 1). Next, we design the convex hull structure using a Graham scan that includes the vertices of the obstacle than need to be bypassed and the points we want to connect (Figure 2).Here we have to choose the route with shorter length along the Convex hull-shaped structures are formed between two nodes (Figure 3).

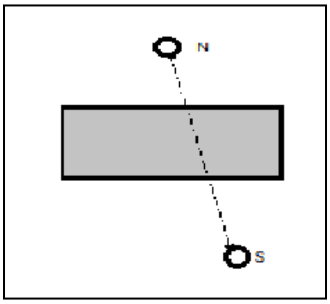


**Figure1.**

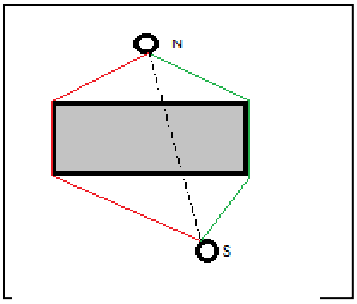


**Figure2.**

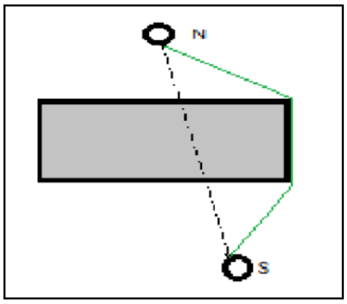


**Figure3.**

**ONU-distance-aware (ODA) scheme with BER performance**

In this system, the designer first need to sort the ONUs according to their distance from the RN, and then assign the wavelength in sequence to the decreasing distance. During wavelength allocation it need to be considered that always allocate best possible wavelength for any RN, therefore an ONU could not be allocated a worse wavelength than that ONUs closer to the RN. The ODA system is able to measure BER between ONUs and helps to reduce variance as it compensates ONU situated at a far fields with better wavelength.[11]. The BER performance of any communication channel depends on the signal strength received at that point. In optical communication, the power received by any port of the communication link may be calculated as:

$$P^{i}_{sig} = L_f \left(d_{feeder} + d^{i}_{drop}\right) L_p L_S G P_t \qquad (3)$$

Where $P^{i}_{sig}$ is the signal power at the i-th port;

$L_f$ is the insertion loss at the feeder section

$L_p$ is the propagation loss per kilometre

$L_s$ is the loss at the drop section

$d_{feeder}$ is the distance of the feeder section

$d^{i}_{drop}$ is the distance of the drop section for i-th port

G is the Gain

$P_t$ is the transmission power

Noise variance for transmission of '0' and '1' are:

$$\sigma_0^2 = \sigma_{th\,0}^2 + \sigma_{sh\,0}^2 \qquad (4)$$

$$\sigma_1^2 = \sigma_{th\,1}^2 + \sigma_{sh\,1}^2 \qquad (5)$$

Where noise variance due to thermal noise is $\sigma_{th}$, and noise variance due to shot noise is $\sigma_{sh}$. The decision threshold set at the receiver end is:

$$I_{th} = \left[\frac{R_\lambda P^i{}_{sig} \sigma_0 + \epsilon R_\lambda P^i{}_{sig} \sigma_1}{(\sigma_0 + \sigma_1)}\right] \quad (6)$$

Where $R_\lambda$ is the photo-detector responsivity ($R_\lambda = 0.8$) and $\epsilon$ is the laser extinction ratio ($\epsilon = 0.1$). Then the BER at the receiver end may be computed as follow:

$$BER = \frac{1}{4}\left\{ erfc\left[\frac{R_\lambda P^i{}_{sig} - I_{th}}{\sqrt{2}\sigma_1}\right] + erfc\left[\frac{I_{th} - \epsilon R_\lambda P^i{}_{sig}}{\sqrt{2}\sigma_0}\right]\right\} \quad (7)$$

This technique is useful to be applied to find out shortest path between CO to the splitter with subsequent ONUs, avoiding the obstacles on the path and then compute the BER performance of the newly designed path. After we determine the shorter length path, next we need to calculate the estimated cost for implementation of the route. So to serve the purpose the following computation need to be applied.

Approximate Cost Calculation of the optimized path -

Cost ($PH_1$) = $UP_1$. Length ($PH_1$) + $UP_1$. Length $_R$ ($PH_1$) + ($UP_2$ + $UP_3$).Length $_{NR}$ ($PH_1$) + $UP_4$.Splice Count ($PH_1$) + ($UP_2$ + $UP_3$+$UP_5$). Length $_O$ ($PH_1$)

Where:

$PH_l$ – the path whose price we are calculating,
$UP_1$ – unitary price of the fibre cable,
$UP_2$ – unitary price of deploying fibre in an already existing conduit,
$UP_3$ – unitary price of creating a new cable conduit,
$UP_4$ – price of realizing a fibre splice between two fibre sections,
$UP_5$ – unitary price of deploying a fibre cable traversing a given obstacle encountered in the signal path.
Length ($PH_l$) – length of the path $PH_l$
Length $_R$ ( $PH_l$) – resource length of a path $PH_l$ defined as the total of lengths of individual links in the said path, which reuse an already existing resource
Length $_{NR}$( $PH_l$) – non-resource length of a path $PH_l$ defined as the sum of the lengths of all individual links in the said path which cannot reuse an existing resource Length $_O$ ( $PH_l$) – length of the path $PH_l$ that passes through an obstacle
Splice Count ($PH_l$) – number of fibre splices in the path The following subsections contain the detailed description

Therefore, finally the entire optimization process along with cost estimation is possible to be accomplished by the following steps as follows:

**Step 1:** Prepare a network diagram, with consideration that the locations of ONU are arbitrarily distributed and positions for the splitter and COs are fixed on the diagram.

**Step 2:** Apply K-nearest neighbour algorithm for finding the shortest route distance of the ONU with the splitter. In this process, whole area of the diagram is divided into sub-area(s), where each sub-area assigned with set of remote nodes and location points of one splitter.

**Step 3:** Compute the shortest distance rout between the CO and each optical splitter in the sub-graph and decide the path to every splitter. Similarly on other hand, calculate the shortest distance route from splitters to ONU.

**Step 4:** The connected shortest route are verified from CO to ONU to find the existence of any obstacle. If any obstacle is there on the path, the route may be adjusted by the procedure described in the section of Obstacle avoidance discussed here, after which the feasible shortest path is possible to determine.

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**Step 5:** Check the communication route from CO to ONU for each line. Then evaluate the BER performance of the path.

**Step 6:** If the BER performance is good and the optimized path is determined, then apply the approximate cost estimation technique on the optimized path to calculate the approximated cost of the possible route.

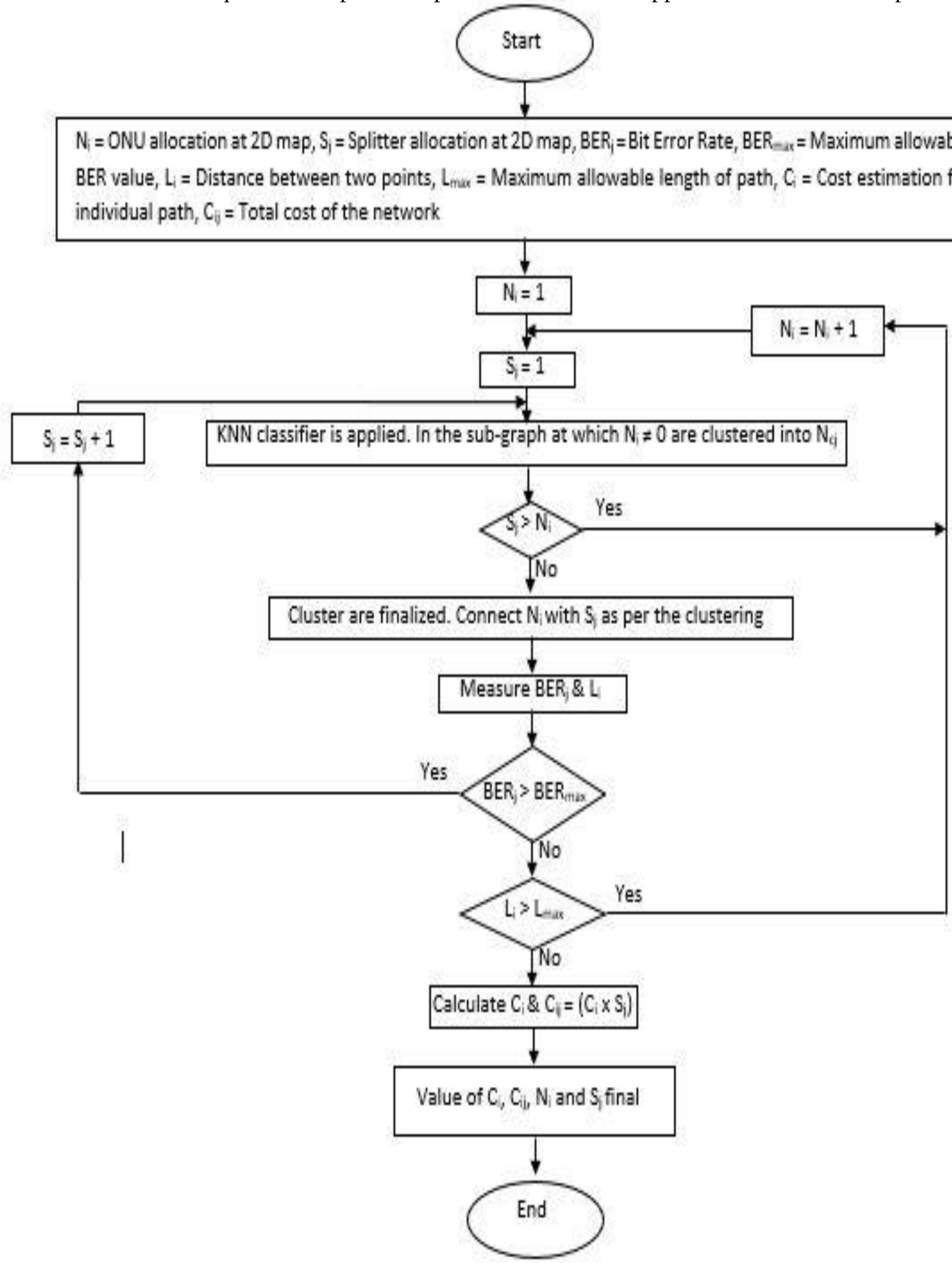


Figure 4 : Flowchart of the propose PON network designing algorithm

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## SIMULATION RESULTS

Here, a numerical simulation result is presented which were performed to evaluate the feasibility of the proposed algorithm. In this evaluation, a graph consisting of 30 randomly arranged remote nodes was used to approximate a network consisting of power splitters. Here in the simulation we used 4 settings for power splitters. Splitters are available in the ratio up to 1:32 even more, so the number of ONU coordinates of each splitter does not exceed the split limit. The input parameters used in the numerical simulation are listed here in Table 2.

Table 2: Input parameters to the proposed algorithm

| **Parameter** | **Value that is counted in the evaluation** |
|---|---|
| G (N,M) | Graph of 30 randomly deployed nodes as ONU and 04 points indicating location of splitters in a geometric plane of 60 square km. |
| K | 2 |
| $N_{splitter}$ | 4 |
| $L_{max}$ | 25 km. |

Now the simulation results are showed and explained as follow:

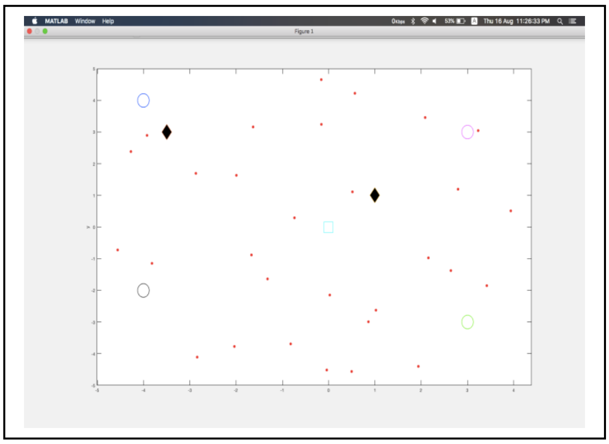


Figure 5(a).

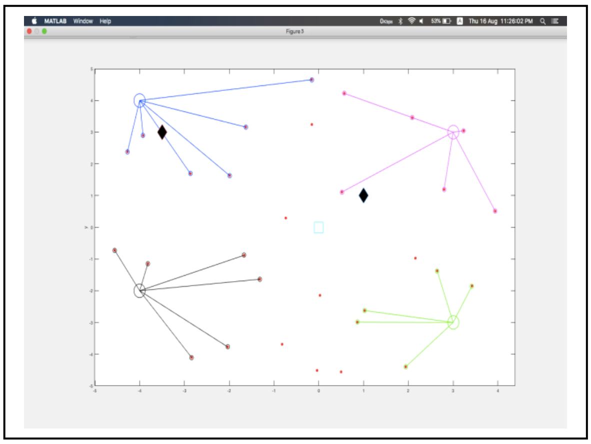


Figure 5(b).

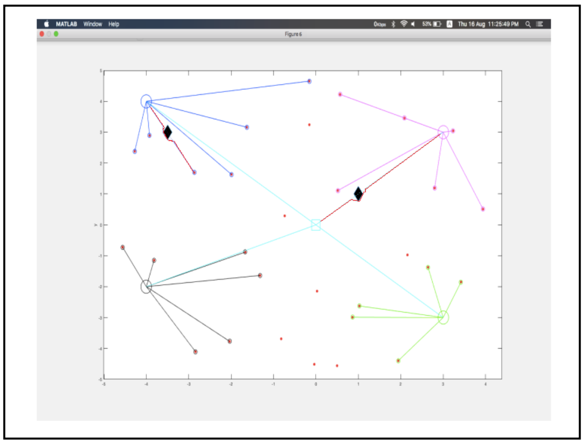


Figure 5(c).

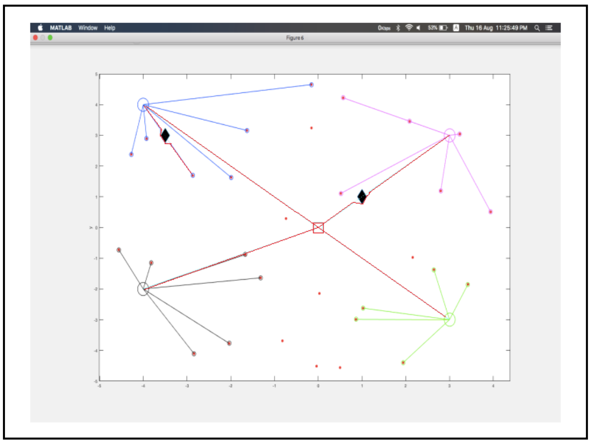


Figure 5(d).

**Figure 5(a).** First, we arbitrarily distribute ONUs or nodes in the network. It is presumed that the positions of the ONUs are at customer's premises around each fixed CO, and the areas of the splitters were put around the CO. Two obstacles are located on the same map. These are all the plots on the map of two dimensional planes.

**Figure 5(b).** We have applied the K-th nearest neighbour algorithm to the power splitters of network. For this reason main graph is divided in sub-graph. Every sub-graph is a collection of ONUs and single splitter. ONUs in the network is connected with Optical Splitters.

**Figure 5(c).** Now with application of Step 3, the shortest path between the CO and each optical splitter which are situated in the sub-graph are marked and related with the CO. Here in the map with four different locations of optical splitters causes the division of map to 4 different sub-regions which are marked by different colours. Next we execute the obstacle avoidance process which is shown in the Figure.

**Figure 5(d).** In this figure we may observe that the obstacle in the rout is bypassed and the sub-optimal route is established from CO to ONU. For the cases where ONU to CO distance crosses maximum limit $\mathbf{L_{max}}$ then ONUs are not marked under any splitter. By this technique optical fiber path is determined through a sub-optimal path between the CO and ONUs.

Now the BER calculation needs to be carried for each ONU to CO connection path. So here BER performance for upstream direction data flow need to be computed for different distance (D) with different transmitting power (Tx) vs BER. Some sample results are:

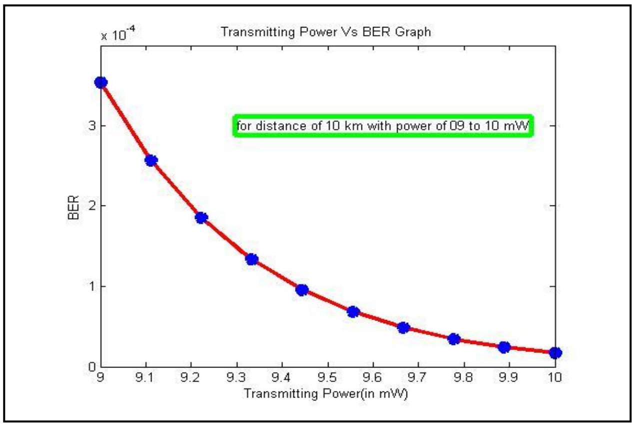



**Figure 6(a):** D= 10 km; Tx= 09 to 10 mw

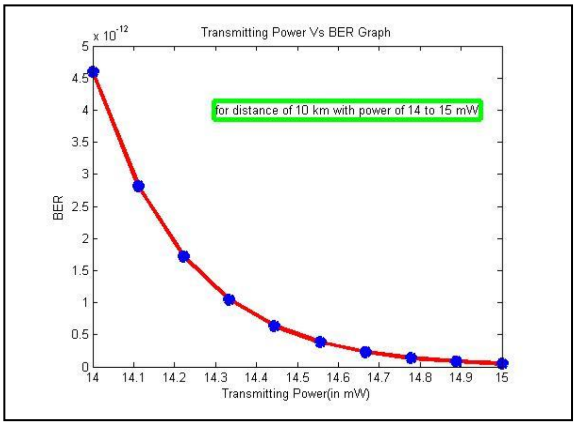



**Figure 6(b):** D=:10 km; Tx=14 to 15 mw

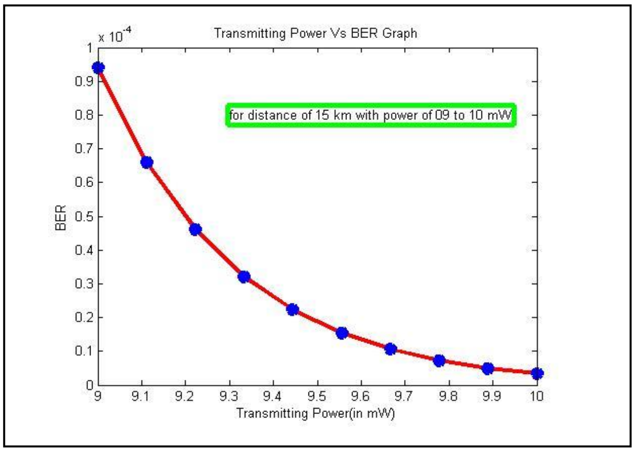



**Figure 6(c):** D= 15 km; Tx= 09 to 10 mw

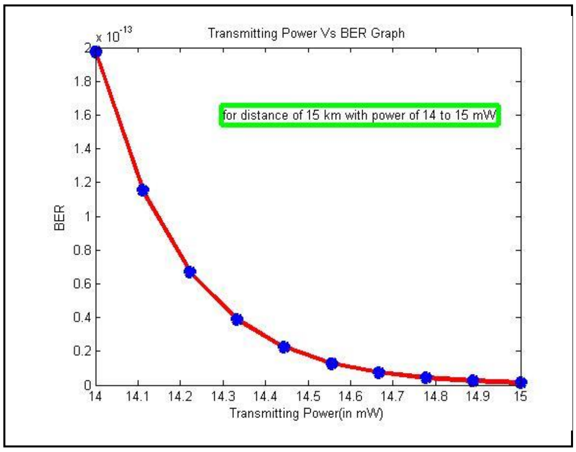
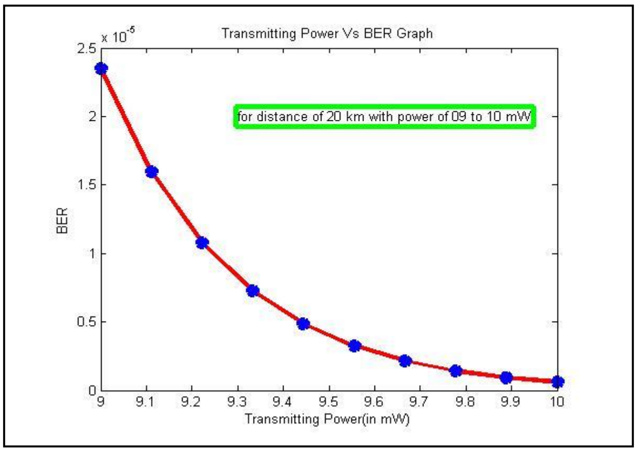
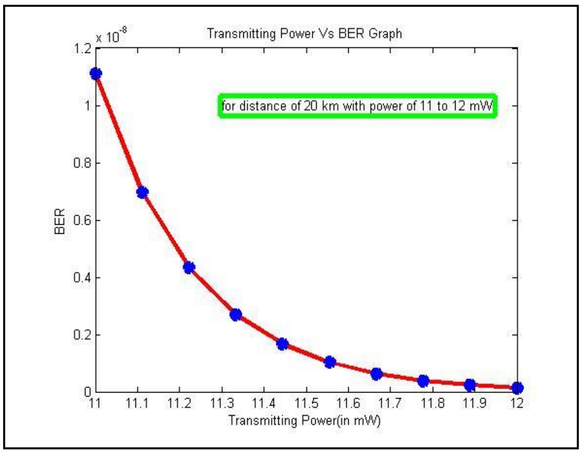



**Figure 6(d):** D= 15 km; Tx=14 to 15 mw




From the above six results (Figure 6(a) to 6(f)) of BER performance evaluation, this is evident that for longer distance (D) we need to employ more Transmission Power (Tx) to achieve lower BER figure. So by calculating the BER performance, the wavelength allocation may be done for the communicating line.

To serve the purpose of approximated cost calculation and concerned budget preparation, we have worked with some available data based on the network system of JIS Group, Kalyani campus and then compared the data with the results obtained from simulation. Some sample results are as follow in the Table 3.

Table 3: Cost Estimation comparison obtained from the proposed algorithm:

| **Path Type** | **Path Length (m)** | **Path Cost ( ₹ )** | **Remark** |
|---|---|---|---|
| Hand made | 485 | 7693 | The result obtained from simulation produce shorter path length and less path cost of deployment |
| Obtained from simulation | 328 | 6995 | |

## CONCLUSION

Here the proposed PON deployment planning algorithm are useful to generate a suboptimal point-to-multipoint network which connects every subscriber (ONU) with the Central Office (CO)s through different power splitter(s), when the locations of CO, subscribers, PSC locations, are defined. The optimal path would be shorter in length. From this simulation results, we become confirmed that here the proposed algorithm is well capable to design the sub-optimal PON system in terms of total optical fiber length short and this is also helpful to calculate the BER figure of the communicating path. This also helps to achieve the lowest average BER for any connecting path of the Passive Optical Network system. Further this also helps us to calculate the approximate cost of the route which would be helpful for preparation of budget to implement any new PON network.

## REFERENCES

1) Akira Agata, and Yukio Horiuchi “PON Network Designing Algorithm for Suboptimal Deployment of Optical Fiber Cabless,” Proc. of SPIE-OSA-IEEE Asia Communications and Photonics, SPIE Vol. 7633, 76330L, pp.1-6 (2009).
2) B. Lakic, M. Hajduczenia, H. da Silva and P. P. Monteiro1, “Using Adapted Visibility Graphs for Network Planning,” in Proc. IEEE Symposium on Computers and Communications 2008, (2008).
3) E. W. Dijkstra, "A note on two problems in connection with graphs," Numerische Mathematik, Vol. 1, pp. 269-271,(1959).
4) F. Aurenhammer, “Voronoi Diagrams - A Survey of a Fundamental Geometric Data Structure,” ACM Computing Surveys, Vol. 23, No. 3, pp.345-405, (1991).

5) J Pandit, S. K. Biswas, "Path Optimization and Cost Estimation using algorithm for sub optimal deployment of Passive Optical Network" presented at ICCECE International Conference, Kolkata (2017).
6) J. R. Shewchuk, "Tetrahedral Mesh Generation by Delaunay Refinement," In Proc. of the 14th Annual ACM Symposium on Computational Geometry, pp. 86-95, (1998).
7) K Satyanarayana, "Recent trends in future proof fiber access passive networks: GPON and WDM PON," 2014 International Conference on Recent Trends in Information Technology 10-12 April 2014
8) M. Abrams, P. C. Becker, Y. Fujimoto, V. O. Byrne, and D. Piehler, "FTTP Deployments in the United States and Japan – Equipment Choices and Service Provider Imperatives," IEEE Journal of Lightwave Technology, vol. 23, pp. 236-246, (2005).
9) M.J. Rattigan, M. Maier, and D. Jensen, "Graph Clustering with Network Structure Indices," in Proc. 24th Annual International Conference on Machine Learning (ICML'07), (2007).
10) S. K. Biswas, A. Podder, "Path Minimization Planning of Passive Optical Network using Algorithm for Sub-optimal Deployment of Passive Optical Network", International Research Journal of Engineering and Technology, Vol. 7, No. 9, pp.3484-3488 (September 2020).
11) S. K. Biswas, M. Chakraborty "Passive Optical Network Design with application of Path Minimization Planning and Novel Wavelength Allocation scheme based on Bit Error Rate (BER) Performance," International Journal of Engineering Research and Application, ISSN: 2248-9622, Vol. 10, Issue 10, (Series-IV) October 2020, pp. 08-14 (2020).
12) YU Nakyama & Ryoma Yasunaga, "ITU TWDM-PON module for ns-3," Wireless Networks 2020, Vol. 4, No. 5, pp.532-533 (May 2020).
13) Y Ji, J Zhang, X Wang, H Yu, "Towards converged, collaborative and co-automatic (3C)" Optical Networks Science, vol. 61, pp. 101-119, (2018).