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# Passive Optical Network Design with Application of Network Path Minimization Planning and Novel Wavelength Allocation Scheme based on Bit Error Rate (BER) Performance

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**ABSTRACT**
Passive Optical Network (PON) is an useful mode for modern communication technology which emphasize on faster, cheaper and more reliable communication system used as access network. PON communication system used to shares one optical fiber cable with multiple subscribers by using a power splitter connected with different Optical Network Unit (ONU) located to subscriber's premises. One of the main objectives of PON network planning is to determine the optical cable path with lower cost of deployment under practical restrictions. So here a plan is proposed to minimize the total path distance by avoiding the obstacle located in the path of the fiber and after the path is defined, the communication possibilities is verified by application of novel wavelength allocation (WA) schemes, where the goal is to improve the BER performance of all ONUs located at subscriber's premises. Finally this proposed planning will help to design cost saving sub optimal network deployment with better BER performance through the optimized network path.

**Keywords –** BER, Optimization, Passive Splitter Combiner (PSC), Path Minimization, Wavelength Allocation (WA)

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## I. INTRODUCTION

Passive optical networks (PON) may be deployed as access network and communicate between Central office (CO) and Optical Network Unit situated at subscriber's premises. While for last few decades access network has experienced little changes but in recent years, long-haul networks have been changed dramatically due to the emergence of wavelength division multiplexing (WDM) technologies. During this same time, local area networks (LANs) have scaled up in the speed from 10Mb/s to 100Mb/s, and subsequently to 1 GB/s. Even 10 GB/s Ethernet products have started to emerge. As a result, there is a growing gulf between high-capacity LANs and backbone networks with the low-speed access networks being the bottleneck. There is very urgent requirement for a technology to develop access networks that are inexpensive, simple, scalable, and capable of delivering integrated voice, data, and video services to the subscribers. Passive optical network (PON) is considered as an attractive solution for the access networks.

Till now little research has been performed on how to plan efficiently for PON distribution, which is very much essential for an economic PON deployment. PON deployment through an optimized shorter path causes economical savings. Here a PON designing algorithm is taken in count which automatically generates a suboptimal point- to-multipoint network that is used to connect every subscriber (ONU) to the respective CO through the power splitters with the total sum of the optical fiber length close to the possible shortest value.

Further when the deployment path is identified, there are possibilities where the shortest path connections are not possible due to the existence of certain obstacles on the path, which cannot be traversed at all (non-traversable obstacles). The said obstacles must therefore be taken into count when finding for an optimum path connecting two arbitrary points on a map. So by applying obstacle avoidance technique stated here, we may avoid the obstacle situated on the path of optical fiber and determine the probable shortest path through which the network fiber may be deployed. As Optical Fiber may be deployed using various topologies like ring topology, bus topology, tree topology etc, but practically for passive optical network, Tree Topology is widely used. So here our discussion is applicable for Tree Topology to connect the ONUs with CO through power splitters. A typical "tree-and-branch" PON contains three parts, optical line terminal (OLT), ONU, and remote node (RN), which resides between the OLT and

ONUs, and also referred to as the local exchange or CO. Wavelength-Division Multiplexing (WDM) is applied to exploit vast bandwidth capacity of fibers, the Arrayed-Waveguide Grating (AWG) is deployed in the RN, serving as a passive wavelength router. Power splitters could be placed after the AWG in RN, or it may be inserted in the drop section to increase the capacity by enabling the statistical sharing of bandwidth in single wavelength among multiple ONUs. For the PON system in general, the loss of power and inter-channel crosstalk characteristics of AWG at different channels (synonymous with wavelengths, with each channel/wavelength emerging from a unique AWG output port) experience different amount of signal attenuations, leading to different bit-error rate (BER) at the receiver end.

The central channel performs better than the side channels. On the other side, the difference of distance in the drop section varies significantly from ONU to ONU which could cause difference in received powers and to the BER too. A far-away located ONU may have worse BER figure than an ONU closer to the RN. An ONU-distance-aware (ODA) scheme will be effective to be used in the short-term scenario to achieve the lowest average BER. In this scheme, first we sort the ONUs according to their distance to RN, and then allocate wavelengths in the order of decreasing distance. Always allocating the best wavelength that is available to the ONU being considered; so an ONU could not be allocated a worse wavelength than that ONUs closer to the RN. The ODA scheme is also capable to balance the BER among ONUs and reduce the variance as it compensates the far-away ONUs with better wavelength channels. By verification of the BER performance of proposed path, the path will be finalized. If BER performance is good, it is all right to finalize the rout otherwise the path is rejected and new path need to be found.

## II. OPTIMIZATION PROCESS FOR OPTICAL PATH

2.1 Network Diagram using K-nearest neighbor algorithm

The K-nearest neighbor (KNN) algorithm is a powerful technique which is applicable to the algorithmic study of geometric problems [1]. Suppose that *N* number of points (*p1, p2,…, pN*), are randomly generated, in a two-dimensional plane to mark the ONU, located at the remote node, and if all the N points are allocated in the same plane along with *M* number of points indicating location of splitters (*s1, s2,..., sM*) and the position of CO is predetermined, such that each N will be connected with CO through their nearest M point by single fiber path and the Total Euclidean distance among each and every N points with CO becomes minimum, the result is partition of the plane into *M*-areas (where M<N). As we use tree topology, so in most of the case the position of the splitter will be located at almost the centre of each region. In nearest neighbor techniques variants for multi-label classification, regression, and semi supervised learning settings allow its application to the classification of remote nodes located at different distance over a two dimensional geometric plane.

2.2 Introduction to Classification and KNN Classifier

2.2.1 Classification

This is the problem to predict discrete class labels for unlabeled pattern or different remote nodes based on observations. Let $\{ (\mathbf{x}_1, y_1),\ldots, (\mathbf{x}_N, y_N)\}$ be the set of observations of *q*-dimensional patterns where

$\mathcal{X}=\{\mathbf{x}\}^N_{i=1} \square\ \mathbf{R_q}$ , and the corresponding set of labels or location of splitter are $\mathcal{Y}=\{\mathbf{y}_i\}^N_{i=1} \square\ \mathbf{R}_d$. The goal of classification is to calculate a functional model $\boldsymbol{f}$ that allows a reasonable prediction of class label $y'$ for an unknown pattern or distribution of remote nodes $\mathbf{x}'$. Remote Nodes without labels should be assigned to the labels.

2.2.2 KNN Classifier

Nearest neighbor classification which is also known as K-nearest neighbors (KNN), is based on the idea that the nearest patterns of remote node to a target pattern or the distribution of remote node **x'**, for which we seek the label, deliver useful label information. KNN assigns the class label of the majority of the K-nearest remote node in data. For this purpose, we have to be able to define a similarity measure in data space. In $R_q$, it is reasonable to employ the Minkowski metric (P-norm)

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

The Euclidean distance for $p = 2$. In the case of binary classification, the label set $\boldsymbol{Y} = \{1, -1\}$ 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 the neighborhood size *K*, *and* with the set of indices ***Nk* (x')** of the K-nearest patterns. The choice of *K* defines the *locality* of KNN.

2.3 The Proposed Algorithm

In many cases, both ends of every path where the optical fiber cable may be deployed are restricted by PSC location, existing network resources (trenches, aerial lines, etc.), and obstacles (both traversable: and non traversable like roads, green-field areas, etc.) Keeping this restriction under consideration, the network designer need to design the PON cable root plan with the objective that the sum of the optical fiber length should be as short as possible.

This problem can be modeled as a suboptimal network designing problem in a given graph *G (N, M)*. In this graph *G*, the set of nodes *N* and points of splitter *M* are used to represent the locations of ONU and splitters respectively. Moreover, the network planner has to consider the splitting ratio of the optical splitter $N_{splitter}$ and the maximum allowable length of an aerial lead-in line
$L_{max}$ that connects the optical splitter and subscriber. We are considering $L_{max}$ because good BER figure for better communication depends on length of the optical fiber. [4] Therefore, these parameters are also taken into count.
The input parameters of the proposed algorithm are listed in TABLE I

**TABLE 1:** Input parameters of proposed algorithm

| Parameter | Description |
|---|---|
| *G (N,M)* | Set of ONU points and set of probable location of splitters. |
| ***k*** | This number decides how many neighbors (where neighbors 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 neighbor 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 to avoid the obstacle (if any) situated in the path of the optical fiber deployment, which can be performed by following method

2.4 Obstacle avoidance

A large part of the practical network deployments need to be carried out in densely populated areas where the shortest path connections are not always possible due to the existence of certain obstacles, which cannot be traversed at all (non-traversable obstacles) or can be traversed but at a cost which is higher when compared with a standard deployment of a new optical fiber cable route. Now the said obstacles must to be taken into account when looking for an optimum path connecting two arbitrary points on a map. First, we need to build a networking map consisting different nodes. Now obstacles that may exist between any two points or more in the map. If there are obstacles obstructing the direct path connection between two points, we get those from the diagram and decide which will be bypassed and which will be traversed (Fig. 1). Next, we build a convex hull using Graham scan process containing vertices of the obstacles we chose to bypass and the points we want to connect (Fig. 2). We then choose the shorter of the paths along the convex hull shaped figure between the two points (Fig. 3).

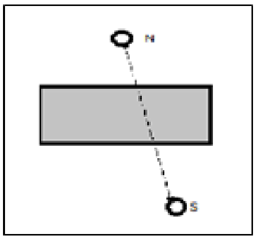


figure 1

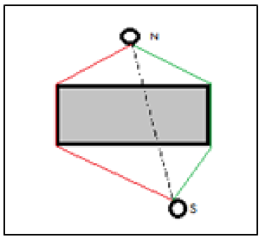


figure 2

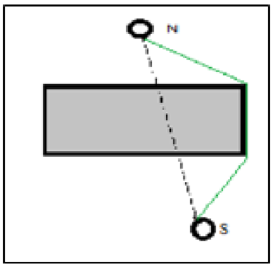


Figure 3

2.5 ONU-distance-aware (ODA) scheme

In this scheme, first need to sort the ONUs according to their distance to RN, and then allocate wavelengths in the order of decreasing distance. Always to allocate the best wavelength available for the ONU to be considered; so an ONU could not be allocated a worse wavelength than that ONUs closer to the RN. The ODA scheme is capable to balance the BER among ONUs and it helps to reduce the variance as it compensates the far-away ONUs with better wavelength channels. The BER performance of any channel depends on the signal power received in any port and the power received by any port may be calculated as:

$$P^i_{sig} = L_f \left(d_{feeder} + d^i_{drop}\right) L_p L_S G P_t \quad (1)$$

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 kilometer
$L_s$ 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:

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

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

Where $\sigma_{th}$ is noise variance due to thermal noise, and

$\sigma_{sh}$ is noise variance due to shot noise.

The decision threshold set at the receiver end is:

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

Where $R_\lambda$ is the photodetector responsivity $(R_\lambda = 0.8)$ and $\epsilon$ is the laser extinction ratio $(\epsilon = 0.1)$

The BER at the receiver end may be computed as follow:

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

So to obtain a suboptimal point to multipoint (P2mP) network which connects each subscriber's ONU to the corresponding OLT at CO with the total sum of optical fiber cable length close to the shortest path, the following process may be followed:

**Step 1:** Construct a network graph, with the assumption of the locations of ONU are random and that of the splitter and COs are fixed.

**Step 2:** Apply K-nearest neighbor algorithm where the shortest path distance of the ONU with the splitter is considered. In this process, the graph is separated into sub-graph(s), where each sub- graph is a set of remote nodes and location point of splitters. In most of the cases splitters are almost centrally located in a region.

**Step 3:** Calculate the shortest paths between the central office and every optical splitter in the sub-graph and determine the route to each splitter.

**Step 4:** Check the connecting shortest path and if any obstacle is there, the path may be modified by the process described in the section of obstacle avoidance, after which the probable shortest path is possible to determine.

**Step 5:** Check the BER performance through communicating path from CO to ONU, if BER performance is poor for any proposed path, allocate proper wavelength for communication through the allocated route.

**Step 6:** Further if the BER figure does not improve, then reject the route and proceed for the next possible route.

This will help to improve the BER performance of all ONUs, balancing their values by compensating for the far-away ONUs with better channel and by this we will obtain better communicating path with least expenses.

## III. SIMULATION RESULTS

To evaluate the feasibility of the proposed algorithm here, we conducted a numerical simulation. In this evaluation, we used a graph which is constructed with 30 randomly deployed remote nodes to approximate a network consisting of power splitters. Here in the simulation we used 4 locations for power splitters. As splitters are available in the ratio up to 1:32 even more, so the number of ONU connections from each splitter do not exceeds the higher limit of splitting ratio.

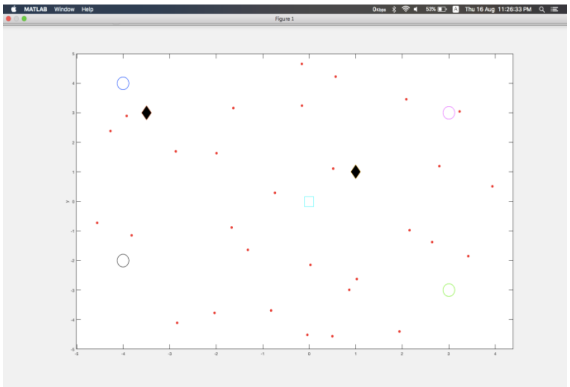
The graph is assumed to represent a set of paths where the optical fiber could be deployed. The input parameters used in the numerical simulation are listed here in Table 2.

**TABLE2**: Input parameters to the simulation.

| 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 10 square km. |
| *K* | 2 |
| $N_{splitter}$ | 32 |
| $L_{max}$ | 20 km. |

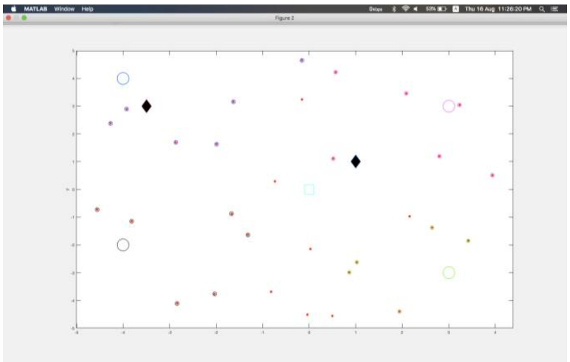
In this proposed algorithm, the path of optical fiber cables may be calculated, by applying the following steps -

First, we randomly placed nodes in the network as the location of the ONU in subscriber premises around a fixed CO, and the location of the splitters was placed around the CO. Two obstacles are also placed on the same plane. All plots were done on two dimensional planes. The given conditions are shown in Fig. 4(a).



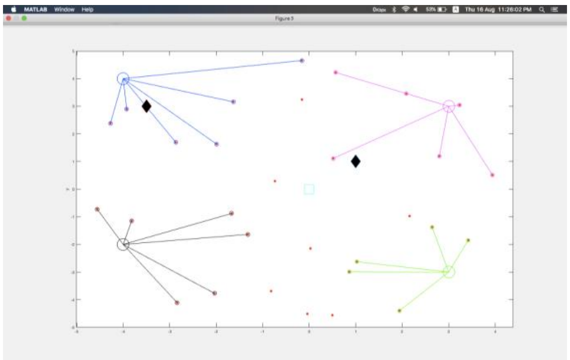
**f**igure 4(a)

Next, we applied the K-th nearest neighbor algorithm to the network, assuming each power splitter has subscriber around it. So, the graph is separated into the sub-graphs where each sub-graph is a set of ONUs and single splitter as the result is shown in Fig. 4(b) as follows



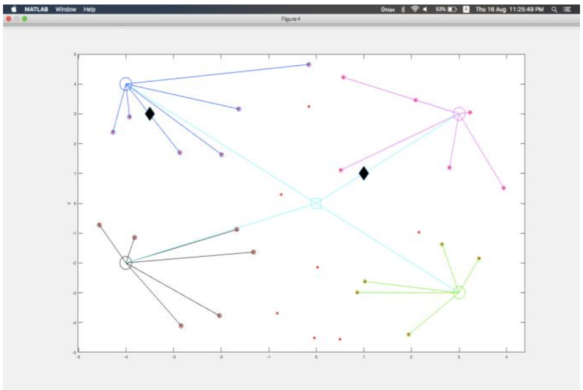
**f**igure 4(b)

Further the ONUs are connected with Optical Splitters which is shown in Fig. 4(c) as follows



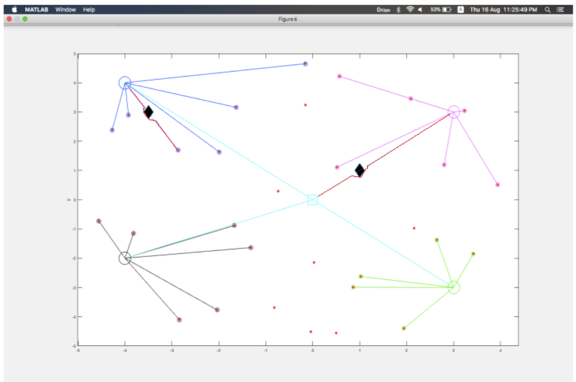
**f**igure 4(c)

Then by applying Step 3, the shortest paths between the central office and every optical splitter in the sub-graph are determined and connected with the CO, as shown in Fig. 4(d).



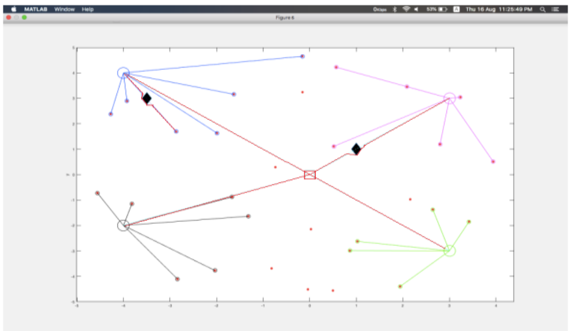
**f**igure 4(d)

For the purpose to reduce the complexity of the figure, different regions and optical splitters in sub-graph are shown by different colors. Now the obstacle avoidance process is being carried out which is shown in Fig. 4(e)



**f**igure 4(e)

It is clear that the route avoiding the obstacle is determined as shown in Fig. 4(f) as follows



**f**igure 4(f)

From this we may decide that the nodes exceeding maximum limit $L_{max}$ is not grouped or labeled under any splitter. Finally, the optical fiber route between the CO and most ONU is determined through the desired suboptimal way.

Now the BER calculation needs to be carried for each ONU to CO connection path. So here BER performance for upstream direction data flow is computed for different distance with different transmitting power vs BER. The results are:

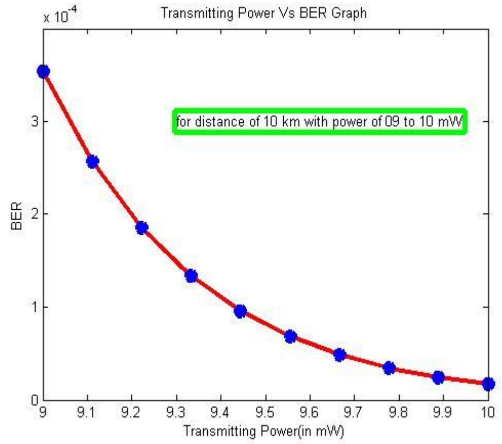



figure 5(a)**:** For 10 km distance with 09 to 10 mw transmitting power.

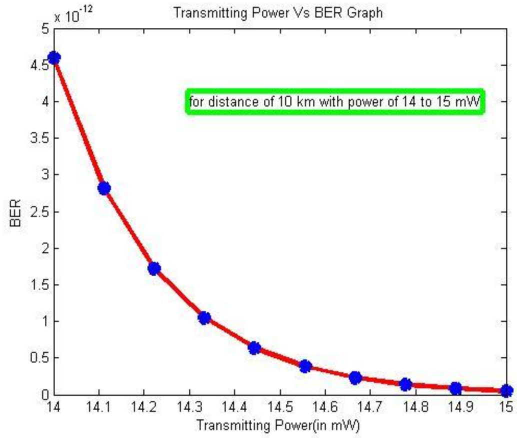



figure 5(b)**:** For 10 km distance with 14 to 15 mw transmitting power.

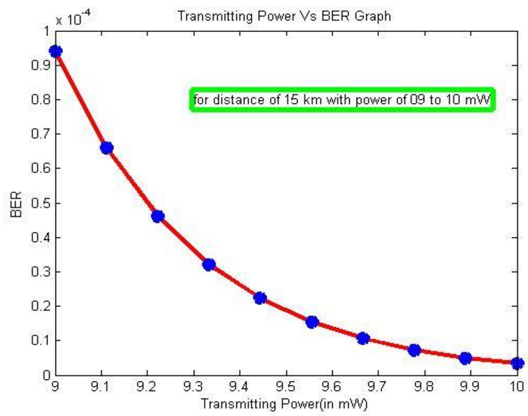



figure 5(c)**:** For 15 km distance with 09 to 10 mw transmitting power.

From the Fig. 5(a) it is clear that the BER value ranges between 1X $10^{-4}$ to 4X $10^{-4}$. Similarly for Fig. 5(b) BER value ranges between 0 to 4.5 X $10^{-4}$ and from Fig. 5(c) BER ranges between 0 to 0.9 X $10^{-4}$ which is good for communication

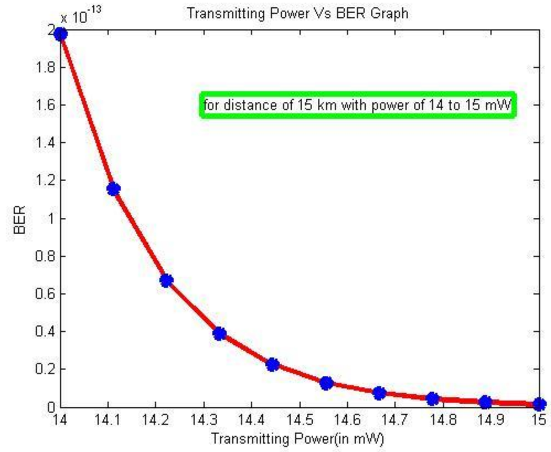



figure 5(d)**:** For 15 km distance with 14 to 15 mw transmitting power.

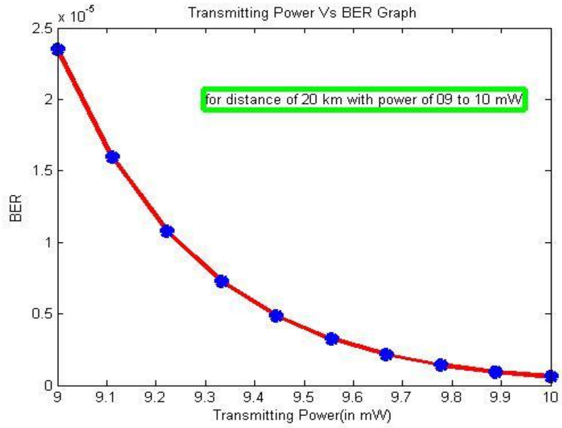



figure 5(e)**:** For 20 km distance with 09 to 10 mw transmitting power.

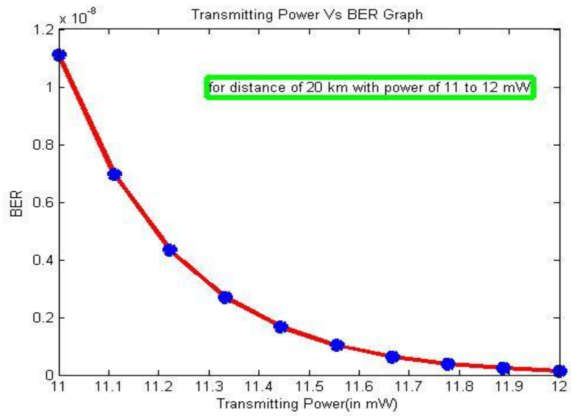



figure 5(f)**:** For 20 km distance with 11 to 12 mw transmitting power.

## IV. CONCLUSION

Here the proposed PON deployment planning algorithm helps to generate a suboptimal point-to-multipoint network that connects every subscriber (ONU) to the OLT(s) situated at the Central Office (CO)s through different power splitter(s), when the locations of OLT(s), subscribers, PSC locations, are provided. The path will be shorter in length. From results of the simulations, we become confirmed that the algorithm can design the suboptimal PON system in terms of total optical fiber length short and this is also helpful to calculate the BER figure of the communicating path. It also helps to achieve the lowest average BER for any connecting path of the Passive Optical Network system. Further this also helps us to understand the importance of ONU-distance –aware (ODA) scheme. Conservatively allocating the wavelengths according to the realistic BER goal, to the subscribers is the best scheme to serve the new customers.

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## 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]. F. Aurenhammer, “Voronoi Diagrams - A Survey of a Fundamental Geometric Data Structure,” ACM Computing Surveys, Vol. 23, No. 3, pp.345-405, (1991).

[4]. 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).

[5]. S. K. Biswas, A. Podder, “Path Minimization Planning of Passive Optical Network using Algorithm for Sub-optimal Deployment of Passive Optical Network” presented at IRJET Vol. 7, No. 9, pp.3484-3488 (September 2020).

[6]. J Pandit, S. K. Biswas, “Digital Image Transmission performance analysis through Passive Optical Network” presented at ICCECE International Conference, Kolkata (2016).

[7]. E. W. Dijkstra, "A note on two problems in connection with graphs," Numerische Mathematik, Vol. 1, pp. 269-271,(1959).

[8]. S. Garg and R. C. Jain, “Variation of k-mean Algorithm: A Study for High-Dimensional Large Data Set,” Information Technology Journal, Vol. 5, pp. 1132-1135, (2006).

[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]. J. R. Shewchuk, “Tetrahedral Mesh Generation by Delaunay Refinement,” In Proc. of the 14th Annual ACM Symposium on Computational Geometry, pp. 86-95, (1998).

[11]. N. Yoshimoto, "NTT’s Deployment of FTTH Services and Future Developments," presented at FTTH Council Conference, Las Vegas, NV, USA, (2005).

[12]. 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).

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