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Path Minimization Planning of Passive Optical Network using Algorithm for Sub-optimal Deployment of Optical Fiber Cable

S. K. Biswas[1], Amitava Podder [2]

[1]S. K. Biswas is working in the Department of Electronics & Telecommunication Engineering, JIS School of Polytechnic, Kalyani, Pin-741235, India

[2]Amitava Podder is working in the Department of Computer Science and Technology, JIS School of Polytechnic, Kalyani, Pin-741235, India,

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Abstract - *Passive Optical Network (PON) is an ultimate solution for the modern communication technology which emphasize on faster, cheaper and more reliable communication system used as access network. The broadband service providers across the globe needs to drive down the complexity of components, time of installation, required skill set for installation and maintenance requirement which ultimately reduces the cost of overall deployment for an access network structure. PON shares one optical fiber with multiple subscribers by using a power splitter connected with different Optical Network Unit (ONU) situated to subscriber's premises.*

One of the main objective of PON network planning is to determine the optical cable path of a point-to-multipoint network which connects every subscriber to the central offices (COs) through power splitter(s) within a lower cost of deployment under practical restrictions, such as possible fiber paths, the splitting ratio of optical splitters and locations of splitters, when the locations of COs and subscribers are given. So here a plan is proposed to minimize the total path distance by avoiding the obstacle in the path of the fiber. Finally the deployment cost will minimize where all ONUs are connected to a Central Office (CO) through their nearest power splitter.

Key Words: PON, Optimization, ONU, CO, Path Minimization, Remote Node (RN), Passive Splitter Combiner (PSC)

1. INTRODUCTION

Passive optical networks (PON) may be deployed in forms of Ethernet PONs, Gigabit-capable PONs (G-PON), or WDM PONs to work as access network and communicate between Central office and Optical Network Unit situated at subscriber's premises. For last few decades much research on PON has focused on dynamic bandwidth allocation (DBA) among ONUs and system up-gradation for wider coverage and higher bandwidth of PON. Nonetheless, little research has been performed on how to plan efficiently for PON distribution, which, however, is essential for an economic PON deployment. PON deployment through an optimized path cause 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 shortest value, when the locations of the central offices (COs), subscribers, locations to place optical splitter are already known. So we use one graph related algorithm as key elemental techniques which is useful as construction method of a network graph close to the shortest path. This technique is useful to find out new optical cable route for the new customers. 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 on the path of optical fiber and finalize the probable shortest path through which the fiber may be deployed. 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 in this paper our discussion is applicable for Tree Topology to connect the ONUs with CO through power splitters.

2. OPTIMIZATION PROCESS FOR OPTICAL PATH

2.1 Network Diagram using K-nearest neighbor algorithm

The K-nearest neighbor (KNN) algorithm is a powerful tool which is essential to the algorithmic study of geometric problems [1]. Suppose that *N* points (*p1, p2,..., pN*), which is randomly generated, in a two-dimensional plane to mark the ONU, located at remote node, and if all the N points are allocated in the same plane along with *M* points which indicate location of splitters (*s1, s2,..., sM*) and the position of CO is predefined, 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 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 $X=\{x\}^N_{i=1}$ □ R_q, and the corresponding set of labels or location of splitter $Y=\{y_i\}^N_{i=1}$ □ R_d. The goal in classification is to calculate a functional model $\boldsymbol{f}$ *that* allows a reasonable prediction of class label $\boldsymbol{y}'$ for an unknown pattern or distribution of remote nodes $\mathbf{x}'$. Remote Nodes without labels should be assigned to 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 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 sake, 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)

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

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

$$\boldsymbol{f}_{KNN}(x') = +1 \text{ if } \sum_{i \in NK(X')} Yi \geq 0; \text{ otherwise -}$$
$$\boldsymbol{f}_{KNN}(x') = -1 \text{ if } \sum_{i \in NK(X')} Yi \leq 0 \quad (2)$$

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 placed are restricted by PSC location, existing network resources (trenches, aerial lines, etc.), obstacles (both traversable: roads, green-field areas, etc. Keeping this restriction under consideration, the network designer has to design the PON ODN plant with keeping the sum of the optical fiber length 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 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 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 share 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 containing different nodes. Now obstacles may exist there between any two points or more in the map. If there are obstacles obstructing the direct path 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).

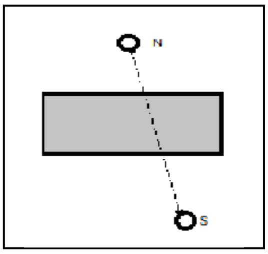

Fig. 1

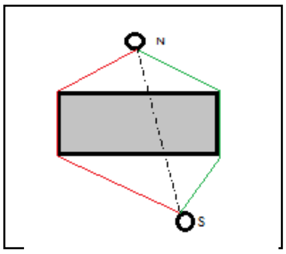

Fig. 2

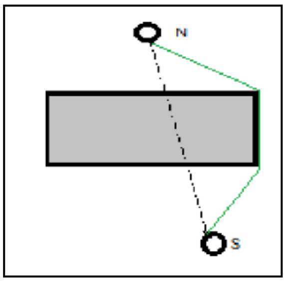

Fig. 3

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 communicating path from CO to ONU, if length of any rout exceeds maximum length limit, reject the route.

3. SIMULATION RESULTS

To purpose 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.

Table -2: Sample Table format

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}	2 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 plane. The given conditions are shown in Fig. 4(a).

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

Here each sub-graph is a set of ONUs and single splitter. Further ONUs are connected with Optical Splitters which is shown in Fig. 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, which is shown in Fig. 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.

In Fig. 4(e), the obstacle avoidance process is being carried out.

From Fig. 4(f) it is clear that the route avoiding the obstacle is determined and 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.

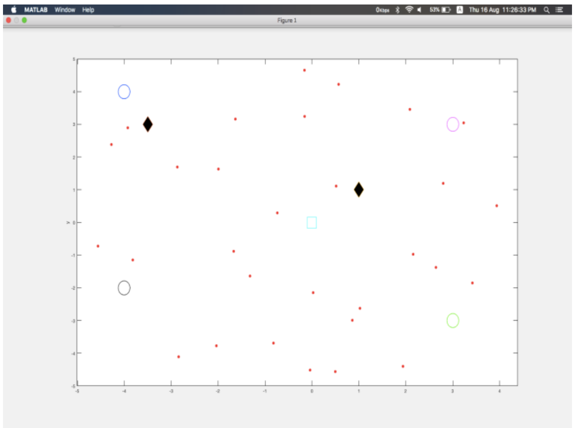

Fig. 4(a)

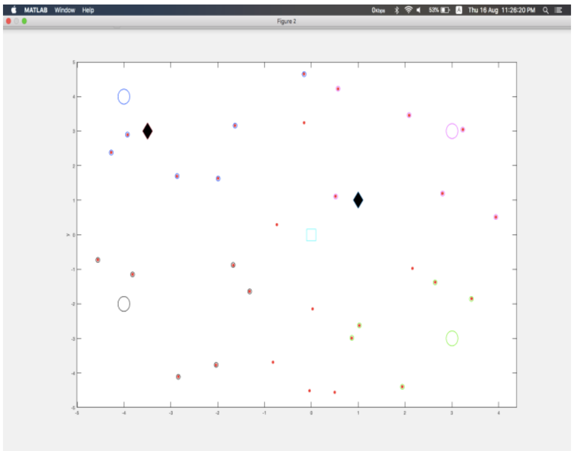

Fig. 4(b)

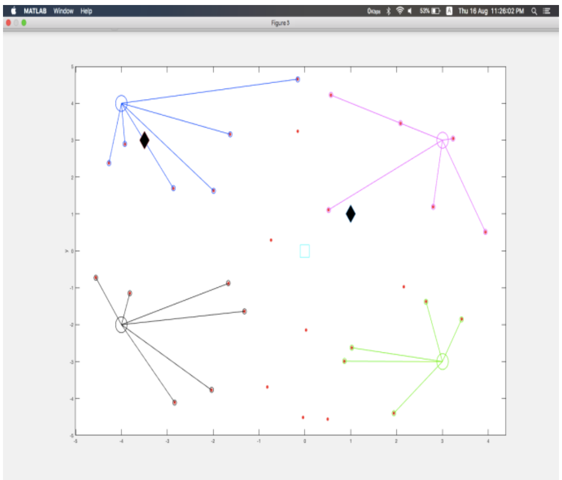

Fig. 4(c)

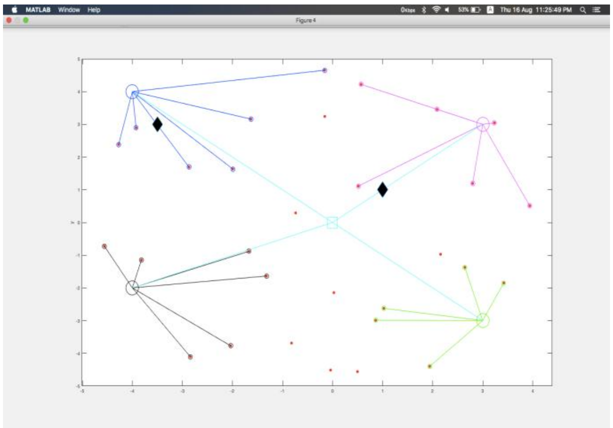

Fig. 4(d)

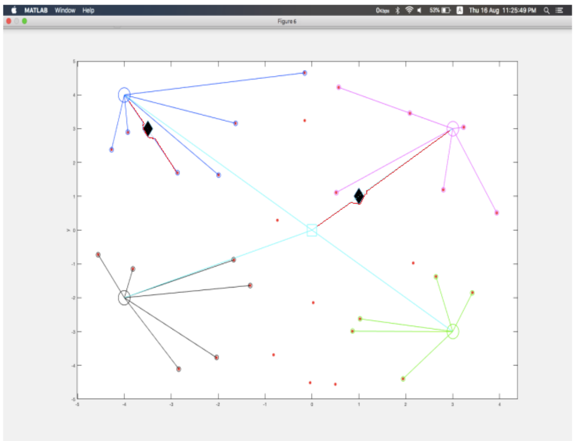

Fig. 4(e)

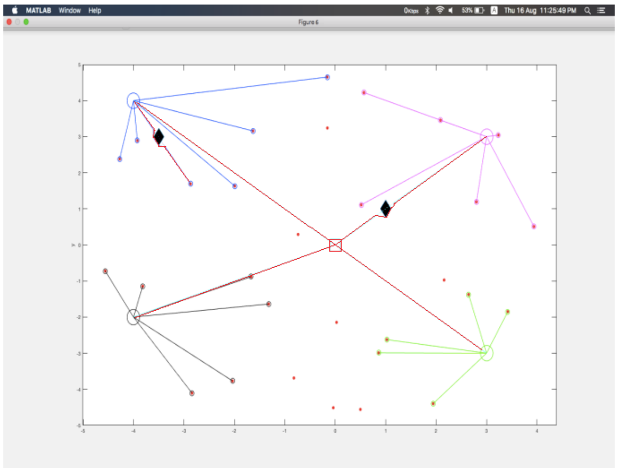

Fig. 4(f)

Fig. 4 Designing process of passive optical network: (a) Locations of Remote Nodes, Splitters and COs are provided with obstacle position, (b) Prepare the sub graphs by KNN technique, (c) Connects ONUs with the optical splitters, (d) Connect the path to deploy OFC between CO and optical splitters. (e) Avoidance of restriction by obstacle, (f) Obstacle avoidance and finalization of suboptimal path for optical fiber cable deployment.

4. 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 splitting ratio of the optical splitter and the maximum allowable length of an optical drop cable that connects the optical splitter and subscriber are also considered under this calculation. From results of the simulations, we become confirmed that the algorithm can design the suboptimal PON system in terms of total optical fiber length and this is also helpful to calculate the deployment cost of the PON system which will be the optimized cost of network deployment.

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BIOGRAPHIES

First Author

Mr Satyaki Kumar Biswas presently working as Head Of the Department (HOD) in the Department of Electronics & Telecommunication Engineering (ETCE) Department, at the JIS School of Polytechnic, Kalyani, Pin: 741235. He completed his M Tech from IIT Kharagpur in the year 2014 and cleared UGC NET in the year 2015.

Second Author

Mr Amitava Podder presently working as Assistant Professor in the Department of Computer Science and Technology (CST), at the JIS School of Polytechnic, Kalyani, Pin: 741235
He completed his M Tech degree from the Kalyani Government Engineering College in the year 2017.