Planning for Passive Optical Network Deployment with K-means Clustering-based Approach

Hao Chen, Yongcheng Li, Gangxiang Shen*
School of Electronic and Information Engineering, Soochow University, Suzhou, Jiangsu Province, P. R. China
*Tel: (86) 512 65221537, e-mail: shengx@suda.edu.cn

Abstract: We propose a K-means clustering-based approach to plan for the deployment of greenfield passive optical networks (PON) aiming to minimize the total deployment cost. Studies show that the proposed approach is effective to significantly reduce the deployment cost compared to a benchmark random-cut approach.

OCIS codes: (060.4250) Networks; (060.4258) Networks, network topology; (060.4256) Networks, network optimization;

1. Introduction
The past several years have witnessed the wide deployment of FTTx around the world due to its inherent advantages of super-high bandwidth, low cost, anti-interference, etc. [1-3]. Since there will be an enormous increase in the number of new FTTx customers in the forthcoming years, it is vital to have an economic PON deployment so as to minimize the total deployment cost. Different algorithms have been proposed to reduce the total deployment cost of PONs [2][4-6]. In this paper, we propose a new K-means clustering-based PON planning algorithm which can realize more efficient designs in terms of total cost than the other approaches in the literature. The algorithm decides an optimal location for each optical splitter in order for the lowest cost of trenching and laying fibers. Moreover, for the purpose of more efficient use of fiber cable conduits, we also propose to allow multiple feeder fibers to share common conduits, which can further decrease the total deployment cost. The simulation study shows that the proposed approach is effective to significantly cut down the total deployment cost compared to a benchmark scheme based on the random-cut strategy in [2].

2. Problem definition

Table I Considered Networks (SR: split ratio)

<table>
<thead>
<tr>
<th>Net</th>
<th>#ONUs</th>
<th>#COs</th>
<th>Max. SR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>146</td>
<td>1</td>
<td>1:16</td>
</tr>
<tr>
<td>Case 2</td>
<td>193</td>
<td>1</td>
<td>1:16</td>
</tr>
<tr>
<td>Case 3</td>
<td>200</td>
<td>1</td>
<td>1:16</td>
</tr>
</tbody>
</table>

Figure 1 illustrates an example of PONs, which consists of disperse optical network units (ONUs) and a central office (CO). Each ONU can be located at a home or connected to a wireless base station (BS) if the PON system is used to function as a wireless network backhaul. The CO accommodates multiple optical line terminals (OLTs) which are connected to ONUs through optical distributed networks (ODNs). Each PON has a limited optical split ratio (SR) which constrains the maximal number ONUs connected to a common PON. Our objective for PON deployment is to minimize its total cost which is composed of various sub-costs, including (i) the system cost of PON, such as the costs of OLTs and optical splitters, (ii) the labor cost for trenching and laying fibers, and (iii) the cost of fiber cables. In general, the cost of trenching and laying fibers is dominant in the whole deployment process. Thus, our approach will put more effort on minimizing its cost. Meantime, because the cost of trenching and laying fibers is much more relevant to the distances of feeder and distribution fibers, the objective of the presented approach is to minimize the total distance of trenching and laying fibers. The constraints of this planning problem mainly include the split ratio of each PON system, the maximal coverage of a PON, and the maximal differential...
distance of a PON. Typically, the split ratio ranges from 1:4, 1:8, 1:16, 1:32, 1:64, to up to 1:1024. The maximal coverage of a PON is the maximal transmission distance between an OLT and an ONU and the maximal differential distance of a PON is the maximal differential distance between different ONUs and a common OLT within the same PON. However, with the availability of long-reach PONs today, we only consider the constraint of split ratio in this study. The solution to the optimization problem includes a total number of required optical splitters, the splitter locations, and the association relationship between each ONU and the splitters.

3. K-means clustering-based approach
The optimization problem may be decomposed into two subproblems, i.e., (i) clustering ONUs, which determines which groups of ONUs should be connected to common splitters, and (ii) determining the locations of splitters. We term subproblem (i) allocation subproblem and subproblem (ii) location subproblem. We extend the K-means clustering approach [7] to solve the above problem. The K-means clustering approach is a method of partitioning n points (i.e., ONUs) into k clusters (i.e., PONs) \( (k \leq n) \) so that in each of the clusters the sum of square of the distance between each point and the cluster centroid is minimum. Fig. 2 illustrates an example of clustering 10 points into 2 clusters. The first cluster contains 6 points and the second one contains the remaining points. The cluster centroids are highlighted with a star in Fig. 2. In virtue of the K-means clustering approach, we can guarantee that the sum of square of the distance between each point and the cluster centroid is minimum. However, in the context of PON deployment, because we aim to minimize the sum of the distances between a splitter and each ONU within a cluster, the centroids found by the K-means clustering approach are not optimal to function as the splitter locations. Rather, we need to find a new location for each splitter using Weiszfeld algorithm [2] which can guarantee to minimize the total distance. In Fig. 2, we highlight the centroid locations obtained by Weiszfeld algorithm with a triangle. Obviously the centroids of the two approaches are different.

![Flowchart of extended K-means clustering-based algorithm](image1)

![A deployment scenario with 193 ONUs and one CO](image2)

Figure 3 shows the flowchart of the above extended K-means clustering-based approach. Specifically, in step 1, we input the location information of each ONU and a CO and assume the maximum optical split ratio to be \( R_s \), which is 1:16 in this study. In step 2, we decide the best \( K \) clusters for the ONUs using the K-means clustering algorithm. In detail, we keep on trying different values of \( K \) from a small to a large one until we see that further increase of \( K \) will not lead to improvement of the criterion that measures clustering. However, due to the page limit, we do not provide more detailed sub-steps here. For each of the clusters obtained in step 2, we check if the number of ONUs \( N_i \) in the cluster is no greater than \( R_s \) (i.e., the ONUs can be accommodated within a single PON). If so, we move to the next step; otherwise, we will further divide the ONUs within the cluster into \( \lfloor N_i/R_s \rfloor \) sub-clusters (i.e., step 4) again using the K-means clustering algorithm. Once the number of ONUs in each cluster or sub-cluster is no greater than \( R_s \), we employ Weiszfeld algorithm to find the splitter location for each of them (i.e., step 5). Next we place the splitters and connect each ONU to its associated splitter and connect each of the splitters back to the CO. We finally find the total distance of feeder fibers and distribution fibers to figure out the cost of trenching and laying fibers. Based on the number of clusters or sub-clusters, we can also find the total cost of PON systems, including the number of OLTs and splitters. As a result, the total deployment cost can be calculated.

4. Cable conduit sharing
Figure 4 shows a deployment scenario with 193 ONUs and one CO connected through optical splitters by means of the extended K-means clustering-based algorithm. The feeder fibers between the CO and optical splitters are represented by thin lines. These feeder fibers can share to use a common cable conduit. For example, for splitters B, C, and D, we may use a common conduit as shown as a pipe to accommodate the feeder fibers. This can reduce the
cost of trenching and laying fibers. Thus, based on the design of the K-means clustering algorithm, we further consider the opportunity of feeder fiber conduit sharing. In this regard, for each of the K clusters found in step 2 in which there can be multiple splitters, we keep on applying Weiszfeld algorithm to decide the location for the far end location of a cable conduit from the CO given the locations of optical splitters and the CO. Specifically, we need to minimize the sum of the length of the shared conduit and the distances from the conduit far end to each of the splitters so as to minimize the cost of trenching and laying feeder fibers.

5. Results and discussions

To evaluate the performance of the proposed K-means clustering-based algorithm and cable conduit sharing scheme, we consider three deployment cases as described in Table I, in which the total numbers of ONUs are given. For performance comparison, we also implemented the benchmark random-cut sectoring approach in [2]. Taking the impact of the randomness of initial cut on the deployment cost into account, we evaluated the performance of the random-cut approach with ten different initial cuts. The assumption on the deployment cost of each sub-component is as follows: the cost of trenching and laying fiber is $16,000/km, the cost of fiber cable is $4,000/km, and the cost of each OLT is $2,500, and each splitter port cost is $100. Without losing generality of our planning approach, the sub-costs can be changed depending on different situations.

![Figure 5. Total deployment costs of different approaches](image1)

![Figure 6. Percentage distribution of major cost components](image2)

![Figure 7. Cost of trenching and layering fibers](image3)

Figure 5 shows the total deployment costs of the three different approaches, including (1) random-cut sectoring (“RandomCut” in legend), (2) K-means clustering (“K-means” in legend), and (3) K-means clustering with shared conduit (“K-means+S” in legend). For the random-cut sectoring algorithm, we show all the results for the ten random initial cuts, among which there are maximum, minimum, and average cost. It is clear to see that the proposed K-means clustering approaches can achieve much better performance to reduce the total deployment cost over 50% compared to the random-cut approach. In addition, the effort of cable conduit sharing is effective to further decrease the total deployment cost compared to the case without conduit sharing. For the K-means clustering approaches, Fig. 6 shows the distribution of different cost components. Apparently the cost of trenching and laying fiber is dominant to occupy about 80%, the fiber cable cost ranks the second to occupy about 20%, while the costs of OLTs and splitters are ignorable to be less than 1%. Also, comparing the cases of cable conduit sharing and non-sharing, we note that the effort of sharing is effective to lessen up to 25% trenching and laying cost of feeder fibers as shown in Fig. 7.

6. Conclusion

We proposed a novel K-means clustering-based approach for greenfield PON deployment and also considered sharing of cable conduits among feeder fibers to further decrease the cost of trenching and laying fibers. Simulation studies showed that compared to the benchmark random-cut sectoring solution, the proposed K-means clustering approaches are effective to significantly reduce the total deployment cost up to 50%. It was also found that the effort of conduit sharing is effective to further decrease the total deployment cost.

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References