OPTIMIZING OF PASSIVE OPTICAL NETWORK DEPLOYMENT USING ALGORITHM WITH METRICS

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Abstract. *Various approaches and methods are used for designing of optimum deployment of Passive Optical Networks (PON) according to selected optimization criteria, such as optimal trenching distance, endpoint attenuation and overall installed fibre length. This article describes the ideas and possibilities for an algorithm with the application of graph algorithms for finding the shortest path from Optical Line Termination to Optical Network Terminal unit. This algorithm uses a combination of different methods for generating of an optimal metric, thus creating the optimized tree topology mainly focused on summary trenching distance. Furthermore, it deals with algorithms for finding an optimal placement of optical splitter with the help of K-Means clustering method and hierarchical clustering technique. The results of the proposed algorithm are compared with existing methods.*

Keywords

Clustering, graph algorithms, optical splitter placement, PON topology.

1. Introduction

THE deployment of passive optical network (PON) topologies is a very discussed problematic and there are many existing solutions discussed and presented in numerous research articles and white papers, e.g. [1] and [2]. Nevertheless, this paper presents an innovative approach to algorithmic designing of optimum PONs, which uses metrics to parametrize and quantify optimization criteria. These are further used in developed algorithm to find an optimum PON deployment solution according to these optimization requirements.

During designing of the passive optical networks, several specifics must be taken into consideration, because they are intended as passive networks and no active elements are used in the path between the Optical Line Termination (OLT) and Optical Network Terminal (ONT) [3]. The only elements used for splitting of optical signals in today's passive optical networks are passive splitters, which needs to be used to create a tree topology and its branching in a passive Optical Distribution Network (ODN). Moreover, because a passive splitter splits power into its output ports, adequate attenuation is created during this operation. Because of the attenuation, certain power limits are needed to be met for the summary attenuation of a whole passive optical network [4] and [5]. Therefore, a PON needs to be designed and deployed in a specific way compared to the standard optical networks [4]. Another typical problem of designing of passive optical network is excessive cost of deployment of ODN and especially of its optical fibers. Due to that various techniques for optimization of summary trenching distance as well as overall length of optical fibers are used in practice, which results in minimization of overall CAPital EXpenditures (CAPEX) of a designed PON [6]. However, on the other hand, optical fibers and components of PONs can be placed and installed typically only in specific locations [7]. For example, in towns, cities and suburbs, the optical fibers are typically installed under or along roads, pavements or in drains (MCS Drain) [8]. This significantly limits the possibilities of optical fibers installation and must be included in the designing of PONs topologies. Therefore, the optimum planning and designing of ODN is a very important task, which needs to be addressed properly [9].

The main contribution of this work is that it combines distinctly designed metrics to quantify network parameters and to use them to create optimum PON in a small residential area. Moreover, this paper uses real map data of area Zahradni Mesto in Prague and uses realistic network of roads in this area in order to obtain realistic network design. This article is trying to solve this subject with Dijkstra's shortest path algorithm together with the application of various metric methods. Distinct types of metrics and optimization criteria are used to identify the optimum PON tree topology and to compare the effectivity of each solution. These criteria are mostly based on approach further defined in Sec. 2.

- Minimum trenching distance.
- Endpoint attenuation.
- Minimum summary length of optical fibers.

For calculating of the summary deployed length of fibers and summary trenching length of a passive optical network and its topology, this paper introduces an algorithm based on Dijkstra's algorithm. Dijkstra's algorithm for finding the shortest path is used in many applications today [10]. This article deals with small and medium tree topologies of PONs, which could be deployed in small residential towns and suburbs. Additionally, this paper is focused exclusively only on the ODN solution of PON. Therefore, it does not take into account any backbone network between OLTs. All calculations performed within this article assumes the existence of a backbone optical network and that it connects all OLTs.

The attenuation is a major issue in optimal deployment of a passive optical network and should not be missed in optimization of PON. The greatest influence on attenuation in this case always has an optical splitter [11]. With higher splitting ratios, the attenuation between OLT and endpoint ONT gets higher. For purposes of this study, the following splitting ratios were used 1:16, 1:32 or 1:64 according to a number of ONTs that are connected to each splitter. For correct function of the passive ODN, the attenuation and power limits must meet strict criteria [11].

Before any calculations and simulations can be performed, valid and realistic data are required to be obtained. Since all simulations and calculations are performed in Matlab environment, the data in a form of maps and GPS positions were obtained from OpenStreetMaps.org and were imported to Matlab environment for further simulations. Next, further processing was performed using proposed functions and algorithms in Matlab and by creating own algorithms for finding optimum and minimum tree and the shortest path in a graph based on identified optimization criteria. After finding the shortest path and minimal tree, the process of finding the metric and criteria for optimal deployment of an optical distribution network was implemented. Finally, algorithms and methods were implemented for calculating summary trenching distance and length of fibers of a passive optical distribution network. The presented solution was also compared with existing solutions.

The rest of this paper is organized as follows; a short review of existing methods and approaches for finding optimum PON topology is given in the following section, while the description of the proposed technique is presented in Sec. 2. Section 3. contains an illustration of results based on the presented technique together with short discussion, while a conclusion is given in Sec. 4.

1.1. Existing Solutions and Related Research

Since this topic belongs to one of the most important topics of PONs today, there are numerous existing solutions and proposals based on various techniques and methods. Summary trenching distance and the length of installed fibers is affected by splitter placement [12] and different methods of calculating the optimum splitter placement are proposed in this article. Optimal placement of optical splitters is discussed in many studies and many methods have been already introduced in those studies. These techniques mostly use various clustering techniques with the help of methods such as Genetic algorithms or Ant Colony algorithm, as can be found in [13], [14] and [15]. Neither Genetic algorithm nor Ant Colony algorithm is used for purposes of this paper.

In [16], authors propose the heuristic method for optimization of passive optical network with use of minimum spanning tree. Moreover, to shorten the computation time they divide large scenarios into smaller ones. The solution described in [17] is similar to the hierarchical clustering splitter technique presented within this article. In [17], all end-users are separated into clusters first, then the clusters are connected to OLT using splitters. However, the criteria for the network optimization are quite different compared to the solution presented in this article, as the technique described in [17] is focused especially on the cost of equipment and fibers. Another paper, which deals with the optimization of PON deployment, is [18]. Here, the hierarchical cascading technique of passive splitters is presented. Contrary to this method, the proposed solution uses cascading of splitters based on metric optimization criteria. The completely different approach of designing optimum PON topologies is presented in [19], in which the solution uses Genetic algorithm for optimizing any PON topology including simple tree access networks. In [20], an algorithm similar to designed methodology was introduced. However, in this paper different criteria, metrics and clustering technique was used. The solution proposed in [20] is complex and its computational demands are very high.

Compared to the existing solutions and approaches described in previous papers, the method for finding optimum splitter placement presented within this paper combines two basic approaches. The first one is basic K-Means algorithm [21] and the second one is complete-linkage hierarchal clustering [22]. Both are used for cluster analysis of ONT units and to choose optimum location of an optical splitter. Moreover, based on these approaches, further calculations of trenching distances and summary length of optical fibers are performed as well.

2. Proposed Metric Clustering Technique

In this chapter, the principles of the proposed method and steps that were performed and used during simulations and calculations are discussed and described. The paper is focused on optimization of passive ODN using quantification of optimization criteria such as trenching distance, fiber length, endpoint attenuation, etc. Normally, this ODN typically contains passive optical splitters, optical fibers, connectors, splices and other passive components and its main purpose is to connect central OLT unit and all ONT units located at its endpoints. First, a brief description of obtaining necessary topology data is given in Subsec. 2.1. , while metric calculations and techniques used for clustering algorithms are presented in Subsec. 2.2. In the following section Subsec. 2.3. , an algorithm to calculate trenching distances and installation length of optical fibers is introduced. The last section Subsec. 2.4. contains the description of proposed clustering methods.

2.1. Topology Analysis

This section contains the description of the process, how the raw data obtained from OpenStreetMaps were initially processed into Matlab. Next, data were further modified and the tree topology was calculated with usage of metric algorithm based on distances in a graph.

From the raw data in XML, data were filtered to the point, in which remained only residential buildings and highways or roads. Highways, roads and paths were used as potential paths in a graph, which can be only used for connecting the nodes and creating PON networks. Buildings are simply represented as single points, which serve as potential locations for OLT or ONT units. For more information on data mining from OpenStreetMaps see [22]. Figure 1 contains the illustration of an example obtained from a map dataset. In an extracted dataset, one building was chosen as a location of an OLT and 40 buildings were chosen as locations for ONTs. All these locations were chosen randomly, just to simulate a situation of a topology in the given area. To illustrate the potential of designed and presented techniques and algorithms and to compare the results obtained by different metrics, all PONs in this article always contain exactly 40 ONTs. However, the algorithms were, of course, tested with random numbers of ONTs as well. The location of OLT, as well as all ONTs, were chosen randomly since the proposed algorithm does not take into account any backbone networks used for connecting OLT. Therefore, there are no limitations used for OLT locations. Next, the process continues with the identification of the closest node of a highway or road in a graph, which is then selected as a starting OLT and ONT point during pathfinding. An example of obtained map data is illustrated in Fig. 1.

Fig. 1: Example data - circles represent buildings and lines represent highway and roads.

The topology itself is then created by finding the shortest paths from OLT to each ONT unit with using Dijkstra's algorithm. This results in 40 separate routes from OLT to all ONTs, these routes are later modified with metric recalculation and it also serves for following optimization based on the proposed metric algorithms focused on optimizing of total trenching distances and installation length of optical fibers as well as endpoint attenuation. The optimum locations of passive splitters are then calculated using K-Means algorithm as well as complete-linkage hierarchal clustering technique. Based on this result, final optimum network design is performed.

2.2. Initial Metric Calculations of Minimum Distances

All calculations performed within this chapter are based on a simplification that only a single-fiber cables are used. No multi-fibers cables are used, therefore each path consists of a separate fiber. This issue will be further evaluated and dealt with in the future research.

In this section, several types of metrics used in topology calculation are introduced in order to quantify criteria typically used to optimize the CAPEX of resulting PON. These metrics are used to parametrize the road and highway network so the Dijkstra's algorithm finds an optimum topology according to the following optimization criteria. These criteria for evaluating metrics include following:

- Total trenching distance - the summary distance of installation of all optical fibers in PON (conventional fiber network construction methods, including excavation work and deploying of fibers).
- Endpoint attenuation - the total attenuation of the entire path between OLT and each ONT unit in PON.
- Summary length of installed optical fibers - the summary length of all optical fibers installed in given PON.

Following metric descriptions are based on minimizing the first criteria, the total trenching distance of a topology. For purposes of this paper, several metrics were designed to further optimization process based on:

- Simple distance approach - meter metric.
- Distance from the centroid of a cluster.
- Iterated metric.
- Metric created by joining previous metrics.

All generated metrics are used together for Dijkstra's algorithm calculation of minimal tree. For demonstrative purposes, the following metrics are shown in a scenario, in which the PON topology contains one splitter placed in a location of an OLT unit.

The first method of generating metric is very simple; it is based only on the calculating distance between each neighboring vertex measured in meters. Because this metric is used with other methods or used during generating metrics based on other methods, it will not be demonstrated here alone.

The second method of metric calculation is based on calculating distance from the centroid of a cluster. First, a position of the centroid of all nodes of the highway and road network in a graph is calculated. Next, a distance between each node and this centroid is calculated. Then the distances from the centroid to two vertices bound by graph edges are compared and a longer distance is assigned as a weight to this edge. For example, if the distance between one of two neighboring vertices from the centroid is 30 meters, while the distance from the second one is 31 meters, then the weight of an edge between these two vertices is 31. The application of this metric results in routes mostly passing through the same edges around the mean center of the topology. This can be positive if targeted ONTs are evenly distributed around the centroid. If the ONTs are in one half of a graph, the summary length of all paths of a network can be longer than previous simple meter based metric. Furthermore, this would force Dijkstra's algorithm to create branching from the position of the calculated mean central position. This metric would often create more than one route and with the help of iterated metric, it can achieve much better results, especially when focused on minimizing the summary trenching distance. Next illustration in Fig. 2 uses solely this metric.

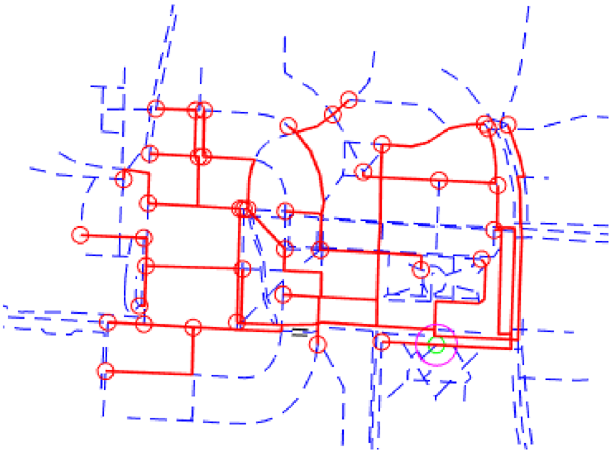


Fig. 2: A minimum topology obtained by centroid based metric.

The red lines in Fig. 2 represent the optical fibers and red circles illustrate the locations of ONT units. The black square shows the location of OLT unit. Note that all paths are passing near the centroid of a graph.

The third method of iterated metric uses an iterated subtraction of metric based on the distance between edges in meters. At first, the first method (simple meter metric) is processed with usage of Dijkstra's algorithm. Then, weight on each edge is reduced by number X (weight-X). This subtraction is repeated defined number of times (iterations). The weight is not subtracted if it reaches value 1 or less. It is set directly to a number 1, because the value less than 1 means that the two vertices are disconnected. Value X represents a metric variable and depends on the number of routes passing through this particular edge. The formula for calculating X is following:

$$X = d \cdot \operatorname{round}\left(\frac{c}{1+a}\right) - b. \tag{1}$$

The numbers a and b are variables used to identify the optimum number of subtractions of the weight of an edge for further description of the distribution of ONT locations within the topology and throughout simulations, the most frequently used values are $a = 2$ and $b = 1$. Variable c represents a count of routes that are passing through an edge. Finally, the parameter d is used for weighting the aggregation option of optical fibers. In all following simulations, its value was set to 5, because it showed the best results when comparing different map data, conditions and optimization criteria. This method can usually result in better optimization of a topology by joining this metric together with splitter placement hierarchical algorithm and other metrics rather than used without them. The branching created by the previous method of generating metric can be minimized by this method so that the route to each ONT unit is taking the path along with paths to other ONT units. The demonstration of this metric is presented in Fig. 3.

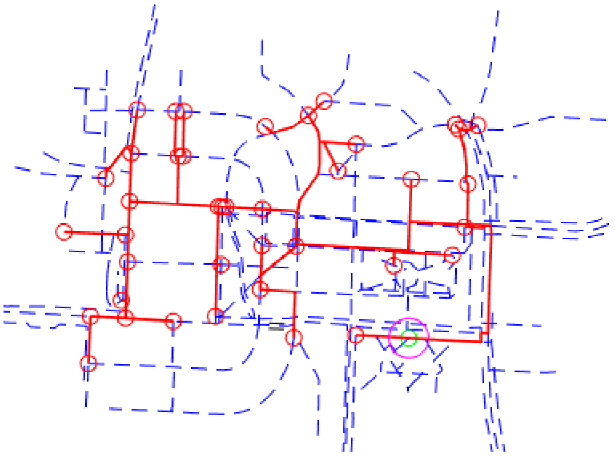
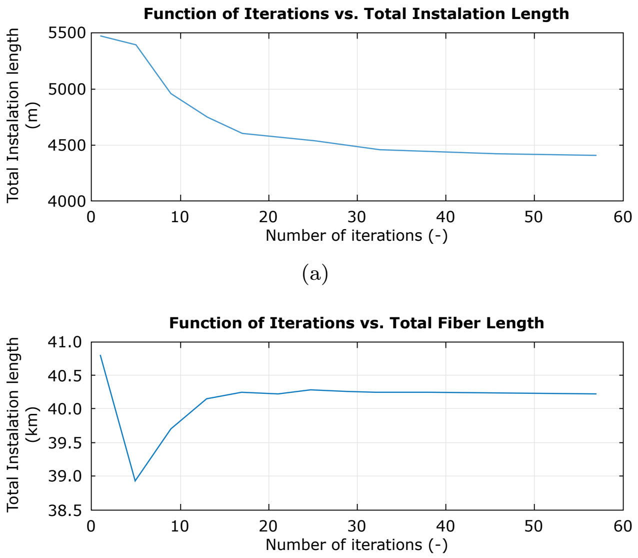


Fig. 3: Optimized topology with use of iterated metric method.

Again, the red lines in Fig. 3 represent the optical fibers, red circles illustrate the locations of ONT units, while the black square indicates the location of OLT unit.

Since this metric is based on iterations, its simulation and dependence on the number of iterations were performed, to reveal its optimum accuracy and necessary computational time. The result is presented in Fig. 4.

With a larger number of iterations, it can be seen that the overall trenching distance of a topology is smaller. On the other hand, the total length of used fibers is minimum for 5 iterations, and with more iterations, it rapidly rises and remains almost constant. Due to that, the optimum value of parameter d was set to 5.



(a)

(b)

Fig. 4: Dependency of trenching distance and total fiber length on parameters of iterated metric.

Probably the best results, however, are achieved by using the fourth method of generating metric. This metric is based on appropriate combination of the previous metrics into one. First, the metric weights were transformed, so it only contains values from 1 to 50 now and they were also averaged with the values of other metrics. This was performed to combine metrics together with appropriate weights. In final simulations, these weights were set to $1/3$ for cluster centroid distance metric and $2/3$ for iterated method of metric generation. In Fig. 5, an example of obtained results is illustrated.

2.3. Trenching and Length Calculations

The following section presents the algorithm for trenching distance and optical fiber length of optimized PON topologies. The calculations of trenching distances and fiber lengths were performed using presented algorithms without using any splitter. The optimum splitter placement is solved in the following Subsec. 2.4.

For evaluating different methods of metric generations, two optimization criteria were introduced:

- Trenching distance of proposed topology.
- Length of deployed optical fibers.

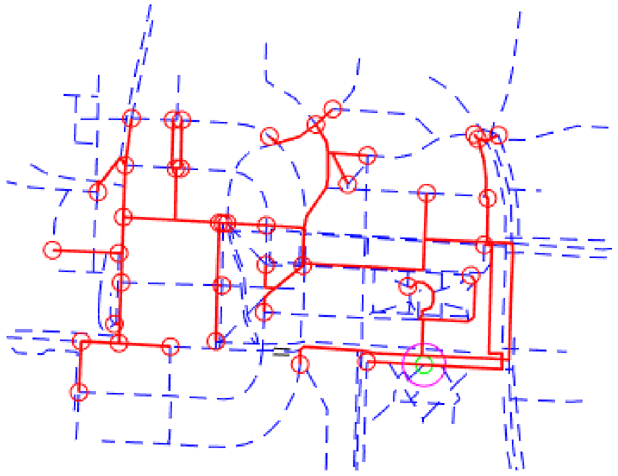


Fig. 5: Joined metrics - cluster centroid distance metric joined with iterated metric.

To calculate trenching distance of a proposed topology, the following algorithm is introduced. The algorithm is able to perform calculation using the data set (prerequisites):

- Set of paths (path consists of a set of nodes which are located between starting point and endpoint).
- Set S for used nodes.
- Temporary calculated distance.
- Weights for all edges in meter.

The algorithm for calculating the summary trenching distance can be then expressed as follows:

Algorithm 1

```
Require: Distance is zero and set S is empty
for each route do
    for each node of route - 1 do
        take pair of neighboring nodes from the start to end (n and n+1);
        if set S does not contain n or n+1 then
            add weight of an edge between nodes n and n+1 to length;
            add nodes that are not in the set S into the set S;
        end if
    end for
end for
```

The algorithm should calculate the summary trenching distance of a proposed topology and this value is given in variable distance. To calculate the length of fibers used in a topology, it simply calculates the length of every route, from OLT to ONT (or from OLT to a splitter and from a splitter to ONT), based on the given weights of all used edges.

Tab. 1: Trenching distance and fiber length comparison for different metrics.

Metric	Summary trenching distance (m)	Length of used fibers (m)
Simple meter	6918	36093
Centroid distance	6406	38913
Iterated	3873	44462
Joined	4549	43758

Table 1 contains the result comparison of the proposed metrics for both trenching distance as well as fiber length. Since the algorithm for optimum splitter placement will be proposed in the following chapter, the attenuation analysis will be performed there.

2.4. Optical Splitter Placement

Generally, the optimization of an optical splitter placement in a graph can be performed by using clustering algorithms. In this report, the K-Means clustering algorithm and complete-linkage hierarchical clustering were chosen due to their simplicity and versatility. K-means is used together with Euclidean distance in meters while complete linkage is based on the distances between nodes in the graph.

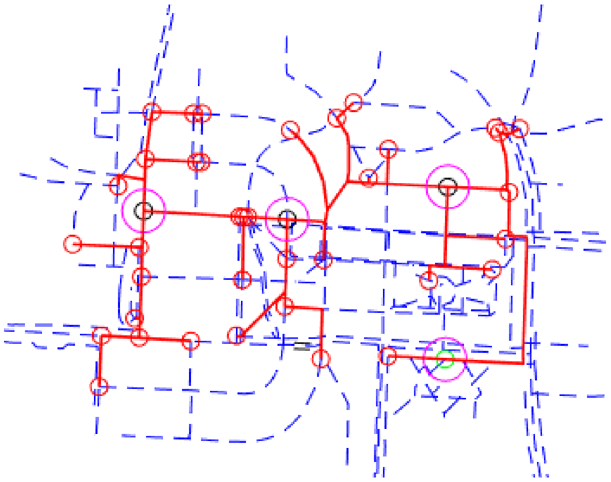


Fig. 6: An example of topology with splitter placement with use of K-Means clustering algorithm.

K-Means is a non-hierarchical clustering algorithm used for cluster analysis. This algorithm creates several defined clusters based on properties of a dataset. This creates clusters with centroids of locations used for cluster analysis. These centroids change in every iteration. They are calculated as a mean center value based on all nodes in a cluster. The goal of this algorithm is that distance between values in one cluster is minimal. This clustering algorithm then creates defined number of clusters each with its own centroid. Splitters must be placed only along roads and highway network. Their locations are not precisely at the center of K-Means centroids. Therefore, their location is, again, adjusted to the closest node of a highway and a road network.

Again, in Fig. 6, red lines represent optical fibers, red circles ONT units, black square OLT unit and black circles optical power splitters.

On the other hand, the complete linkage is an example of agglomerative hierarchical clustering. In this clustering method, all points are treated as clusters, and then clusters with the smallest distance are merged. This distance is the smallest in comparison to other clusters but it is the farthest distance between the points in two clusters. Complete linkage clustering thus creates compact clusters with a small diameter.

Input for the cluster analysis is a list of geographic coordinates of all ONTs and OLT in the graph. Outputs of clustering are geographic coordinates of the central point in each of 3 clusters, which are then used as a location for splitter placement.

The splitting ratios of splitters are used according to the number of ONTs belonging to splitter cluster. This ratio is the number of the nearest bigger power of 2. If a cluster has 14 ONTs then the splitting ratio will be 1:16. If a cluster has only 5 ONTs then the splitting ration is 1:8. Furthermore, only splitters with fixed and symmetric splitting ratio are used. In resulting topology, the maximum number of cascaded splitters was set to 3, because cascading more splitters could result in excessive attenuation. Another solution is to use non-symmetrical splitters with unequal splitting ratios. This option will be a subject of future research. An example of optimum splitter placement is illustrated in Fig. 7, in which splitter positions are marked with black circles.

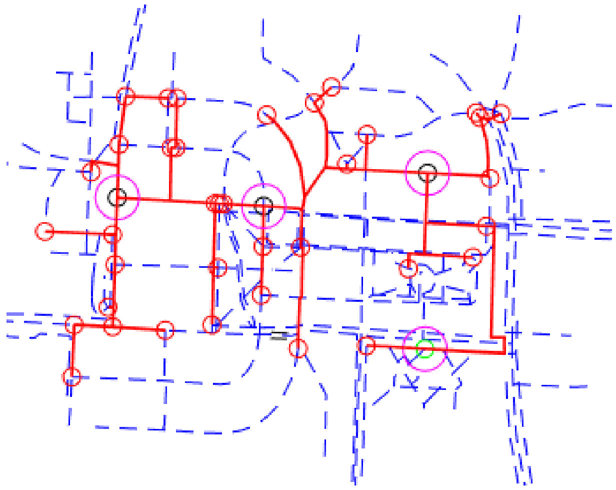


Fig. 7: An example of a topology with splitter placement based on complete linkage hierarchical clustering method.

3. Results and Discussion

The final solution is based on complete linkage hierarchical method and all presented metrics were combined. The optimum values of a, b, c variables in Eq. (1) of iterated metric were iterated for a specific data set. The presented map data set was divided into 3 clusters using complete linkage clustering, this was due to the size of an area used for simulations and a number of ONT units. Moreover, the possibility of cascading more than 3 splitters would probably bring high values of attenuation exceeding the attenuation limits.

To find the most optimum solution based on presented joined metric together with the algorithms above, the following flowchart in Fig. 8 was created to describe the whole process.

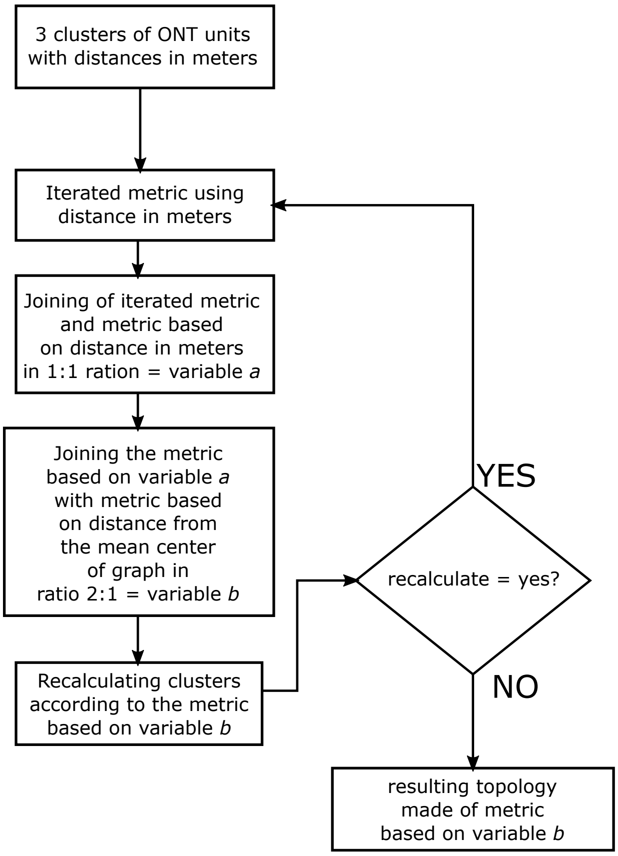


Fig. 8: Proposed algorithm flowchart to find optimum PON topology.

The previous flowchart (Fig. 8) shows the methodology of creating topologies from dataset using the metrics created according to methods introduced in Sec. 3. above. The variables a, b are just temporary variables for storing the calculated metric of designed topology.

First, the option of topology recalculation should be checked, since the updating of cluster centroids during proposed distance centroid metric can result in a new constellation of clusters. More iterations of recalculating can be done but during testing of this methodology it was revealed that metric variable b is almost the same, so only one recalculation is usually performed. Based on resulting metric variable b, the calculation of following parameters is done:

- Summary trenching distance of a topology.
- Endpoint attenuation.
- Summary length of fibers.

The result of the whole optimization process is then identified according to the optimization criteria and respective parameters. Finally, it is necessary to verify the maximum endpoint attenuation as well as the maximum distance between OLT, and similarly each ONT and the maximum differential distance between all ONT units, while these values must meet strict criteria. Due to that, the solution presented for example in Fig. 7 is unsuitable since the endpoint attenuation in the presented topology is almost 47 dB, which is unusable. Due to that, the maximum endpoint attenuation for any topology solution was set to 30 dB. This value is usually a typical maximum attenuation for today's PONs. Similarly, the distance constraints, in accordance with ITU–T and IEEE standards for PONs, and the maximum distance between OLT were implemented. All ONT units were set to 20 km, as well as the maximum differential distance between all ONT units. After implementing these threshold values into previous algorithm flowchart (Fig. 8), the recalculation of optimum topology was performed again. Due to the maximum endpoint value, the optimum topology solution results in separating the entire PON into 2 separate topologies. One created by cascading 2 splitters and one created by one splitter only. The resulting optimum topology for the example above is demonstrated in Fig. 9.

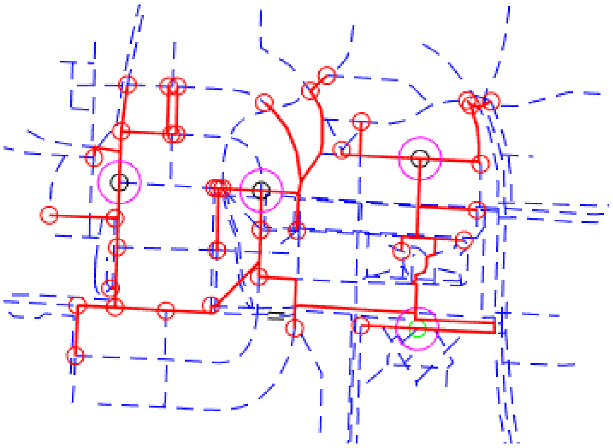


Fig. 9: Resulting topology with the shortest trenching distance, fiber length and acceptable maximum endpoint attenuation.

The optimized topology presented in Fig. 9 is created by presented algorithm together with proposed parameters and criteria, therefore it meets the criteria of the shortest trenching distance, the shortest length of fibers as well as the maximum allowed endpoint attenuation, maximum allowed distance and differential distance.

The value of an attenuation was calculated as the sum of attenuations of all passive optical components between central OLT unit and each end-point ONT unit. This sum can be simply calculated using Eq. (2):

$$A_{total} = \sum A_s + \sum n_{pe} \cdot A_{pe} + \sum \alpha \cdot d + A_{res}, \quad (2)$$

where A_s represents the summary attenuation of all passive splitters between OLT and selected ONT unit in dB, npe is the number of passive optical elements (such as connectors, splices, etc.) with their attenuation A_{pe} in dB between OLT and ONT unit, α is the attenuation factor of optical fiber in dB·km^{-1} with length d in km and Ares is the attenuation reserve in dB for compensation of aging, temperature fluctuations, deformations of optical fibers, etc. The calculation of attenuation presented within this article is based on typical values used in Eq. (2) according to [11]. The attenuation of 1:8 splitter is 10.8 dB, 1:16 is 14.1 dB and 1:32 is 17.3 dB including one connector, the attenuation factor α of optical fibers is 0.3 dB·km^{-1}, 2 connectors for connecting OLT and each ONT unit with attenuation of 0.3 dB each are included in the calculation and attenuation reserve Ares is 2 dB. Based on these, Tab. 2 contains a comparison of the two designed solutions according to all three optimization criteria.

Tab. 2: Comparison of found solutions.

Attenuation (dB)	Total trenching distance (m)	Total length of used fibers (m)
48.2	3684	10020
20.1	4058	10064

Evidently, the first solution does not meet the maximum attenuation limit. Therefore, it cannot be used in practice. Due to the implementation of PON constraints (attenuation, distances), the second solution was obtained with minimized trenching distance and total length of all fibers and this solution meets all PON constrains. The values of attenuation and distances in Tab. 2 includes the summary maximum attenuation and maximum distances between OLT and end-point ONT units in designed PON topology.

3.1. Discussion and Future Improvements

This paper discusses the implementation of a passive optical network over a real residential area. Thus, the

Euclidean distances are not ideal because the line between two points must be located on the highway network and cannot be placed through locations of residential buildings. In comparison to the [16], this paper supports real-world distances through the highway network, on the opposite to the [16], which uses K-Means algorithm and Euclidean distances. Furthermore, the [16] is more oriented on a total cost of the implemented network; this paper discusses attenuation, summary trenching distance and summary length of used fibers. Nevertheless, these results could be transformed into the implementation cost of a topology (CAPEX).

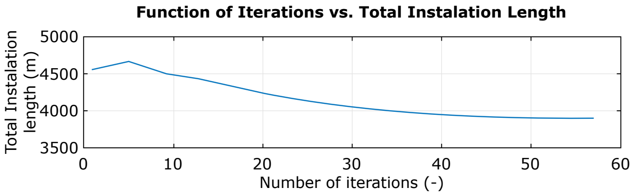


Fig. 10: The summary trenching distance based on the number of iterations.

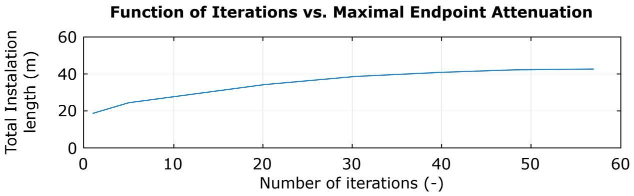


Fig. 11: The dependence of summary fiber length on the number of performed iterations.

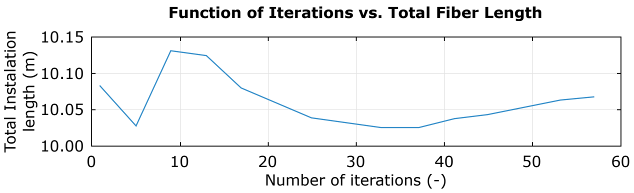


Fig. 12: The resulting endpoint attenuation based on the number of iterations.

Moreover, the method presented within this article uses hierarchical cascading of passive splitters similar to [18], but these are created automatically. Moreover, the issue of attenuation is considered in this work so the attenuation of three cascaded 1:32 splitters is significant and can cause non-compliance of power limits of the PON. This leads into implementation of separating the PON into several separated topologies to meet the maximum endpoint attenuation criteria.

The resulting methodology presented in this paper is aimed solely at creation of TDM-PON type network, other types of PON like WDM-PON and LR-PON will be dealt with in future research. Since the presented method of metrics is based on iterated parameters, their dependence on the number of performed iterations was tested. The main goal was to observe the dependence of the resulting topology optimization level on the number of iterations. The result for example of map data set presented here is illustrated in following figures. Figure 10 contains the dependence of summary trenching distance on the number of performed iterations, Fig. 11 illustrates the resulting endpoint attenuation and finally, Fig. 12 presents the summary length of optical fibers.

4. Conclusion

All discussed methods were tested over a single data set based on a real map extracted from OpenStreetMaps. The residential area used for calculations is based on the location of Zahradni Mesto in Prague. For all calculations, a following simple setup was used: 40 ONTs, 1 OLT and a number of splitters varied from 3 to 1 with various splitting ratios. Their locations were randomly chosen, again, from a set of the residential buildings in the area.

The solution for optimizing both, the trenching distance and summary length of optical fibers, is based on the combination of metrics and proposed algorithms together with hierarchical clustering algorithm for cascading of passive splitters. The most promising approach was to join centroid distance metric together with iterated metric to obtain the topology with minimum summary trenching and fiber length. This solution was further evaluated by complete-linkage hierarchical algorithm as well as K-Means algorithm to identify the optimum number, type and placement of passive optical splitters within the designed topology. Finally, the maximum endpoint attenuation limit was implemented to design optical network with suitable attenuation level. In order to control the maximum allowed endpoint attenuation, the proposed algorithm described by a flowchart in Fig. 8 can perform decomposition of the topology into separated networks in order to use fewer splitters. Due to that, the recalculation of the entire scenario is necessary in such situation, as illustrated in Fig. 8.

This works aims on parametrizing and quantifying the implementation of a passive optical network topology for further processing. The metrics and clustering can be used with different parameters. This could be potentially useful for use with fuzzy logic and neural networks, to find the desired topology in short time. This idea will be further addressed during our future research on this topic.

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