FTTH Network Design with Google Map integration

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***Abstract*—In this paper, we propose a model for designing optical access network for EVN Hanoi. We also integrate Google Map in this design tool in order to take into account real fiber layout paths. The numerical results show that our solution out performs the exiting solution in [5] for the same datasets.**

I. INTRODUCTION

Optical fiber step by step becomes an evident choice for the core and also the access networks in order to meet increasing users and service provider demands. FTTH (Fiber to the Home) is a viable solution to deploy access network, which allows serving multiple end users simultaneously at high speed. In the common architecture, FTTH networks carry signal from the center office, which is a node in the metro core network, to end user devices by running a fiber from this center office to an remote node in the middle of the way and then continuing by different fibers to different customers. FTTH can be deployed using passive or active technology [6]. Active Optical access Networks (AON) contain active electronic elements that need power supply for operation, for example: switches, routers and multiplexers, between the central office or head-end switches and the customer-premises equipments. Normally, optical signals need O-E-O transformation in each device. The Passive Optical Network (PON) does not contain any electronic devices using power supply between the central office/head-end switches and the customer premises equipments [7]. When the passive technology is used, passive splitters are used as remote node which split passively the signal from the same center office device to multiple end users in different places without using power supply.

The FTTH network providers often design their network manually because of missing of design tools, for example in EVN Hanoi. Manual design results in a network instance which can satisfy all the providers requirements but may be far from an optimal instance, for example using too much of fiber than needed. According to the design idea of EVN Hanoi, the network composes of three layers (see Fig. 1). The core layer consists of optical switches (SW1) that are connected meshly to each other by 40GB links using WDM technology. The boundary layer contains boundary switches (SW2) with 10GBs connections using the ring topology. The access layer connects the network to end users by 1GB links, using ring topology again. Ring is chosen in order to provide the survivability because each working path on one site of the ring has a back up path on the other site of ring.

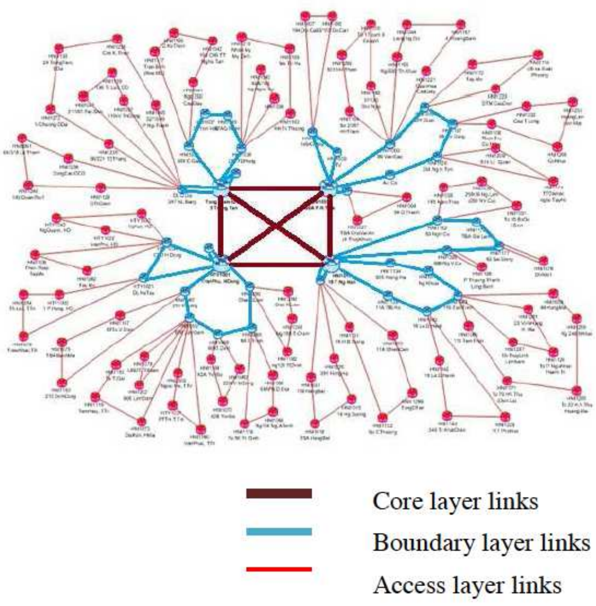

Fig. 1. EVN Hanoi FTTH network.

The study in [5] has proposed a solution to connect the optical switches automatically while satisfying the EVN Hanois requirements such as redundancy and resources saving. This solution still has some drawbacks, for example it is not optimal and cable paths between two nodes are assumed to be as a direct arc. In the reality, cables are hung along streets and can be turned at street corners. Some other researches have been conducted in designing PON access networks such as [3], [1], [4] . However all of them focus on star PON without any redundancy consideration. Therefore the results networks cannot be survivable upon a failure.

In this paper, we propose a solution for designing FTTH network according to the 3 layers architecture of EVN Hanoi with the objective of minimizing the total fiber length to be used. We believe that the main network cost is the fiber laying out cost which is proportional with fiber length therefore minimizing fiber length will minimize the network cost. Although we have considered some specific requirements of EVN Hanoi in our solution, the solution is generic so that it can also be applied for any other access networks. The proposed solution makes use of A* algorithm [2] in order to be able to find a better cable saving solution than that of [5] . The proposed solution is then implemented in a FTTH design tool, where Google Map is also integrated in order to take real street routes as fiber running paths. There exists also some tools for designing optical networks such as Cisco MetroPlanner DWDM or Nokia Siemens Networks Transnet, however those tools are mainly commercial product which serve for designing metro core instead of access networks. Our tool will be an open source design tool for access networks.

The remaining of this paper is organized as follows. Section II describes the problem of designing FTTH network according to EVN Hanoi architecture and requirements. Section III briefly presents an existing solution proposed in [5] for this problem. Section IV presents our solution. Section V provides some numerical results, which demonstrate the advantage of our solution. Section VI describes the integration of Google Map in the design tool. Conclusions follow in Section VII.

II. PROBLEM STATEMENT

According to the requirements of EVN Hanoi, the FTTH access network should be organized in three layers:

- *Core layer:* composed of optical switches (called SW1) that are fully connected to each other by 40 GBs links using WDM technology.
- *Boundary layer:* composed of optical switches (called SW2) that are connected to each other in ring in order to provide a reliable structure with backup ability.
- *Access layer:* composed of optical switches (called SW3) that are connected to each other in ring.

The network design problem is stated as follow:

Input:

- Given n0 SW1s and their positions in map
- Given n1 SW2s and their positions in map
- Given n2 SW3s and their positions in map
- Shortest path length between the optical switches in the map

Goals:

- Connect all the devices in the network together according to the required three-layer structure.
- Minimizing fiber miles.

Constraints due the limited physical capacity of devices:

- An optical switch of a upper layer can serves at maximum 5 optical switch of lower layer, i.e. each ring can contain up to 6 optical switches, including 1 from upper layer and 5 from lower layer.
- The diameter of each ring must be smaller or equal to 20 km
- A SW1 of Core layer has 8 ports thus each SW1 can belong to in maximum 3 rings.
- A SW2 of Boundary layer has 6 ports thus each SW2 can belong to in maximum 2 rings.
- According to practical experience in EVN Hanoi, creating a new ring is more practically complex and expensive than extending an exist ring. Therefore, rings are made as large as possible as follows:
    - If the number of SW3s connected to a SW2 does not exceed 5 then only one ring will be built.
    - If the number of SW3s connected to a SW2 is between 5 and 10 inclusively then two rings should be built
    - Similar choices are applied to the numbers of SW2 to be connected to a SW1 device.

III. EXISTING SOLUTION

The study in [5] has proposed a solution for the above network design problem. In this solution, real fiber running path has not been considered. The author has just tried to connect SW1s, SW2s, SW3s according to the required structure by straight links which may be impossible in the reality due to real obstacles like high buildings or street coiners on the way. The design algorithm is as follows:

1) SW1s are connected together by full mesh topology.
2) Group SW2s with the SW1 that should be connected with in rings. Each SW2 is grouped with the closest SW1 until the SW1 is full. Since there are in maximum 5 SW2s in each ring with SW1 and a SW1 can belong to in maximum 3 rings then each SW1 can be grouped with in maximum 15 SW2. The 16^{th} SW2 will be grouped with its second closest SW1.
3) For each SW1‘s group, making a ring by following steps: (i) take the SW2 which is closest to the SW1, and connect it to SW1. (ii) Then this SW2 will be connected to the nearest SW2 in the group. At the just connected SW2, continue to connect to the other SW2 nearest to it amongst the SW2s left. (iii) When five SW2s are connected, connect the last SW2 to SW1 for closing the ring.
4) Repeat the above steps until all SW2s in the SW1‘s group are in a ring.
5) Similar process is applied for connecting SW3 to SW2 in order to form the Access layer.

This algorithm meets all the design constraints but it is far from optimal in term of total fiber length. It just greedily connects one device to the other closest one but the total ring length is not minimal.

IV. PROPOSED SOLUTION

In order to overcome the limitation of the existing algorithm, we propose another design algorithm. The objective of the design is to minimize the total fiber length to be used while satisfying all design constraints. For solving this problem, we propose a solution which is based on A* algorithm that will be briefly described in Section IV-A .

1) Group lower layer devices with a higher layer device.
    - Group SW2s with the SW1 in the same way as in the second step of the algorithm in Section III.
    - Group SW3 devices with a SW2 device: similar to grouping SW2s to SW1.
2) Connecting devices of each group in rings so that the total fiber length of the ring is minimal. For this purpose,

we use A* algorithm to find out the shortest path to make the ring.

A. A* Algorithm

The A* algorithm [2] uses a best-first search to finds the least-cost path from a source node to a destination node in a graph. From the source node, A* algorithm tries to reach to the destination node by going to further nodes step by step. At the current node n, A* estimates the cost for reaching to the destination by function:

$$f(n) = g(n) + h(n) \tag{1}$$

where:

- $g(n)$ is the total path length to take from the source node to the current node.
- $h(n)$ is the estimated path length from the current node n to the destination node. An heuristic function can be used to estimate how far away it will take to reach the destination.
- $f(n)$ is the current estimated shortest path.

The searching process starts with the source node, it maintains a priority queue of nodes to be traversed, known as the open set. The lower $f(n)$ for a given node n, the higher its priority. At each step of the algorithm, the node with the lowest $f(n)$ value is taken from the queue for consideration and it becomes the new current node. The adjacent nodes of the current nodes are then added to the queue with the values g is computed as the path length from the source node to this adjacent node though the current node. The value h for the adjacent node is the estimated path length from it to the destination. The f values of those adjacent nodes are then updated. The algorithm continues until the destination node has a lower f value than any node in the queue (or until the queue is empty). It worth to note that the destination node may be browsed several times if there remain other nodes with lower f values, since these nodes may lead to a shorter path to the destination.

B. Detail of the Proposed Algorithm

- Group SW3 devices with a SW2 to make a SW2‘s group; and group SW2 devices with a SW1 to make a SW1‘s group as follows:
  - Assign each SW3 device to SW2‘s group by two steps: (i) Ordering the actual path lengths from all SW3 devices to SW2 device ascending order;(ii) Check the full ring condition with SW2. Each SW2 belong to at maximum two rings so SW2‘s group consists of maximum 10 SW3 devices;
  - Similar process is applied for grouping SW2 devices with SW1‘s group.
- Connecting devices of each SW2‘s group in rings:
  - For each SW2‘s group, the number of rings to be created is determined by: (i) If number of SW3 is smaller or equal to 5, then one ring will be built; (ii) If number of SW3 is between 5 and 10 then two rings will be created.
  - If the number of devices in SW2‘s group does not exceed 5, A* algorithm is applied for making one ring. SW3 nodes are nodes of the graph. The SW2 is considered as the source and destination node, the smallest ring to be made is actually the shortest path from the source to the destination to be found by A* algorithm.
    - ∗ The algorithm starts from the SW2 and adds SW3 one by one in the ring.
    - ∗ The cost path $g(SW3)$ is defined as the total of fiber length from the SW2 device to the current SW3 device.
    - ∗ Heuristic function $h(SW3)$ is defined as the fiber length from the current SW3 device to the destination.
    - ∗ Cost evaluation function $f(SW3)$ is the sum of $h(SW3)$ and $g(SW3)$, and is the current approximation of the shortest fiber length to the destination node.
    - ∗ The algorithm stops when all the SW3s in the SW2‘s group have been put into the ring with the lowest $f(SW3)$ value.
  - If the number of devices in SW2‘s group is between 5 and 10, A* algorithm is applied similarly, but the function $g(SW3)$ is the sum of the first ring cost and the cost of the building ring.
- Similar process is applied for making rings of Boundary layer with SW1‘s groups.

TABLE I

COMPARISON OF FIBER LENGTH BETWEEN SOLUTIONS IN [5] AND THE PROPOSED SOLUTIONS

Nb. of SW1	Nb. of SW2	Nb. of SW3	Fiber length		Fiber saving (%)
			Sol. in [5]	Proposed sol.	
3	8	23	7960	6720	18.45
3	8	20	7250	6315	14.81
2	5	19	6521	6013	8.44

V. NUMERICAL RESULTS

In order to evaluate the proposed solution, we test the solution with 3 datasets. Each dataset contains the positions of SW1, SW2, SW3 nodes. The proposed algorithm connects these devices in a topology following requirements of EVN Hanoi. The three datasets have been used in [5] . Table I shows the comparison of our solution results with those of [5] in the same datasets.

The column fiber saving gives the percentage of fiber length saving that our solution economizes in comparison with the solution in [5] . The percentage is computed by the following formula:

$$\text{fiber saving} = \frac{\text{fiber length given by [5]}}{\text{fiber length given by the proposed solution}} - 1$$

The test results show that the proposed solution finds the topology with less fiber length than the solution in [5]. In

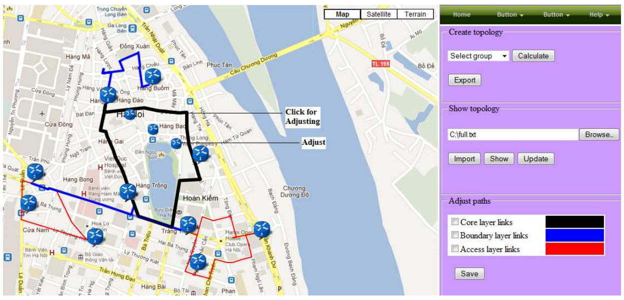

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Fig. 2. Integrated Google Map in design optical network tool.

the three testing cases, the proposed solution can save up to 18.45% fiber length.

VI. GOOGLE MAP INTEGRATION

We use the proposed algorithm for developing a tool for designing FTTH network. In this tool, the path connecting two devices are real street path taken from Google Map between the two devices. In the proposed algorithm, the distance between any two devices is calculated from this real street path. The tool provides 2 main functions:

- Calculate the real distances between devices: With the tool, user can design a new topology that contains the map of devices. Then the tool automatically calculates distances between points by the available Google API algorithms. The distances will be used in the proposed algorithm.
- Show topology network: From the output of the proposed solution, the tool draws the topology. This tool also allows to adjust fiber layout paths if network designer considers that the current path is not suitable because any reason, for instance missing poles or some streets do not permit to connect cable etc.. User can also store topology, cable statistics; print Map etc.

Fig. 2 illustrates the interface of the designer tool.

VII. CONCLUSIONS

In this paper, we have proposed an algorithm for designing FTTH networks which can be applied currently for EVN Hanoi. The numerical results show that the proposed algorithm is more efficient on fiber length saving than the existing solution which can save upto 18.45% in the experimental cases. We have also developed a tool for designing the FTTH networks using the proposed algorithm in the reality where the digital map is integrated in the process of design in order to take into account the real fiber layout routes.

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