OPTIMAL DESIGN OF ACCESS POINTS IN FIBER OPTIC NETWORK WITH THE HELP OF LINEAR PROGRAMMING

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ABSTRACT
Fiber to the home is the most advanced technology for building the next generation of communication networks around the world. FTTH is the most promising technology that can provide high bandwidth with more reliability and very high quality of service compared to the previous type of traditional internet connection technologies such as DSL. There are several open issues and research in the implementation of these networks. Among these research topics, the optimal placement of the ONU is very important because it leads to cost efficiency and resource optimization. Various schemes and optimization algorithms have been implemented and compared to determine the location of the ONU in previous work. In this paper, with the help of linear programming algorithm, a suitable method in terms of speed and accuracy in order to optimize network creation costs according to the proposed model is presented. The results confirm that the proposed method has the best performance in terms of simulation time among the existing algorithms. It is also competitive with other algorithms in terms of cost savings.

Keywords: Fiber Optic - Linear Programming - Optimization - FiWi Network.

1. INTRODUCTION
Recently, advances in communication services have seen rapid expansion. This expansion is due to subscribers' thirst for a variety of services. Customers need services such as video telephony, TV and radio broadcasting, high speed internet connection, video-based multimedia, fast file transfer as a peer, high quality online gaming, etc. [1]. Internet technology has become an essential part of digital life in recent years. Almost all the efforts made such as connecting to a bank account (mobile bank, bank teller), Facebook and other social networks, Google services, online shopping can be mentioned [2]. It is very important to note that information and communication technology (ICT) has a great impact on the economy of human society. Subscribers need global internet and on the other hand, in order to do their job in the best possible way, they need high bandwidth and better reliability internet [3]. In terms of speed, more stable connections, and the need for high-speed Internet, DSL and Wi-Fi subscribers are not able to meet the needs of subscribers. Therefore, with all these interpretations, the only solution to this conceptual problem called fiber optics will be the solution. Fiber optics with high bandwidth characteristics and also a very high throughput will on the other hand provide low attenuation of subscribers' needs. The function of fiber optic cable is to produce data and information in the form of light according to light technology, which in turn transmits data and increases information at the same or the same speed of light (the fastest media introduced). Therefore, this feature will create a large bandwidth capacity for data rates with very high service speed. The reliability of this medium is the lowest amount of noise that has the

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ability to affect the signal. This technology has become reliable because electromagnetic interference is not able to affect light. This technology has the basis of optical technology. Which will connect internet services to the subscriber with the help of fiber optics and its speed. Fiber to the Home (FTTH) is an architecture available in a variety of forms. In addition, FTTH has a very flexible technology that can be implemented in any country, but it has many differences that will be reflected in national policies [4-8]. Fiber to the home supports a variety of locations, which makes the design and architecture of network infrastructure different depending on the location and geographical area.

In [9], a solution for simultaneous propagation of optical and radio frequencies on an optical fiber bond with optical stimulus and dual phase stabilization is proposed and presented experimentally. Implementing FTTH for network operators is challenging given the large amount of investment, such as cost of capital (CAPEX) and operating cost (OPEX). The review and classification of approaches to reduce the cost of FTTH implementation in this work has been done according to a new classification in [10]. Linear Mixed Integer (MILP) programming is suitable for designing passive optical networks. However, overstatement times in order to solve large-scale sample problems make this method impractical. The main purpose is to minimize capital expenditures related to the implementation of FTTH-OAN, meaning the cost of inactive tools and the cost of active tools is the cost of site planning and labor required in the network [11]. Article [12] Two techniques for health monitoring The network is provided by creating an FBG (FBG code) configuration design to identify error branches. Also, the simulation results have been analyzed and a suitable technique has been presented by considering several aspects, including economic and technical aspects. In the article [13] to optimally place several units of optical network (ONU) in the FiWi network using two recent optimization algorithms called Harris Hawks optimization (HHO) and locust optimization algorithms (GOA) has been done. The results are then tested according to the Whale Optimization Algorithm (WOA). The results show the superiority of the proposed HHO algorithm over the GOA and WOA algorithms and return the lowest value of the cost function.

In this paper, a method to optimize the ONU location in the FiWi network with the help of linear programming algorithm is presented. The proposed method is a suitable method in terms of speed and accuracy in order to optimize the costs of creating a fiber optic network. The proposed method is able to find the optimal location of fiber optic network equipment in less time than meta-heuristic algorithms. Also, this method shows good performance in terms of user coverage compared to other methods. Continued in Section 2 Materials and Methods. In the results section, the proposed method is given. Section 4 also summarizes the results.

2.MATERIALS AND METHODS

The proposed method includes a method to optimize the location of ONUs to minimize the cost of establishing a FiWi network. For this reason, this method includes three stages of system modeling, selecting the appropriate optimization method and selecting the appropriate objective function for the optimization algorithm, which we will describe in the following. Block diagram The suggested method for doing this is given in this section. Which we will describe in the following.

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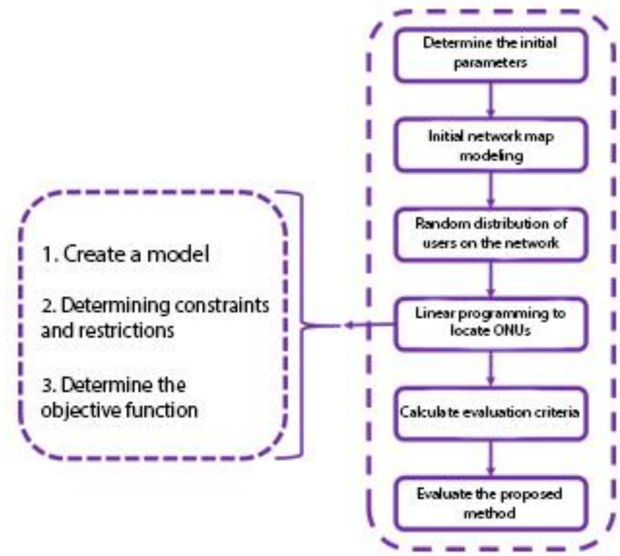

Figure 1- Diagram of the proposed method

The steps of the proposed method are explained below.
A.System model
This section contains the following sections:
A) Network components:
To network modeling, the components of modeling must first be identified and quantified. These components are shown in Table 4-1.
B. B) Network architecture
This section describes the architecture of the FiWi network. Figure 2 shows an example of a FiWi network. In this work, since our goal is to find the optimal location of the ONUs, we first create users with a random distribution in our model. Then, with the help of linear programming, we will locate the ONUs properly.

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Table 1 Network components

Parameter	Symbool	Explanation
Network size	-	Size of the network map 1000*1000.
Number of users	Num_user	The number of users in network is 100.
Number of ONUs	Num_ONU	The number of ONUs in network is 15.
x_j	x_user	The x location of jth user.
y_j	y_user	The y location of jth user.
Xi	x_ONU	The x location of ith ONU.
Yi	y_ONU	The y location of ith ONU.
D_{ij}	distance_ONU_user	Distance between ONU i and user j,
Total distance ONU_i	d_total_ONU	Sum of distance between ONUi and all users
Total distance	d_total	Sum of distance between all ONU and all users

As shown in Figure 2, the FiWi network is shown within a certain range. The recommended network architecture includes the following components:

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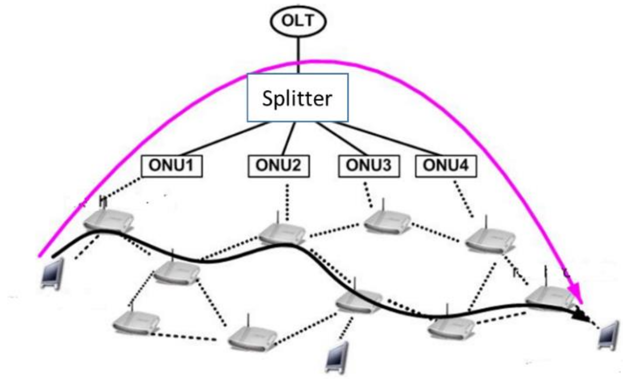

Figure 2- FiWi network pattern

• Optical Line Terminal
Is a device that acts as the end point of the service provider of an inactive optical network.

- Optical Network Unit

Is a device that provides customer service interfaces to the user.

- Splitter

It is the unit that takes the fiber optic internet network from the OLT and distributes it among the ONUs.

C) Network assumptions

We have the following assumptions about designing an efficient FiWi model in the target network:

- Users are randomly modeled on the map.
- The location of ONUs is determined by linear programming to provide proper Swiss coverage.
- The number of users and the dimensions of the map are determined in advance.
- ONUs have the same coverage (antenna).
- Optimizing the location of ONUs will minimize the cost of setting up a FiWi network.
- Optimized ONU positions should be in the search space.
- ONUs should not overlap. Common positions of ONUs have invalid locations.
- The grid area is considered square (A × A).

Using a linear programming algorithm to determine the optimal location of ONUs

After modeling the system, we need to select a suitable algorithm to optimize network deployment costs. In the basic article, the wall optimization algorithm is used to optimize the network. This algorithm is one of the meta-heuristic algorithms. The most important disadvantage of these algorithms is their high computational time. For this purpose, we use the linear programming algorithm in order to achieve our goal of minimizing the cost of network deployment. Because the use of linear programming reduces computational costs in modeling compared to evolutionary

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algorithms. The linear programming algorithm requires backing up the objective function as well as setting constraints for implementation. In the following, we will describe them.

- Determine the objective function and constraints

This dissertation is presented to minimize the running time and cost of implementing a FiWi network with the help of linear programming. Therefore, to determine the objective function, the following procedure must be performed:

First, the distance (cost) of users from the -i trusted ONU is defined according to the following equation:

$$D_{ONUi} = \sum_{j=1}^{Ni} \sqrt{\left(X_i - x_j\right)^2 + \left(Y_i - y_j\right)^2} \qquad (1)$$

Which in the above equation:
Xi position x ONU ith
Yi position y ONU ith
xj Position x User jth
yj Position y User jth
Number of ONU users ith
DONUi is the total distance of ONU ith users from it.
Since linear programming does not have the ability to solve quadratic equations but the distance is a quadratic equation, we simplified the above equation as follows.

$$D_{ONUi} = \sum_{j=1}^{ni} \left(X_i - x_j\right) + \left(Y_i - y_j\right) \qquad (2)$$

$$subject\ to\ X_i > x_j \qquad j = 1.\dots.n_i$$
$$Y_i > y_j \qquad j = 1.\dots.n_i$$

It should be noted that due to the omission of power, we consider the above two constraints for Equation (2).

The distance (cost) of all users from all ONUs is now defined as follows.

$$D_{total} = \sum_{i=1}^{N_{ONU}} D_{ONU_i} \qquad (3)$$

In the above relation ¬ NONU is the total number of ONUs.

Finally, the above function is considered as the final goal function.

$$cost\_function = C = D_{total} \qquad (4)$$

We also considered the following constraints to optimize the location of ONUs.

1. The location of ONUs should not be outside the map.

$$0 < X_i < x_{max} \qquad i = 1.\dots.N_{ONU}$$
$$0 < Y_i < y_{max} \qquad i = 1.\dots.N_{ONU} \qquad (5)$$

2- Do not place ONUs at the border edges of the network map

$$t1 < X_i < t2 \qquad i = 1.\dots.N_{ONU}$$
$$t1 < Y_i < t2 \qquad i = 1.\dots.N_{ONU} \qquad (6)$$

In the above equation, t1 and t2 are two arbitrary thresholds that regulate the distance of the ONUs from the edge of the map.

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3. RESULTS

In this section, we will model and simulate a fiber optic system and compare its performance with other tasks. To evaluate the proposed solution, the criteria of calculation time and distance of all users from ONUs (total cost) will be evaluated, which can be calculated from the following formula.

$$D_{total} = \sum_{i=1}^{N_{ONU}} \sum_{j=1}^{Ni} \sqrt{(X_i - x_j)^2 + (Y_i - y_j)^2} \qquad (7)$$

In the above relation, NONU is the total number of ONUs and Ni is the number of users related to the 1st ONU.

The cost improvement criterion will also be evaluated according to the following equation.

$$cost_{improvement} = \frac{\Delta cost}{total_{cost}} \times 100 \qquad (8)$$

In the above formula, $\Delta cost$ is the difference between the cost function (total distance) in the optimized model and the greedy mode. Total-cost is also a function of the total cost in the greedy state.

Evaluate the execution time of a linear optimization algorithm for a number of different ONUs

In this section, we will compare the execution time of the program with increasing the number of ONUs. Execution times are plotted in the figure below for different numbers of ONUs in the figure below. As shown in Figure 3, execution time increases exponentially as the number of ONUs increases. In this experiment, the number of users is fixed and equal to 100.

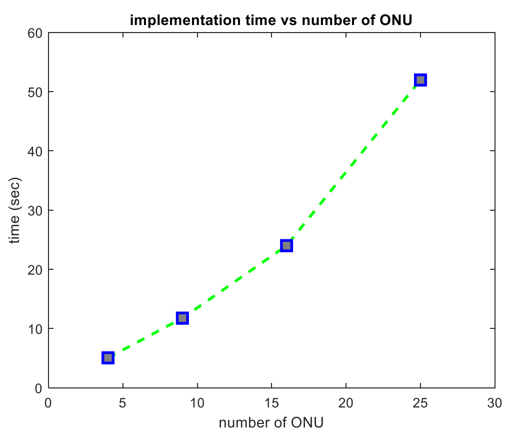

Figure 3 Execution time of linear optimization algorithm for different number of ONUs

Estimate the total cost (total distance) for the number of different ONUs

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In this section, we compare the total cost with the increase in the number of ONUs. The total cost (total distance) in the figure below is plotted for the different number of ONUs in the figure 4. As shown in Figure 4, the execution time increases with the number of ONUs. In this experiment, the number of users is fixed and equal to 100.

Evaluate the total improvement for the number of different ONUs

In this section, we compare the total improvement with the increase in the number of ONUs. The total recovery rate is plotted in the figure below for the different number of ONUs in the figure below. As shown in Figure 5, the overall recovery rate increases exponentially as the number of ONUs increases. In this experiment, the number of users is fixed and equal to 100.

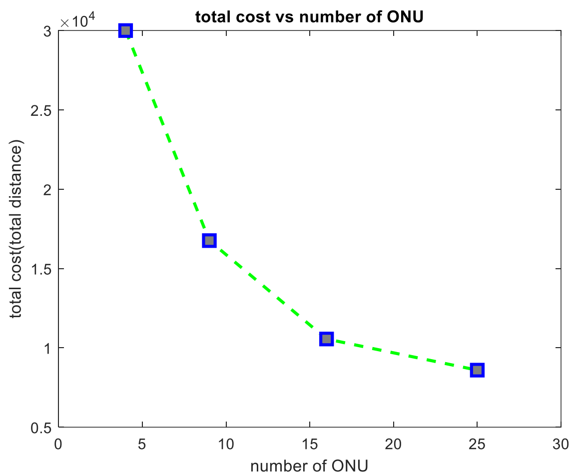

Figure 4- Estimation of total cost (total distance) for the number of different ONUs

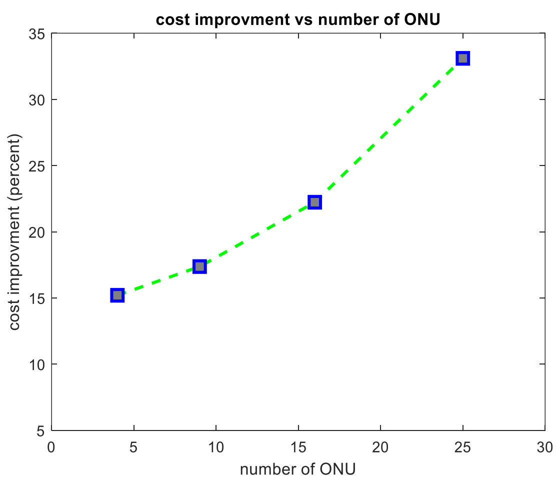

Figure 5. Evaluation of total improvement for the number of different ONUs

D. Comparing results

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In this section, the estimated time of program implementation and cost improvement will be evaluated. Table 2 compares the execution time of the program with MFO, WOA and HHO methods [13-15]. As can be seen, linear programming is not as repetitive as meta-heuristic algorithms and has a very short execution time. Since the result of the article [13-15] for one hundred users and three ONUs with map dimensions of 1000 * 1000, the comparison of the proposed method has been done with the same value. In order to evaluate the results of the proposed method, the cost improvement criterion is used. The result of this criterion is also shown in Table 3 and compared with the article [13-15]. These results show the efficiency of the proposed method compared to other methods. The proposed method has the same performance in terms of cost improvement as the article [13-15] but has performed much better in terms of implementation time. It should be noted that the results of the proposed method are the result of averaging the program 20 times. Because users are created randomly each time the program is run.

Table 2 Comparison of implementation time and cost improvement of the proposed method and article [13] per 3

Method	Author	Year	Cost improvement over greedy algorithm	Time (seconds)
MFO	Puja Singh [13]	2017	5.8	1266.8
WOA	Puja Singh [14]	2019	14.33	399.34
HHO	Puja Singh [15]	2020	15.2	111.48
linear programming	−	2022	15.2	5.01

In this dissertation, the optimization of the position of several ONUs in the FiWi network was presented. Optimal ONU placement has advantages such as increased throughput, cost efficiency, efficient load balancing and reduced network overlap. Due to this, the use of linear programming model has been used. Comprehensive simulation experiments have been performed to analyze linear programming in optimizing the position of ONUs in the FiWi access network. To this end, different settings have been tested when users are accidentally online. The simulation results of the proposed method are compared with the two existing strategies of MFO, WOA and HHO algorithms. The results confirm that the proposed method has the best performance in terms of simulation time among the existing algorithms. It is also competitive with other algorithms in terms of cost savings. Returns the optimal value of the cost function along with the WOA algorithm, taking into account the analysis based on the percentage reduction of the cost function.

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REFERENCES

[1]T.Koonen,Fibertothehome/fibertothepremises:what,where,andwhen?Proc.IEEE 94(2006)911–934.
[2] Ab-Rahman, M. "Analysis of Current Demand Features of Fiber-to-the Home/Desk (FTTH/D) Network in Malaysia," Journal of Applied Sciences Research, 7(5), pp.572–577, 2011.
[3] TJ Abaas, AS Shibghatullah, MM Jaber, "Use Information Sharing Environment Concept to Design Electronic Intelligence Framework for Support E-Government: Iraq as Case Study," Advances in Computing 4 (1), 22-24, 2014.
[4] TJ Abaas, AS Shibghatullah, MM Jaber, "Use Information Sharing Environment Concept to Design Electronic Intelligence Framework for Support E-Government Iraq as Case Study", Advances in Computing, 4 (1), 22-24, 2014.
[5] Sugumaran, S., Lakshmi, D. N., & Choudhary, S. (2021). An Overview of FTTH for Optical Network. Advances in Smart Communication and Imaging Systems, 41-51.
[6] Sen, D., Kaur, R., Kaur, K., & Bhamrah, M. S. (2021). A REVIEW ON PASSIVE OPTICAL NETWORK WITH COLORLESS ONU TECHNOLOGY.
[7] Yuan, M., Li, Y., Zhang, L., & Pei, F. (2021). Research on intelligent workshop resource scheduling method based on improved NSGA-II algorithm. Robotics and Computer-Integrated Manufacturing, 71, 102141.
[8] Li, J., Liang, Y., Wang, H., & Xin, H. (2021, February). Discussion on Installation and Maintenance of Optical Fiber Transmission Equipment Based on Computer Controlled Mode. In Journal of Physics: Conference Series (Vol. 1744, No. 2, p. 022049). IOP Publishing.
[9] Tian, X., Hu, L., Wu, G., & Chen, J. (2020). Hybrid fiber-optic radio frequency and optical frequency dissemination with a single optical actuator and dual-optical phase stabilization. Journal of Lightwave Technology, 38(16), 4270-4278.
[10] Asgarirad, M., & Jahromi, M. N. (2020). A taxonomy-based comparison of FTTH network implementation costs. Majlesi Journal of Electrical Engineering, 14(2), 71-80.
[11] Naeem, A., Qurashi, S. S., Khan, Y., Ahmed, S., & Safwan, N. (2021). Fiber to the Home (FTTH) Automation Planning, Its Impact on Customer Satisfaction & Cost-Effectiveness. Wireless Personal Communications, 117(2), 503-524.
[12] Ab-Rahman, M. S., Ridzuan, A. M., Kaharudin, I. H., & Hwang, I. S. (2022). Real time FTTH network monitoring using binary coded fiber Bragg grating. Optik, 251, 168408.
[13] P. Singh, S. Prakash, ONU placement by Moth-flame optimization algorithm, Opt. Fiber Technol. 36 (2017) 403–411.
[14] Puja Singh et.al. (2019). Optical network unit placement in Fiber-Wireless (FiWi) access network by Whale Optimization Algorithm. Optical Fiber Technology 52 (2019) 101965
[15]mPuja Singh et.al. (2020). Optimizing multiple ONUs placement in Fiber-Wireless (FiWi) access network using Grasshopper and Harris Hawks Optimization Algorithms. Optical Fiber Technology 60 (2020) 102357.