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Fiber to the Home (FTTH) Automation Planning, Its Impact on Customer Satisfaction & Cost-Effectiveness

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Abstract
The use of automated network planning systems is crucial for reducing the deployment cost and planning time of passive optical telecommunication networks. Mixed-integer linear programming (MILP) is well suited for the purpose of modeling passive optical networks; however, excessive computing times for solving large-scale problem instances render these approaches impractical. This research presented a formulation that was based on MILP. It is for the issue of optimum dimensions of fiber equipment of the FTTH optical-access network (FTTH-OANs). The key objective is to minimize the capital expenditure associated with the implementation of FTTH-OAN, i.e. the expense of passive and active tools (splices, fiber terminations, closures, cables, optical splitters, and OLT cards, etc.) site planning costs and the cost of labor needed. This formulation is installed and tested. The key results are derived from practical physical systems installed in homes.

Keywords MILP · Network design · Access networks · PON · FTTH

1 Introduction

Global consumer internet protocol traffic is expected to reach 233 EB per month by 2021 [1]. Increased demand for bandwidth requires Internet service providers to deploy access networks that can keep up with the increase in bandwidth usage. Asymmetric digital subscriber line (ADSL) technology is currently widely used in Pakistan and is on average slower than fiber-to-home (FTTH) [2]. Such an enhancement can be made by bringing fiber nearer to the client. Hence, A high trend in the replacement of outdated copper wires to fiber in their network access regions. The obvious solution would be to move away from ADSL and to passive optical networks (PONs), but this requires extensive network planning.

From this perspective, gigabit passive optical networks (GPON) [3, 4]) are now being introduced, which is an appropriate solution, particularly in the long term. GPON, also

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known as XG-PON, has enough more bandwidth than copper wires, resulting in additional efficient handling of higher demand. The XG-PON covers both operating and capital expenditure rationally concerning competing technologies such as active Ethernet, optical P2P, and Ethernet PON [5, 6].

We considered the FTTH-OANs that were built on GPON. An FTTH-OAN [3, 4, 7, 8] considered between optical network units and optical line terminals. Each FTTH-OAN optical network unit is segregated into sets. Each optical network unit of a particular set is linked via an optical allocation network to the same router of the optical line terminal, using multipoint resources based on passive optical splitters. Optical line terminal devices support bi-directional communication among the each connected optical network unit and line terminal, in the case of GPON, up to 10 Gb per second downstream and up to 2.5 Gb per second upstream.

The complexities involved in the design of the PON require the use of automated network design tools. Apart from the choice of splitter types and splitter locations, a cost-effective topology design is essential. There are several approaches (Table 1) in the literature to the design of cost-effective PONs, but there is typically a trade-off between the use of heuristics and accurate solution approaches. The former is typically more computationally efficient without any quality assurance solution, while the latter has the attractive feature of providing proven optimal solutions that may, however, be at the expense of computing times and memory usage Integer Linear Programming (ILP) is well suited for the purpose of modeling passive optical networks; however, it is an accurate solution approach, i.e. it may result in excessive computing times when solving large-scale problems.

2 Literature Review

The architecture issues of PON have been rigorously reported over the last few years, which is why it has massive research work. Unfortunately, however, various models introduced were presented when industrial experience in the roll-out of these types of networks was rather rare. As a result, many of the assumptions adopted in those research works are controlled by generalized considerations. Sometimes the reports do not contain essential elements, making them unworkable for commercial applications.

According to [9], if more UNs connect to the same fiber optic splitter, the most likely fiber optic cables would share portions of the same route. As the number of nodes increases, the number of routes between the UN and the optical splitter increases rapidly. While examining distinct routes between ONUs and optical splitters, it is possible that such routes could link trenches with routes to certain UNs. Van Logger Enberg, Grobler, and Terblanche [10], put forward a network flow-focused algorithm that constructed feasible solutions by limiting the number of pathways to improve the sharing of fiber ducts. Heuristic disintegration [11] in an attempt to reduce computing times by using the output of a centroid, a density-based, and a hybrid clustering algorithm. The computational results are favorable for large problem instances. Van Loggerenberg [12] uses a Benders decomposition approach to improve scalability. Ouali and Poon [13] demonstrate how ILP can be used to automate FTTH architecture by lowering the cost of telecommunications business capital. The proposed model involves inter-hierarchical PONs and optimum methods could be computed on the basis of so-called MediumNet data, composed of ninety-four UNs and two optical splitters, considered in their study. No optimal solutions for the so-called BigNet datasets (five optical splitters and 482 UNs) could be calculated.

Table 1 Model and heuristic notation

Name	Description	Usage
RECREM	Recursively removes the splitter that has the most impact on network deployment costs	When there is no obvious structure visible
KSPLIT	Clustering algorithm based on k-means. Estimates Potential optical splitter positions by grouping together optical network units based on their strategic position using the optical splitter position closest to the centroid	When ONUs are in clusters
CPARC	Commodity-pair arc-flow model, where ‘commodity-pair’ refers to a pair containing an optical splitter and a UN, or an optical splitter and a CO. Flow variable are defined for each pair of commodities	To obtain optimal solutions
HPATH	Path-flow model with paths limited to the shortest paths	Used as a heuristic by limiting the number of paths
AARC	Aggregated arc-flow model, where a single flow variable for each edge is defined	To obtain quality partial solutions
APATH	The aggregated arc-path model in which the distribution network uses the path-flow formulation and the feeder network uses the aggregated arc-flow formula	Attempt to combine features from aggregated arc-flow and a heuristic path-flow to reduce memory usage and network deployment cost

Various approximation approaches to solving PON planning problems are suggested—for example, simulated annealing, particle swarm optimization, and genetic algorithms [14–17].

Ample research is being done to optimize the design of GPON FTTH networks. Numerous methods of optimization used by MILP [18, 19] for metaheuristics [20, 21]. In addition, several design scenarios research work, observing the scopes of Green-field and Brown-field, and matching GPON 's split-level multi-level design, such as paper [18] highlighted the architecture of FTTH PONs with 2-level splitters and presented the MILP optimization model. This model minimizes cost splitters as well as fiber cables. The key objective of the authors was to increase computational performance through the use of an approach. According to this, it adds effective dissimilarities to the MILP on the basis of a mixing integer round rule that reduces the network graph by eliminating few possible sites for splitters that do not affect the viability of optimum resolution of the real issue. The results verified the effectiveness of this.

Another Green-field FTTH planning methodology was introduced in [22]. Customer houses and street sites are thus extracted from the Open Street Map [23]. Street routing graph made for computing distances, customers clustered and assigned to aggregate Remote Node (RN) equipment after which RN sites have finally resolved wire routes linking OLT to RNs and RNs to UNs have been optimized. Whenever a new connection is established and its cost significantly decreases, it will increase its chances of being selected again.

Mainly stated systems based on cost minimization, without taking into account administrative and maintenance restrictions. The [24] is the scarcest research that has dealt with a few of these issues. However, this research work uses distinct GPON architectures proposed as splitters that could be placed anywhere in the network and any node. Empirical factors are then immaterial in our situation where 32 way splitters are located in the FC cabinet. We, therefore, proposed the GPON FTTH design strategy, which used information on geographic roads to pacify cost minimization and realistic design.

The methodology that may be used in PON architectures is composed of MILP, which is Mixed-Integer Programming. However, the business sector is also reluctant to use real MILP approaches due to their major drawback, i.e. their ability to manage impairments in real deployments, while their major gain is a confirmed optimization gap that may not be of major importance. Many of the MILP methodologies presented earlier for FTTH network design are only effective in comparatively smaller test cases or inadmissibly basic models.

Similarly, split ratios are not taken into account according to [25], Additional details on the MILP models have been presented in [26]. This work also addresses the attenuation and cost of splices. Unfortunately, however, these types of models can only be used in small-scale implementations, such as twenty-eight client networks in this study [26]. It is worth remembering, however, that a small number of cases have arisen where the MILP method is used in companies [27]. The methodology used in the research presented required simplification, such as the efficient FTTH range, which would practically not exceed 10 km for the 1:64 gap [28], However, any simplification was defensible from a business perspective, as the effective scope of FTTH telecommunications was unrelated in heavily occupied urban areas that have been deliberated. One more instance of reducing complexity was the assumption that a large urban dissident infrastructure is accessible at any time, which is not inevitable in developing countries or small cities. The approach used in [27], is based on the MILP approach. Inequality and numerous algorithmic improvements are simplified.

New research [29], not taking into account the OLT and the costs of splitting, is noteworthy, however, in its thorough analysis of the issue of fiber splicing. Finally,

[30] presented a literature review of the MILP methodologies for PON architecture. According to the above discussions, the methodology that uses the MILP approach to FTTH architecture is significantly affected by a lack of docility that restricts its usefulness. The emphasis of scientists on empiric methodologies which would be addressed in the following section. Let's consider FTTH optimizing the solution proposed in [31], which resolved architectural issues on the basis of a 4-step methodology, where the first tree was initialized, after which all ONTs were divided into sets. For each set, an optimum location for a fiber-focused location is selected using the Ford technique. Finally, the researchers used the smallest route technique for the determination of distribution wire paths and a wide range network [32] for the determination of feeder wire paths. According to [33], an optimization methodology is proposed, i.e. an assortment of efficient methodology and a range of tree techniques. Finally, RARA, i.e. the Recurrent Associations and Relocations algorithms, was presented in [34]. This algorithm is an extension of the Coopers algorithm [35] which used multi-facility address and assignment issues in logistics research.

Recently, another empiric methodology was presented in [36]. This methodology depends on cluster and Tabu searches, which have been improved by the flexibility of treatment schemes as described in [37]. The methodology that we used in this research was initially proposed in [38] and focused on beam search [39]. This methodology is improved with the problems of indecision treatment under the scheme [40] and improved with the MILP refining scheme [41]. The final concept is a mixture of the MILP approach and the heuristics that have recently proved to be very effective and used in [42]. To summarize these approaches, which have been presented so far, are either faster heuristic approaches but, in many cases, cannot provide optimum resolution or accurate approaches that depend on the MILP working with simplified models and comparatively small networks.

3 Motivation

A PON implements a point-to-multipoint architecture in which the optical splitter serves multiple optical network units (UNs). UNs convert optical signals to electrical signals and are the devices used by customers to connect to the network. The central office (CO) contains optical line terminals (OLTs) which control the flow of information to the UN. The network has two components: the feeder network that connects the CO to all-optical splitters; and the distribution network that connects the UN to the optical splitters. The typical PON structure is shown in Fig. 1. Optical splitters cannot be used as switches and transmit the same data to multiple UNs. The main advantage of the optical splitter is a reduction in the cost of network deployment. Only one fiber from the CO to the optical splitter is needed to connect multiple UNs. Each optical splitter can serve a predetermined number of UNs, usually by a power of two. Multiple types of optical splitters may be placed at a single location.

PONs have a tree structure and the cost of network deployment can be reduced by placing several fiber cables in a single trench (duct sharing). The number of optical splitters at each location, the types of optical splitters, and the layout of the fiber cables (via optical splitters) must be chosen to ensure that all ONUs are connected to the CO at a minimum deployment cost.

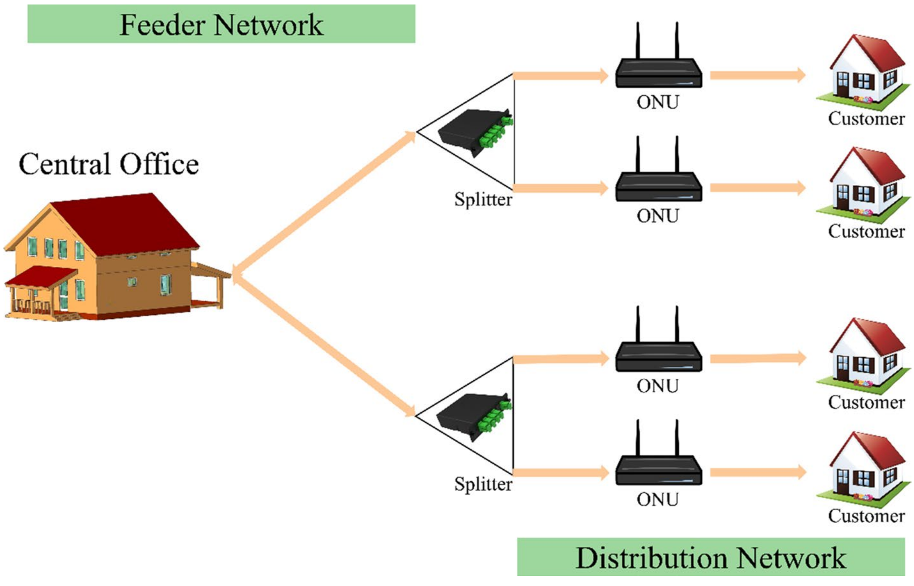


Fig. 1 Basic PON structure

4 Process and Planning Based on Automation

To maintain the FTTHN problem, the automation arrangement was established taking into account the general optimization framework shown in Fig. 2 at different stages.

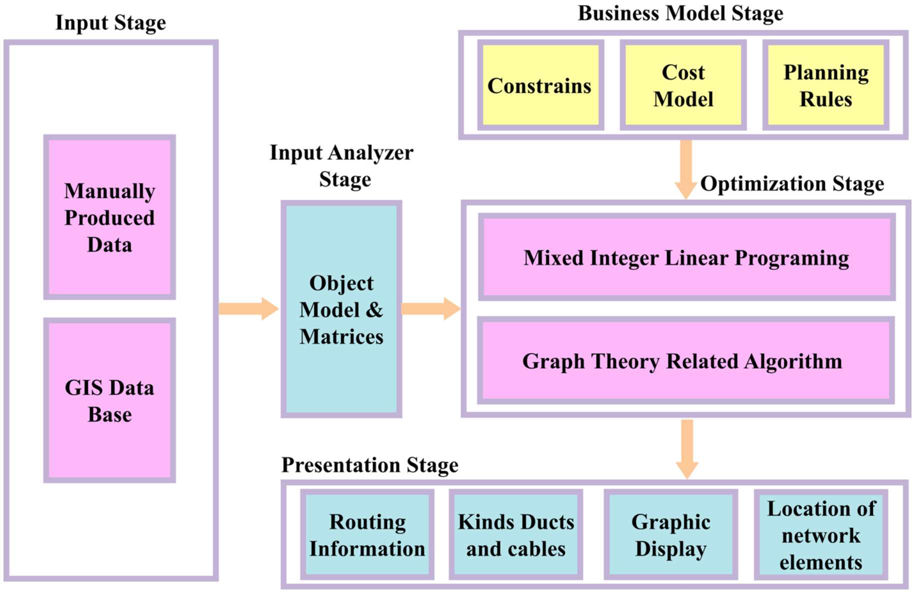


Fig. 2 Automation based planning process

4.1 Input Phase

At this stage, multiple origins can be used to obtain information like

1. Manually created files
2. Geographical Information Systems (GIS)

One of the main sources for the input data stage is the manually formed files. Usually, the designer uses an exchange or region diagram. The region is further divided into different sub-areas. Typically, designers select the center point of the region to install the main distribution box, which consists of several splitters. Besides, Client cables are assigned to DC splitters, i.e. Cabinet distribution. GIS data then covers network connection set-ups. Typically, there was a 3D data arrangement with a global database. It combines a vast array of geographical objects with an abundant set of characteristics so that data can be recovered quickly.

4.2 Input Analysis Stage

Since the information collected from different sources is in various forms, such as form, Esri, and DXF, this phase is used to extract the necessary information from the source. First, the data is transformed into certain vectors that make up the data needed to implement efficient optimization techniques.

4.3 Business Logical Stage

At this point, we summarize the cost model with the engineering principles. The engineering principles will be used to minimize the cost of network architecture. This expense model covers various network construction costs, such as HR, ducting, wiring, and network equipment costs. This process is extremely problematic as well as being changed regularly to meet the need. Besides, this step validation can be achieved manually. In this process, full cost measurement and design limitations should be tested. The project planner may use the proposed model to test their business strategy. It can be evaluated on different methods of optimization after the completion of the business strategy planning.

4.4 Network Optimization Phase

- This stage consists of an optimization technique based on MILP. In MILP some parameters have a numerical value. Binary parameters are molded to our issue in MILP. Before implementing the MILP-based design method, we assumed that the following information would be available:

    - Spare technology specifications needed to support the potential development of the network.
    - A public layer network that defines the connection in different network elements.
    - Quantity of residences for all buildings, specifying the total number of PON connections required.
    - Potential CD that is cable distribution sites

- Location of the exchange installation and
- Positions of the customer site

5 Formulations of Partial Problems

This section provides a comprehensive formulation of partial problems that are, bundle layer dimensioning partial problem which is denoted by $\mathcal{P}^{BL}$, cable partial problem which is denoted by $\mathcal{P}^{IL}_{cable}$ and site partial problem that is represented by $\mathcal{P}^{IL}_{site}$.

All sections are made up of four portions.

i. Assumptions that comprise assumptions that are assumed to be relative to any partial problem;
ii. Part of the variable cost
iii. A possible part of the package of concepts
iv. Variable definition of part of the decision

The partial site, cap, and splice problems provide objective development of variables that link to decision-making factors and to bundle layers to address the partial dimensioning problem.

The goal of optimization is to minimize the entire cost of network deployments.

5.1 Layer of Bundle and Partial Issue Dimensioning

Such issue dimensioning objective is to determine the type and quantity of splitters that are mounted on the access, division, and header node bundles. In addition, the type and quantity of the OLT CO location card are chosen. This approach ensures that almost every CP location is provided with sufficiently robust optical signals, regardless of the distance from the CO location.

5.1.1 Suppositions

The following are the suppositions:

i. Only 1 head terminal packet node, n^{blh} exists
ii. The division cone of each node of the bundle distribution is given,
iii. The physical size of all infrastructure routes provided; thus, distances from each connection package to the header of the package node are also specified.
iv. Any signal network link that fulfills the access package node petition, shares the same delivery infrastructure trail and similar trunk infrastructure trail.
v. Just proportioned splitters with undifferentiated splitting ratios are permissible.

In the above assumptions, the first three consequences are derived from the way in which the proposed model is used. Refurbish the resolutions repaid by adjusting the wire sizes and adjusting the cabinet splitters. Trails and their size are also provided that they are not susceptible to variance. 4th Supposition restricts resolutions based on the use of a single route and petition. Resilience is overlooked in the study; therefore, resolution using multi-route approaches may result in cost issues for the individual client. At the end of the day, authors restrict their function to the symmetrical splitter, as they are often used. Our presented technique the coverage of asymmetric splitter cases could still be widened.

5.1.2 Decision Variables

Below variables of decision has been added based on partial problem signal layer.

Integer variables signify splitters number of splitters of class $r \in \mathcal{S}^r$, is provided from OLT card of kind $c \in \mathcal{S}^c$, installed, at the head terminal, division $v \in \mathcal{N}^{BLD}$, or accession $t \in \mathcal{N}^{BLA}$, bundle nodes.

The variable $\mathcal{X}_{vcr} \in \mathcal{K}$ which signifies the quantity of signal connections based on head-terminal node bundle to a trunk connection n^{blh} to division node bundle $v \in \mathcal{N}^{BLD}$, is provided from OLT cards kind $c \in \mathcal{S}^c$, and linked to head-terminal node bundle against kind $r \in \mathcal{S}^r$ splitter.

The variable $\mathcal{X}_{vtcrs} \in \mathcal{K}$ which signifies the amount of links to the bundle distribution connection $l \in \mathcal{L}^{BLD}$, driving from bundle division node $v \in \mathcal{N}^{BLD}$: $bb\ \_a\ (l)=v$, towards accession nodes $t \in c(v){:}v=bb\_\ b(l)$, in v's division cones; signals connections is provided based on OLT cards of kind $c \in \mathcal{S}^c$, a being linked at division v and accession t node bundles towards, $r \in \mathcal{S}^r\ and\ s \in \mathcal{S}^r$ kind of splitters.

The variables of integer $\mathcal{M}_{vcnm} \in \mathcal{M}_+$, which signifies the range of signal connections on the bundle trunk connecting the head-terminal of the node bundle to the division node bundle $v \in \mathcal{N}^{BLD}$, loaded based on the OLT cards of kind $c \in \mathcal{S}^c$, and linked to the splitter of type $n \in \mathcal{S}^r$, at head-terminal node bundle and to the splitter of $m \in \mathcal{S}^r$ kind, on the division node bundle v.

Lastly, the integer variable $\mathcal{C}_c \in \mathcal{M}_+$, signifies the quantity of OLT card $c \in C$ kind, that is mounted on the at head-terminal nodes.

5.1.3 Set of Reasonable

For streamlining formulations challenge, the authors henceforth adopt singleton sets $\mathcal{S}^c$ which means that it involves just 1 kind of card of OLT which could be mounted on bundle node head-terminal; therefore, we could avoid to index set $\mathcal{S}^c$ in restraints (1a–1f). Formerly, partial problems of the signal layer can be expressed as.

$$\sum_{v \in \mathcal{N}^{BLD}} \mathcal{X}_{vcr} \le \mathcal{K}_{cr}\eta^r, \quad r \in \mathcal{S}^r \tag{1a}$$

$$\sum_{r:\exists(r,s)\in\mathcal{S}^{2r}} \mathcal{M}_{vcrs} = \mathcal{K}_{vcs}, v \in \mathcal{N}^{BLD}, s \in \mathcal{S}^r \tag{1b}$$

$$\sum_{s:\exists(r,s)\in\mathcal{S}^{2r}} \mathcal{M}_{vcrs} \le \mathcal{X}_{vcr}, v \in \mathcal{N}^{BLD}, r \in \mathcal{S}^r \tag{1c}$$

$$\sum_{t \in bb-c(v)} \mathcal{X}_{vtcrs} \le \mathcal{M}_{vcrs}\eta^s, v \in \mathcal{N}^{BLD}, (r,s) \in \mathcal{S}^{2r} \tag{1d}$$

$$\sum_{w\in\mathcal{S}^r}\mathcal{K}_{tcw}\leq\sum_{(r,s)\in\mathcal{S}^{2r}}\mathcal{X}_{vtcrs},v\in\mathcal{N}^{BLD},t\in bb\_c(v)\tag{1e}$$

$$\mathcal{K}_{tcw}\leq\sum_{(r,s)\in\mathcal{S}_t^{2r}}\mathcal{X}_{vtcrs},v\in\mathcal{N}^{BLD},t\in bb_{c(v)},\in\mathcal{S}^r\tag{1f}$$

$$\sum_{s\in\mathcal{S}^c:p^s\geq p^u}\sum_{r\in\mathcal{S}^r}\leq\sum_{c\in\mathcal{S}^c:p^c\geq p^u}C_c\eta^c,u\in\mathcal{S}^c\tag{1g}$$

$$\sum_{c\in\mathcal{S}^c,w\in\mathcal{S}^r}\mathcal{K}_{tcw}\eta^w\geq h(t),t\in\mathcal{N}^{BLA}\tag{1h}$$

Limitations (1a) confirms all signal connections on the bundle of trunk connections linked on the node of head-terminal of kind $r\in\mathcal{S}^r$ splitters, Isn't really larger than ports of the output of those splitters mounted at head-terminal nodes.

Limitations (1b) impose signal numbers connections inflowing division node $v\in\mathcal{N}^{BLD}$, and linked to splitters via $s\in\mathcal{S}^r$, It is the same number as those splitters which are mounted at v node.

Constraints (1c) impose stability in $\mathcal{M}_{vcrs}and\mathcal{X}_{vcr}$ variables uttering that number $\mathcal{X}_{vcrs}$ based on signal connections on the bundle trunk link $l\in\mathcal{L}^{BLD}$: $bb\_a(l)=n^{blh}$, $bb\_b(l)=v$, that have been linked to $r\in\mathcal{S}^r$ splitters, at the head-terminal node and ended $s\in\mathcal{S}^r$ splitters, at v distribution node which is lesser than $\mathcal{M}_{vcrs}$ of signals connections on the link bundle linked to splitters r on the head-terminal nodes.

Likewise, limitations (1d) impose stability in $\mathcal{M}_{vcrs}and\mathcal{X}_{vtcrs}$ uttering signal number connections joining accession nodes $t\in\mathcal{N}^{BLA}$, and driven at head-terminal with division node by splitters $(r,s)\in\mathcal{S}^{2r}$, not surpass the quantity of s-type splitters Splitter Interface Ports that are mounted at v *node*, as imposed by $\mathcal{M}_{vcrs}$.

Constraints (1e) confirm complete splitter number that is mounted on $t\in\mathcal{N}^{BLA}$ accession nodes, which do not surpass the complete signal number connections joining this node.

The limitations (1f) define the quantity of splitters of w- the kind that is mounted on t an access nodes which do not surpass the number of signal connections entering the node which provide appropriately robust signals. It takes benefit of a supplementary set that is $\mathcal{S}_t^{2r}\subseteq\mathcal{S}^{2r}$ of pairs of splitter which assures the gratification of power expenditure on the t accession node that is specified as $\mathcal{S}_t^{2r}=\left\{(r,s)\in\mathcal{S}^{2r}\ :\ \exists(a,b,w)\in\mathcal{S}^{3r},a=r,b=s,a_{rsw}+d_t.a\leq t_c\right\}$. In this expression "$a$" signifies a reduction introduces to optical fiber signal 1 km while t_c signifies optical signal power that is requisite on the ONT/UN entry ports.

The limitation (1g) create a number C_c of the cards of OLT of $c\in\mathcal{S}^c$ type, mounted at head-terminal node

Lastly, the constraints (1h) describe that each signal demand h(t) is gratified; therefore, the total number of output signal connections of t access node is not lesser.

5.2 Partial Cable Issue

Partial cable issues include the estimation of the quantity, kinds of distributions trunk and wires to be built in all segments of infrastructure, while each segment of infrastructure is represented as $l \in \mathcal{L}^{IL}$. Mounted cables shall supply the variety of trunk and fibers delivery as needed under $\mathcal{P}^{BL}$.

5.2.1 Suppositions

We apply the following suppositions:

- There is a maximum a single trunk cable at any infrastructure segment,
- The bundle of distribution links does not exchange parts of the networks,
- A maximum of a single distribution cable at one infrastructure segment is present,
- Distribution fiber segments and Trunk fiber segments can't share any cable segment which means that he fiber and trunk for transmission should not be enclosed in one cable.
- An infrastructure potion should be attributed to a maximum of one portion preparation.

These Hypotheses are proposed mostly to make the subsequent optimization algorithm extra docile but also to improve the control, repair and operation of the networks. The assumption number five limits the scope of possible resolutions by eradicating certain designs that demonstrate cost-effectiveness.

However, our initial work does not recur in cases where the transmission trunk and fiber have a common connection. Succinctly, the fifth assumption raises the costs of the resolutions that have been reached, but this increase is not important.

5.2.2 Linking Variables

We introduced $\mathcal{X}_l^{ILH} \in \mathbb{K}+ \ : l \in \mathcal{L}^{ILH} and\, \mathcal{X}_k^{ILD} \in \mathbb{K}+ \ : k \in \mathcal{L}^{ILD}$ variables to connect the cable partial problem by bundle layer partial problem which is addressed in Sect. 5.1. These variables signify requisite fibers at, trunk segment and distribution segment that are represented by $l \in \mathcal{L}^{ILH} and\ k \in \mathcal{L}^{ILD}$ respectively. They are connected to theundle layer partial problem's variables through the following expressed constraints (2).

$$\mathcal{X}_i^{ILH} = \sum_{c \in \mathcal{S}^c} \sum_{r \in \mathcal{S}^r} \sum_{v \in \mathcal{N}_i^{BLD}} \mathcal{X}_{vcr}, i \in \mathcal{L}^{ILH} \tag{2a}$$

$$\mathcal{X}_i^{ILD} = \sum_{c \in \mathcal{S}^c} \sum_{r \in \mathcal{S}^r} \sum_{v \in \mathcal{N}^{BLD}} \sum_{t \in c(v) \cap \mathcal{N}_i^{BLA}} \mathcal{X}_{vtcr}^{BLD}, i \in \mathcal{L}^{ILD} \tag{2b}$$

In the above constraints, we feat sets of accession nodes and b bundle distribution nodes that are represented by $\mathcal{N}_i^{BLD} and\, \mathcal{N}_i^{BLD}$ respectively. These are represented in the below equations:

$$\mathcal{N}_i^{BLD} = \left\{ \mathcal{V} \in \mathcal{N}^{BLD} \ : \ \exists l \in \mathcal{L}^{BLH}, bb_b(l) = v \cdot i \in bi_p(l) \right\} \tag{3a}$$

$$\mathcal{N}_i^{BLA} = \left\{ t \in \mathcal{N}^{BLA} \ : \ \exists l \in \mathcal{L}^{BLD}, bb_b(l) = t, i \in bi_p(l) \right\} \tag{3b}$$

5.2.3 Decision Variables

We implemented a binary variable G_{lg}^{IL} for any infrastructure portion that belongs to the set i.e. {0,1}. It specifies the segment preparation g that belongs to $\mathcal{S}^{g}(l)$, that was chosen in this portion.

The fibers that are mounted on the infrastructure portion of transmission and trunk cables are depicted via $\mathcal{M}_{l}^{ILH} \in \mathbb{M}_{+} and \mathcal{M}_{l}^{ILD} \in \mathbb{M}_{+}$; respectively, that are integer variables. The real quantity of communication trunk and wires of every kind, that installed in there is signified by, $\mathcal{A}_{la}^{ILH} \in \mathbb{M}_{+} and \mathcal{A}_{la}^{ILD} \in \mathbb{M}_{+}$ respectively

5.2.4 Viable Set

Henceforth authors will depict limitations (4) whic impose a dimension of just division wires at the infrastructure portion. The whole design requires further similar sets of limitations for trunk cables dimensions.

$$\sum_{g \in \mathcal{S}^{s}} G_{lg}^{IL} \leq 1, l \in \mathcal{L}^{ILD} \tag{4a}$$

$$\mathcal{A}_{la}^{ILD} \leq \sum_{g \in \mathcal{S}^{g}(l):a \in \mathcal{S}^{a}(g)} G_{lg}^{IL}, l \in \mathcal{L}^{ILD}, a \in \mathcal{S}^{a}(l) \tag{4b}$$

$$\sum_{a \in \mathcal{S}^{a}(l)} \mathcal{A}_{la}^{ILD} \leq \sum_{g \in \mathcal{S}^{g}(l)} G_{lg}^{IL}, l \in \mathcal{L}^{ILD} \tag{4c}$$

$$\mathcal{M}_{l}^{ILD} = \sum_{a \in \mathcal{S}^{a}(l)} \mathcal{A}_{la}^{ILD} \eta^{a}, l \in \mathcal{L}^{ILD} \tag{4d}$$

$$\mathcal{M}_{l}^{ILD} \geq \mathcal{X}_{l}^{ILD}, l \in \mathcal{L}^{ILD} \tag{4e}$$

In above (4a) imposes that every infrastructure distribution segment which is represented l which is represented by 1 t one segment preparation type.

Equation (4b) and (4c) addressed that type a which belongs to $\mathcal{S}^{a}(l)$ of transmission cable that is mounted in portion l which belonged to $\mathcal{L}^{ILA}$, is constant with cable preparation type g that belongs to $G^{g}(l)$, nominated for this segment.

Equation (4d) is set the value of $\mathcal{M}_{l}^{ILD}$ of total fibers in division wires that is mounted at the poltion l. Lastly, the Eq. (4e) confirms the fibers quantity in division wires mounted at the infrastructure portion l.

5.3 Site Equipment Partial Problem

Partial issue of site equipment issue includes determining the type and quantities of equipment built at each infrastructure site.

5.3.1 Suppositions

No supposition has been stated.

5.3.2 Variables of Linking

Cumulative quantity of signal connections to or from sites belonging to $\mathcal{N}^{ILSL}$, indispensable for ascribing head end, division $d \in \mathcal{N}^{BLD}$, and accession $a \in \mathcal{N}^{BLA}$ nodes bundle intended to be installed there, specified, by $\mathcal{V}^{BLH-} \in \mathbb{M}_+, \mathcal{V}_s^{BLD+} \in \mathbb{M}_+, \mathcal{V}_s^{BLD-} \in \mathbb{M}_+, \mathcal{V}_s^{BLA+} \in \mathbb{M}_+ and \mathcal{V}_s^{BLA-} \in \mathbb{M}_+$ variables. It is easily stated by signal partial problem variables.

5.3.3 Variables of Decision

The following are certain variables in the decision, we consider:

- Choosing a location kind $f \in \delta^f$ assigned to locations $s \in \mathcal{N}^{ILS}$, we consider the Boolean variable $\mathcal{F}_{sf}$,
- Complete quantity of cabinets of kind $e \in \delta^e$, that are mounted at infrastructure locations $s \in \mathcal{N}^{ILS}$, For the head-terminal held in there, division $\mathcal{N}^{BLD} \subseteq \mathcal{N}^{bl}$ and access $\mathcal{N}^{BLA} \subseteq \mathcal{N}^{BL}$, bundle nodes is signified, by $\mathcal{Y}_{ve}^{BLH} \in \mathbb{M}_+, \mathcal{Y}_{ve}^{BLD} \in \mathbb{M}_+ and \mathcal{Y}_{ve}^{BLA} \in \mathbb{M}_+$, integer variables respectively.
- Quantity of OLT kind $o \in \delta^o$ that are mounted on CO location are signified by $O_o \in \mathbb{M}_+$ integer variable.

5.3.4 Viable Set

The partial issue of location infrastructure included some of the below limitations that are expressed by (5a–g).

$$\sum_{f\in\partial^{f(s)}} F_{sf} \le 1, \quad s \in \mathcal{N}^{ILS}, \tag{5a}$$

$$\sum_{e\in\partial^e} (Y_{se}^{BLH} + Y_{se}^{BLD} + Y_{se}^{BLA}) \le \sum_{f\in F_v} \eta^{fe}, s \in \mathcal{N}^{ILS} \tag{5b}$$

$$\sum_{o\in\partial^o} \eta^o O_o \le \sum_{f\in\partial^{f(v)}} F_{nf}\eta^{fo}, \left(n \equiv n^{ilso}\right), \tag{5c}$$

$$\sum_{c\in\partial^c} W_c \le \sum_{o\in\partial^o} O_o\eta^o, \left(n \equiv n^{ilso}\right), \tag{5d}$$

$$V^{BLH-} \le \sum_{e\in\partial^e} Y_{ve}^{BLH}\eta^e, \left(n \equiv n^{ilso}\right), \tag{5e}$$

$$V^{BLD+} + V^{BLD-} \leq \sum_{e \in \partial^e} Y_{ve}^{BLD} \eta^e \quad s \in \mathcal{N}^{ILS}, \tag{5f}$$

$$V^{BLA+} + V^{BLA-} \leq \sum_{e \in \partial^e} Y_{ve}^{BLA} \eta^e \quad s \in \mathcal{N}^{ILS}, \tag{5g}$$

The constraints (5a) expressed that site $s \in NI\ S$ is maximum of a single site of type $f \in \partial^f$

The (5b) and (5c) constraints confirm the entire mass of cabinets while the entire mass of OLT equipments that are mounted on site s not surpass the cabinet η^{fe} and OLT η^{fo} *the* capability of that site.

The (5d) constraint ensures that the equipment of OLT that are mounted at CO locations could carry the necessary quantity of cards of OLT of the required kind.

Lastly, (5e), (5f), and (5g) constraints guarantee the cabinets that are mounted on the locations are capable of controlling requisite signal number connections, either distribution or trunk, entering or leaving these locations.

6 Results and Outcomes

This section is intended to assess the overall performance of the proposed MILP methodology. Initially, we present the test methodology that we take into account in the experiments. The third sub-section sets out the benefits of the proposed MILP approach.

This section will end with the argument that the optimality breaks have been achieved.

6.1 Methodology of Testing

The proposed technique is consistent with the heuristic methodology. It was implemented in the C-sharp version of Visual Studio 2010. These two approaches have been run in the 2016 version of Windows Server.

Testing scenarios have been developed through a process optimization technique implemented in [43] on real-world FTTH architecture issues in the Peshawar area of Planned Accommodations. This region of Peshawar is a mixture of different building designs from the business districts of towers, the multi-unit suburban districts, and the vast single-family rural neighborhoods' techniques used to optimize positions at the head terminal and the division point that are based on computational hardening. Process Initiated by choosing arbitrary head terminal and division positions, and by expressly limiting time efficiency, we can achieve consistent designs considered by separate distribution points and head-end nodes. Therefore, the test cases obtained are by no means identical to the FTTH OAN cases.

Simulated hardening is used to optimize the trunk and distribution of trees. Using a strategy that combines the shortest distance and the least spanning tree algorithm, the starting trees are chosen. By using the same compromise strategy, adjacent solutions are achieved by bringing costs from a few bounds to zero. Testing can be achieved by using these strong, but logical and cost-effective trundle and distribution trees. Finally, the primary collection of mixtures of used splitters is optimized by the use of simulated hardening.

It is presumptuous because any requirement can be met by a limited splitter quantity, which in turn restricts and reduces the number of vacancies.

Table 2 Test cases

Entity	Maximum	Average	Minimum
The total size of Edges	106.1 km	67.7 km	38.2 km
Edge	3180	2108	739
Demands	1440	994	321
Customers	36,849	23,308	13,152

Twenty designs of the FTTHOAN cover of Peshawar were used. The overall designs that are organized are 200 different FTTH OANs, which vary in size and capacity. Four general statistical test cases originate in Table 2 below.

The testing approach is the following.

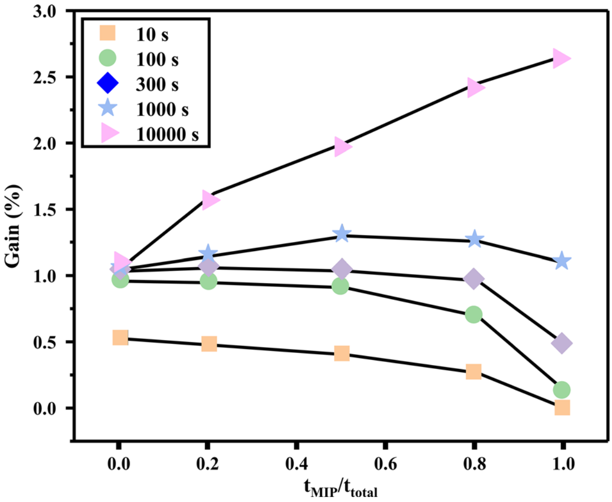
First, the experiential method used in [38] was run for t_{heur} time. The attained resolution was used as a preliminary resolution for the MILP approach that was run for the t_{MIP} time. Entire-time was signified by the equation $t_{total} = t_{heur} + t_{MIP}$. In different experimentations, we inspected that most of the values of t_{MIP} and t_{heur} comparing the whole expenses of the design of the prototype. Outcomes have been deliberated under the following section.

6.2 Improvement

By using the stated approach, the capability of the proposed MILP methodology improved empirical resolutions was assessed. The outcomes are shown in Fig. 3. In this figure, improvements are specified for the values that have time limits t_{MIP} *and* t_{heur}.

Let C_{st} be the expense of a solution using technology standards [44] for splitting the design choice and C_{fns} for resolution expenses. It has improved the splitting designs that are using an approach which is stated in the preceding section. The improvement is understood by $\frac{C_{st}-C_{fns}}{C_{st}}$.

Fig. 3 Attained improvement



Observe that C_{fns} must be lesser than C_{st}. In experimentations, five values of the entire running time were used, that are 10, 100, 300, 1000, and 10,000 s. In experimentations, five values of the entire running time were used, that is:

i. $t_{heur}=0, t_{MIP}=t_{total}$
ii. $t_{heur}=t_{total}, t_{MIP}=0$
iii. $t_{heur}=\frac{1}{2}\cdot t_{total}, t_{MIP}=\frac{1}{2}.t_{total}$
iv. $t_{heur}=\frac{1}{5}\cdot t_{total}, \quad t_{MIP}=\frac{4}{5}\cdot t_{total}.$
v. $t_{heur}=\frac{4}{5}, t_{total}, t_{MIP}=\frac{1}{5}, t_{total}.$

The results achieved could be simple when the overall execution duration is long or small.

During the first example, the limitation period was too low associated with MILP methodology, which requires a significant duration of the initial CPLEX calculations and reduces production; therefore, prioritizing the methodology of the growing fraction of production. t_{MIP}/t_{total}, and it only led to a decline in time, which is used for actual optimization by empirical methodology. If so, if the t_{total} is amply greater, the MILP methodology can simply display its supremacy over empiric methodology. Figure 3 shows exactly where t_{total} = 10,000 s. If the time limit is large, the MILP methodology exceeds the empirical methodology. Moreover, it does not have to be directed to provide high-quality start-up resolution but is equally effective when only a realistic start-up resolution is provided. Cases become extra complex in the case of a mean time limit of thousands or three hundred seconds, as in presented study. Outcomes specifying the average time limit the MILP to be applied to the full level of its competencies. In the event that a full-time range of of three hundred or thousands seconds was employed only via the MILP, the findings were not reasonable. Although the same MILP technique has been used for eighty percent of the time available to facilitate resolution obtained by observational methods running for the first twenty percent of the time available, the findings are much more desirable. With a time of 300 s, the best approach is to use the empiric methodology based on entire duration. Though, for the duration limitation of 1000 s, the range of methodologies presented outcomes of effective performance. Figure 3 shows a case of a 1000 s time constraint strategy, the time available was approximately the same in methodologies. If the time set for the MILP technique $\leq 20\%$ of the complete duraiton, CPLEX cannot make the most of its analytical resources.

In contrast, when the duration was longer or identical to eighty percent of the entire duration, the intial resolution set to CPLEX was of low value and that could not instantaneously enhanced. Lastly, outcomes depicted based very large duration time, attainment few hours for every FTTH tree, MILP expressively outclassed empirical methodology that provides improvement nearly 3 percent, while empirical methodology after preliminary improvement generated in the first hundreds of seconds did not increase greatly but lastly provided improvements lesser than 1 percent.

The results were produced with a test case time of 10,000 s using the maximum time used by the MILP methodology. Outcomes show that almost total improvement was achieved by dropping the size of the cables and controlling the amount of splicing. But the number of OLT cards has been dimly increased by the use of additionally effective fibers. We are providing a clear illustration of this phenomenon. A small community of three houses, each with 40 apartments. This could be assisted by 3 fibers linked to 3 OLT inputs, which end at a sixty-four-output splitter every of these three structures. As a result, 5–8 output dividers can be mounted in these buildings through a fifteen-fiber wires that leaves the clearance. The 15 fibers could be linked to the eight channel splitters. The previous resolution requires a thin 3-fiber cord that connects settlements and 3 OLT ports to the head terminal node. The later resolution used a 15-fiber thicker cable requiring two ports of OLT ports on the head terminal node.

According to our test case, deceptively earlier such resolutions had been extra-anticipated. It can not be seen as a generic outcome—an ideal resolution framework that depends on the prices of multiple materials and is incredibly dependent on a particular test case. The alternative view shown in Fig. 4 is that the effects of cabinets and splitters on overall improvement are comparatively low. Though the complete price of splitters is constant, these certainly cannot be detached based on the MILP model due to close linkage to the cost of OLTs. On the other hand, the influence of the cabinet is not very significant. Assuming there is a relatively limited selection of the current cabinet, the dimensions of the cabinet used are rarely changed. These may then be detached on the basis of the MILP model. But the complication of cabinet restraints is comparable to their effect on outcomes.

Finally, this is important to address the role of splicing in the MILP model. This appears as though splicing may have detached from the MILP model since splicing rates were closely related to cable rates. Our research shows that this is just a little correct. Observably, the reduction in cable size also reduces the number of splices. It, therefore, lowers the price of splicing. Achieved improvement due to the optimization of splicing cannot result only from decreasing cable sizes. Comparative alterations of different expense of parts are shown in Fig. 5. MILP optimisation lowered the overall expense of cable division by <1%. At about the same time, the average cost of distribution splicing decreased by about four percent. Suppose that the price of the head terminal splitters is $10,000 in base design, while Fig. 5 shows the head end splitters whose price is almost $8,200 in optimized design. Results significantly specifying the splicing improvement are not only produced by decreasing the splicing amount by decreasing the cable sizes but are opposed to its main part resulting from optimized splicing, such as tapping the cable into two separate cables instead of splicing it.

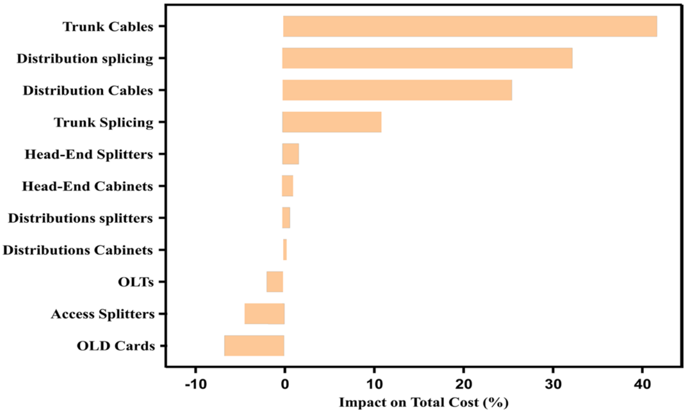


Fig. 4 Effect on the total expense of various parts of the solution

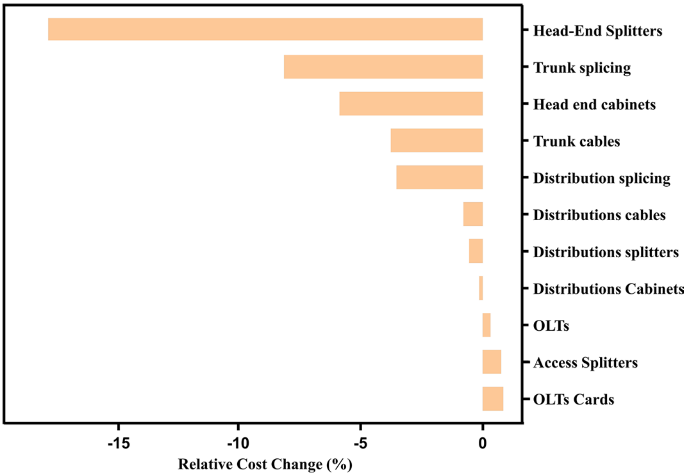


Fig. 5 Comparative cost variations of components

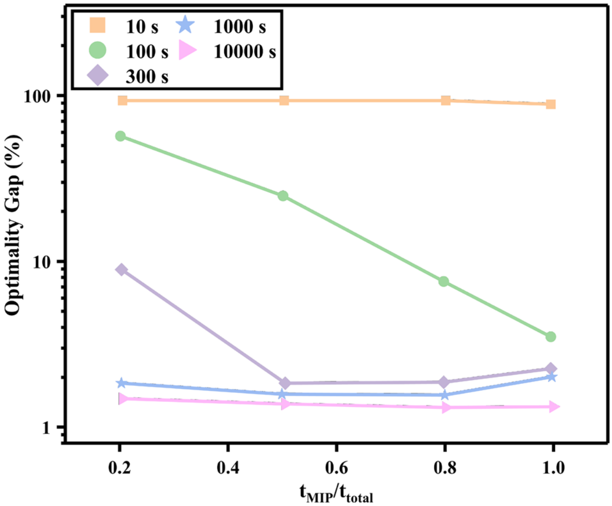


Fig. 6 Optimality gap

6.3 Optimality Gaps

According to the figure above, there are gaps in the optimality achieved by the MILP solver. The approach used to achieve results is similar to the previous case.

In Fig. 6, the optimality gaps reduce by increasing the running time allocated to MILP. For the longest time limits, the optimality gaps reduce almost 1.3 percent, allowing us to argue that the existing MILP technique usually produces high-quality resolutions. For the time limits of one hundred and three hundred seconds, the distance increases when the whole duration is given to the MILP. Thus, at that time, the

MILP solver did not really raise the lower bound as effectively as the empiric technique reduced the higher bound, which was also a good reason to strengthen the MILP with empirical techniques for the test cases considered to be intermediate specific times.

7 Conclusion

The MILP framework was proposed for the optimal structural design of the FTTH tree device issue. This wording and the primary network topology have been defined and explained. This model has been accepted and introduced. The final results depend on the empiric tests identified in the real world discussed in this study. Our methodology presented has shown that it is effective and capable of improving the resolution achieved through a standard empiric methodology. Our experiments have shown that the proposed approach is effective as a standard for improving resolutions when running time is extremely limited. It's not a problem, though, in case of limited time. The proposed methodology is significantly more effective than standard approaches, as long as a proper preliminary resolution is provided. Proper preliminary resolution can easily be achieved by applying engineering rules.

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