Towards automation of fibre to the home planning with consideration on OPTIC access network model

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Abstract: Owing to the rapid technological evolution, tough competition and budget limitation, the service providers are struggling to provide a cost-effective solution to minimise their operational cost with extraordinary customer satisfaction. One of the factors that increase the cost of overall Fibre To The Home (FTTH) network is the unplanned deployment resulting in utilisation of extra components and resources. Therefore, it is imperative to determine a suitable technique, which helps to reduce planning process, required time and deployment cost through optimisation. With the intention to meet the increasing demand of future higher bandwidth applications, the fibre-based access is considered best resolution to deliver triple play services (voice, data, video). It is therefore preferred with great need to migrate from traditional copper-based network to fibre-based access. Automation-based planning is one of the possible ways to automate the network design at probable lowest cost. In this research, a technique for migration from copper to fibre access network with a climbable and optimised Passive Optic Network (PON–FTTx) infrastructure is proposed identifying the need for new technology in developing countries.

Keywords: passive optical networks; GPON; triple play; FTTH; fibre to the home.

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1 Introduction

In developed countries the broadband internet access plays a major role in the foundation of a society. A few nations are now completing their way toward broadband society, while remaining countries are still on their way to complete their journey. For this purpose, the network provider must consider new fibre-based technologies instead of their old copper-based access infrastructure to complete the journey. In addition, the bandwidth limitation in copper and wireless networks, makes it possible to bring the fibre as close as possible to the subscriber; which is the major cause for replacing the old copper network with fibre in the access parts. In this scenario Passive Optical Network (PON) is an appropriate resolution, specifically for a long term planning. Fibre-based network can deliver more bandwidth as compare to available copper and wireless network, it also making it easier to efficiently cater the high bandwidth demand for data hungry customer in the future.

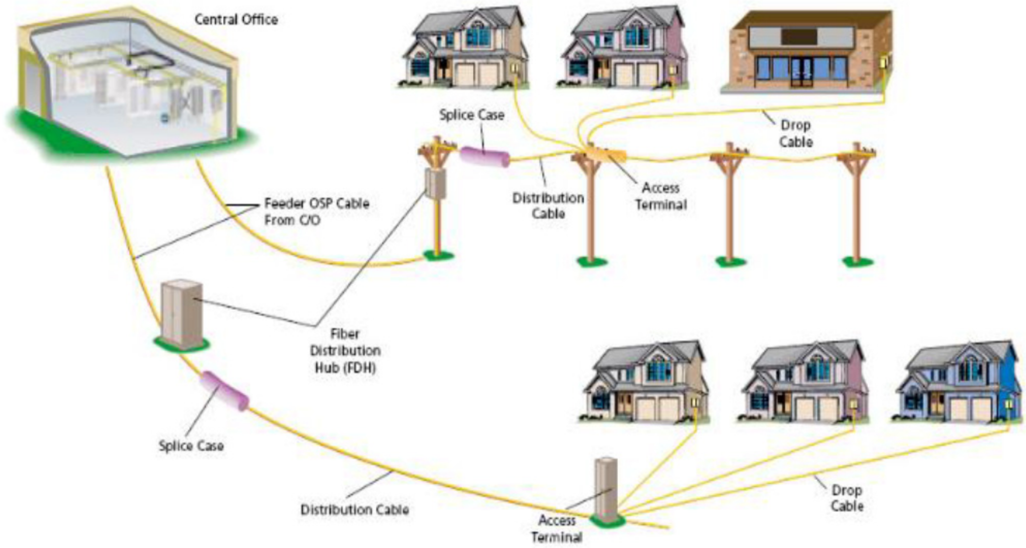
Currently, FTTH network is the prime solution for PON which allows 128 Optical Network Units (ONU) to be connected with one fibre from OLT terminals. The optical splitters are used to share the bandwidths which are connected with OLT. This reduces the time slots in the optical signal. These time slots further allocate to a certain ONU with the capacity of 10 Gbits/s in downloading and 2.5 Gbits/s in uploading. In effective deployment of FTTH network, fibre is extended to each subscriber which needs intensive labour work and extra funds for its completion. In this manner, to reduce the massive investment cost detailed and systematic deployment design is needed. The optimisation of FTTH network is a very vast field that can be entered from many directions using various techniques based on mathematical programming (Bley et al., 2013; Angilella et al., 2018; Hervet and Chardy, 2012; Li and Shen, 2009), pure heuristics (Mitcsenkov et al., 2011), or a mixture of the above (Zotkiewicz et al., 2016). The customer location in a normal FTTH network is known and the major task is to find out best location for distribution box and access points. After that, it is important to joint them with optical fibre through splitter. To reduce the power budget, the OLT must be installed at the central point.

In this way, an acquired result can't utilise long routes and sizes of splitters utilised between subscriber and OLT are also restricted not only by the power budgeting, but also due to technical reasons. All these factors must be taken into account when designing an FTTH network, along with trenching and equipment costs.

1.1 Components of GPON FTTH network

A Passive Optical Network (PON) is capable of having P2M (point to multipoint) network with passive components like optical splitter or coupler along the transmission section. It uses active components only at CO and at customer premises. It uses WDM to mix up video signals with the data and voice from OLT. Figure 1 shows a basic FTTH network.

Figure 1 FTTH network



1.1.1 Optical line terminal (OLT)

It is the most important part of the network, where the electrical signals from the service provider's equipment are converted into optical signals and given to the feeder network. The mode of transmission from ONT is broadcasting (Zotkiewicz et al., 2016; Cantono et al., 2019) from where it sends GEM frames through the GEM port with GEM port IDs It is capable of having multi-service chassis for FTTx deployments, supports a variety of service types, non-blocking architecture with and routing within distributed architecture, scalability and line rate performance, Full electrical and optical redundancy Outstanding scalability and line rate performance, real-time network traffic monitoring and analysis.V8240 GPON OLT is used.

Figure 2 Optical line terminal

1.1.2 Optical network terminal (ONT)

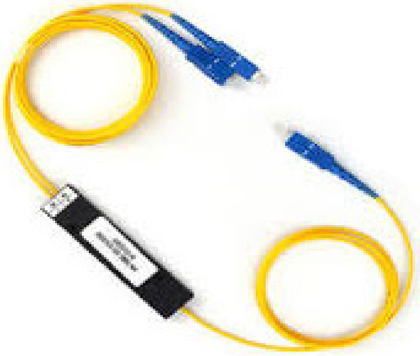
It is an active component used at customer premises which converts optical to electrical signals. ONU/ONT represents the single customer where they will get the triple play application. H640 series GPON ONT are used. It is capable of having carrier class VoIP telephony supporting both MGCP and SIP protocols, flexible VLAN tagging support, QoS for traffic prioritisation and bandwidth management, IGMP support for IPTV applications.

1.1.3 Optical splitter

The passive optical splitter (also called "optical splitter" or "splitter") is the key equipment of a PON. This equipment is connected to one optical fibre on one side (upstream fibre), and to several fibres on the other side (downstream fibres). It splits the signal coming from the upstream fibre on downstream fibres, and groups the signals coming from the downstream fibres on the upstream fibre.

Splitters are used to physically split the fibre into number of fibres; to couple same or different information to N users. MxN planar splitters are used which is based on Planar Light wave Circuit (PLC) technology and high precision alignment. MxN splitters can split or combine light from one or two fibres into N outgoing fibres uniformly over a wide spectral range with ultra-low insertion loss and low polarisation dependent loss. With up to 64 output ports, these splitters are ideal for high density split applications like Fibre To The Home (FTTH) networks, FTTx Deployments Optical CATV Networks, CWDM and DWDM Systems, Passive Optical Networks, Fibre Communication Systems Telecom, LANs. It has the features like Low Insertion Loss, ultra broadband performance (1260–1630 nm), Low PDL and PMD, stability towards thermal variations, superior port to port uniformity. A splitter type is shown in Figure 3.

Figure 3 PLC splitter with ribbon fibre

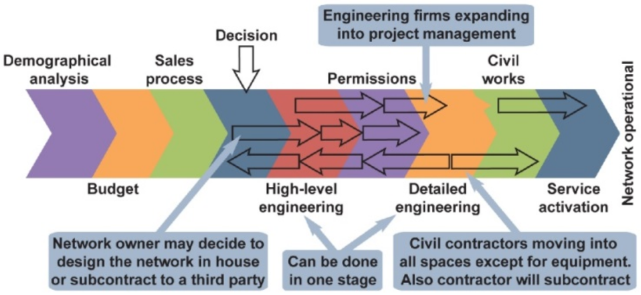


2 Business model of FTTH planning

2.1 *Business model of FTTH planning*

With the intention to meet the increasing demand of future higher bandwidth applications, the fibre-based access is considered to be a best resolution to offer triple play services. It is therefore preferred with great need to migrate from traditional capper-based network to fibre-based access. A business Model of new FTTH network deployment is illustrated in Figure 4. This includes some dependent and independent variables.

Figure 4 Business model of FTTH optimisation



2.1.1 *Business input*

In Pakistan the broadband growth in Wireline is very slow which is very much obvious. In Cantono et al. (2019), the slow growth is due to some factors that need improvement; these factors include:

- Low literacy rate
- Low (level of) consumer awareness
- No coverage of broadband services
- Traffic reduction in broadband services low computer penetration
- Cost of service (tariff)
- History of market and national regulation

2.1.2 *Business output*

The output of new FTTH deployment translates into different benefits (Chen et al., 2006)

i *End user/customer benefits*: High bandwidth is the main selling product of FTTH network; it provides the highest available bandwidth in both directions (downstream and upstream). A FTTH user can download data over 10 times quicker than ADSL user. Transfer rates of different content over various types of networks are shown in Table 1.

Speed of ADSL over copper network is inversely proportional to distance from customer end to telephone exchange, while in FTTH network distance does not effect on speed. In DSL network Signal to Noise Ratio (SNR), interference and crosstalk during operation also reduces the throughput. Customer satisfaction ratio in FTTH network is above 85 %, higher customer satisfaction has a tendency to enhanced customer retention and reduce churn.

Table 1 Download/upload transfer rate

Data	*FTTH*		*CATV*		*DSL*	
	Down	*Up*	*Down*	*Up*	*Down*	*Up*
Pictures up to 1 GB	1 M 23 S	1 M 23 S	2 M 46 S	13 M 52 S	19 M	2 Hr 32 M
Standard video Up to 5 GB	6 M 31 S	6 M 31 S	13 M 2 S	1 Hr 5 M	1 Hr 29 M	11 Hr 29 M
HD quality video up to 25 GB	24 M 40 S	24 M 40 S	1 H 9 M	5 Hr 47 M	7 Hr 55 M	–

ii *Service provider benefits*:

- ✓ The lifespan of fibre cable is very long as it is more than 30 years therefore FTTH is known as a "future-proof technology". Fibre cable made of simply plastic and glass, which reduce its lifespan extremely slowly. The fibre cable has almost unlimited capacity and expansion in bandwidth needs only changes to the hardware at the ends of the link.
- ✓ Operational cost (OPEX) of FTTH networks is very low as compare to existing copper networks. It consumes 20 times less power than other. The operational and maintenance cost can be minimizing by automation control. Maintenance costs can also reduce because there is no active device in the field to maintain, and optical components have better reliability.
- ✓ Customer satisfaction will reduce the churn value and retain customers, which also reduces operational cost. To keep the existing customers is so easy as compare to enlist new one.

iii *Community benefits*: FTTH enable communities to get a lot of benefits with a wider range of internet services. Some examples of possible benefits with FTTH networks are as under:

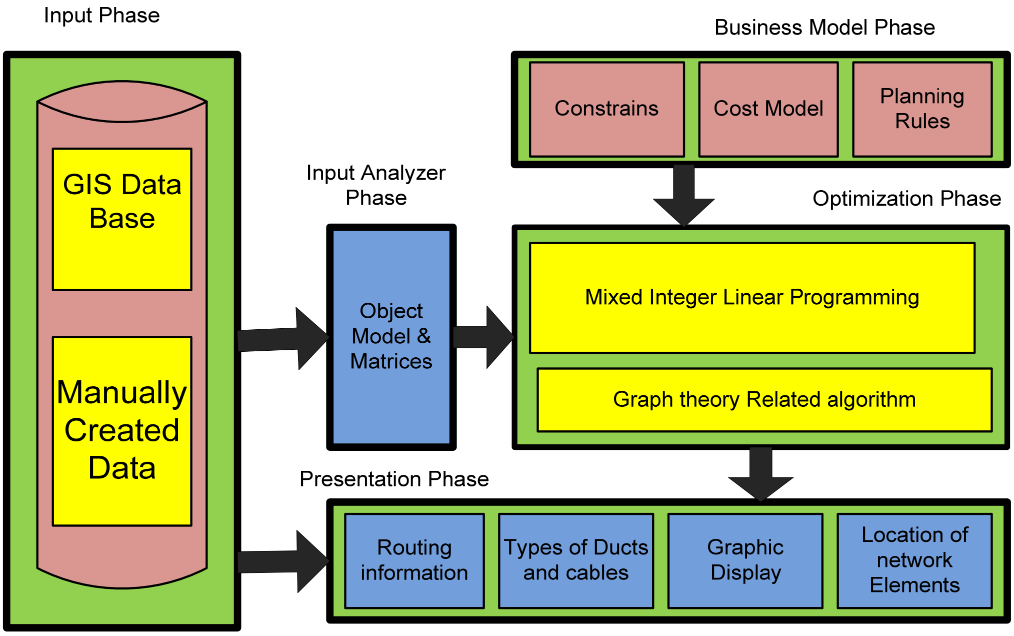
- ➢ Financial boost with global competition.
- ➢ Attraction for new businesses.
- ➢ Provisioning of state of the art services in education and health sector.
- ➢ Improving overall quality of life in a community by increasing the opportunities for communication.
- ➢ Controlling of road traffic blocking/problem

2.1.3 *Automation-based planning and process*

To grip complication of FTTHN, an automation scheme is settled by keeping in mind, common optimisation framework, which shows in Figure 5 with different phases.

A *Input phase*: In this phase various sources can be used to retrieve the data

Figure 5 Automation-based planning process



i Geo-graphical information systems (GIS)

ii Manually formed files

GIS data contains the setup of access network. Usually it used a geographical database with a three-dimensional data structure. To get the quick recovery of information, it associates a wide range of geographic items with a rich set of attributes.

Manually created files are the second source of input data phase. A map of an exchange or area is typically used by planners. The area is further divided into different regions. The planners usually choose a central point of the region for installation of Main Distribution Box (MDB) which consists of various splitters. Moreover, they allocate cables from end user to splitters through Distribution Cabinet (DC).

B *Input analyser phase*: As the data gathered by different sources are in different format such as DXF, Esri Shape, so this stage is utilised to filter the required data from input source. The data is first transformed into some matrices which consist of required information to perform optimisation procedures efficiently.

C *Business logic phase*: The comprehensive cost model with engineering rules summarises in this stage. To reduce the cost of network design problems the engineering rules used for constrains. Different costs of network design like HR cost, ducting costs, cabling and network equipment cost includes in this cost model.

This phase is especially problem particular as well as frequently modified to meet necessity. Moreover, the verification of this phase can be obtained by manual solution. Calculation of complete expenditure and design limitation will validate in this phase. The business designer can validate their business model with the proposed model. After the completion of business model, it can be tested on various optimisation methods.

D *Network optimisation phase*: This phase consists of optimisation approach based on Mixed Integer Linear Programming (MILP). It is a distinct variation of the linear programming. In MILP few variables have integer values. In MILP, our problem is moulded by binary variables (Amable and Vela, 2019; Poon and Ouali, 2011; Skubic et al., 2009).

Prior to executing the MILP-based design tool, we assumed that below given details are delivered:

- Locations of customer sites.
- Location of one exchange E.
- Possible sites of Cable Distribution (CD)
- Number of occupancies for all premises, that determines number of required PON links.
- Civil layer network which specifies connectivity in different network components.
- Requirements of spare capacity needed to accommodate future network growth.

3 Motivation

In this paper, a network design tool for the GPON/FTTH network is proposed to automate the planning process. Thus, given the locations of customer plots, possible locations of CDs and SPs, the tool decides the optimal or near optimal locations of CDs and SPs taking into account the future growth and spare capacity distribution. In addition, cables are assigned from each plot to a CD and to the selected SP.

The solution is optimal in the sense that it leads to the minimum cost of deployment which includes the number of network elements required, the total cabling distance and the installation costs.

By using an automated planning assistant tool, the planner can:

- Minimise network capital expenditure, i.e., installation and materials costs.
- Quickly achieve the network design of a given area.
- Compare what-if scenarios to meet changes in planning requirements.
- Rapidly re-cost networks for contract control and installation.
- Produce cable design and bill-of-materials automatically.
- Specify pre-determined locations for network elements prior to performing the network optimisation.

The benefits of automating network design include reducing installation and material expenses, decreasing time to make a design from hours to minutes, speedily re-costing networks for different labouring or equipment costs and making network design as well as automatically making bill-of-materials too.

4 Literature review

In GPON network, the cost optimisation is very appealing theme but maximum researches are made in developed countries, where public concentration is high; According to Amable and Vela (2019), the authors built up a cost optimisation with a structure based on Integer Linear Programming (ILP), which is utilised in execution and designing of PON networks in brownfield, and when details about existing infrastructure is known, this is done deploying small cell backhaul. The outcome is a half cost saving as compared to point to point, and the expense incorporates fibre and hardware.

In Felix et al. (2013), a hierarchical model for dimensioning GPON is proposed considering different deployment alternatives like fused fibres, man-hole usage, street cabinet, etc. We can utilise this model for centralised GPON architecture where flexibility of network itself, which is a drawback for GPON network. The research was conducted taking into account economic indicators such as net present value, internal rate of return, etc., and the outcomes were approved thinking about various situation , the variance is due to the utilisation of street cabinets, hand holes and the availability of network in the feeder and distribution points. In Shakya et al. (2018), the networks that based on MILP, a design tool for GPON/FTTH networks are proposed. This tool automates the planning process of networks. By providing positions of customers and probable positions of SPs and DCs, it adopts optimum positions of DCs and SPs as well as assignment of cables in network elements and customers. Thus minimises entire network development cost. The researchers took in to consideration future progression and introduced a technique for planning large networks.

Poon and Ouali (2011) proposed a mixture of heuristics and mathematical programming for minimising deployment cost of a GPON. The methodology of this research work was similar to simulated annealing by which assignment of cables as well as positions of splitters recursively reallocated till the best cost was found. Akhtar et al. (2018) proposed a tool for semi-automated network planning. It defines a suboptimal route distribution for deployment cost. It utilises existing cable channels. After clustering customers, the authors of this research utilise GA for route deployment process. The outcomes are compared to network designs attained by manual process which depicted that in most cases this tool generates an inexpensive network.

Hervet et al. (2013) proposed a MIP-based approach which used with an effective inequities and different algorithmic improvement. Another recent work by Orange Labs is Angilella (2018). Most of assumptions and approaches used in this study are similar to our research. But, it concentrates only the last FTTH network access part therefore, they do not consider splitting and OLT costs. Still, the detailed view on the fibre splicing problem presented in Skubic et al. (2009) is definitely worth noting. There are two main streams of research focusing on GPON technology: Dynamic Bandwidth Allocation (DBA) algorithms among OLT and ONUs, which can be found in Chen et al. (2006) and optimal network design of the physical layer for GPON deployment.

There are two main streams of research focusing on GPON technology: DBA algorithms among OLT and ONUs, which can be found in Lee (1993); Bock et al. (2008); Skubic et al. (2009); Chen et al. (2006), and optimal network design of the physical layer for GPON deployment. The latter is the one considered in this research and discussed in detail. Using the classical operational research approach, the planning problems can be considered as a ordered concentrator network problems. In context of GPONs, the concentrator acts as a splitter to connect several ONUs to an OLT in a star topology. When several splitters are connected to the OLT at different locations, it becomes a double-star topology.

Lv and Chen (2009) developed an optimisation solution to perform multi-hierarchy PON planning. In their case, upper Optical Branching Devices (OBDs) and lower OBDs were introduced. The upper OBDs were used to connect between OLT and lower OBDs whilst lower OBDs were used to connect between ONUs and upper OBDs.

The locations of OBDs were calculated based on the Max-Min Distance Cluster (MMDC) algorithm which can be found in Shakya et al. (2018). Regarding the optimisation framework, authors in Lukasiewycz et al. (2011) introduced a segmental framework which primarily emphasised on metaheuristic optimising approaches. Practical samples from motorised domain were used to validate how overall problem could break down in to sub-jobs and controlled through propose framework.

In Steve (2008), the author works on collective deployment of access network architectures such as Fibre To The Node (FTTN), Fibre To The Micro Node (FTTN) and Fibre To The Premise (FTTP) to decrease span of loops of coppers through use of DSL access multiplexer in external cabinet and field micro node which are nearer to subscribers. Several classes of services and subscribers per class per point of demand are considered. The MILP model has been proposed together with a tabular search base process for improving computational time needed for finding best resolution.

5 Automation leading to optimisation

MIP approach is usually using in different means in FTTH networks designing. According to our research work, we adopt MIP for the improvement of results that are returned by empirical algorithms of optimisation framework that are introduced in Zotkiewicz et al. (2016). Framework used: locations of demand, the available setup, with labour and equipment as well as technology restraints. It returns a complete network planning comprising: the topology of network, OLT, splices, splitters, OLT cards, cables, splices closures as well. By using stated aspects in modelling of a problem would lead to a myriad of variables and restraints making acquired model unsolvable by overall up-to-date MIP solvers. Hence, issue must be shortened for making it amenable. Key supposition for using this approach is for improved acquired solutions; simplifying of model depends on neglecting ostensibly least significant factors, such as splicing. While apparently additional significant factors, such as the OLT sites, may be static and detached from model. In our research our purposes are optimisation of capital expenses essential for the placement of FTTH-OAN which contains one or more OLTs at the CO location and group of points of access that are located in the or nearby to the CP locations. Networks require loads of all points of access take in to account permissible power budget of optical links and split scenarios.

5.1 *Prerequisites data*

The problem that is denoted by Δ needs the given below input data:

- Passive and actives equipment's record.
- Infrastructure networks topology
- Every distribution and access node infrastructure paths that are selected
- All access nodes signal demand
- The infrastructure sites that are decided for the installing active, passive equipment's.

5.2 *Decision variables*

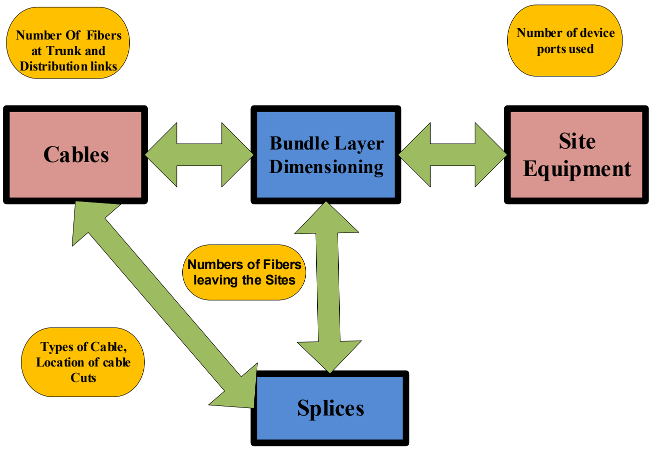
For optimisation, the decision variables are followed:

- Cabinet types utilisation (given nodes).
- All types of splitter with locations utilisation.
- All types of cables utilisation (given topology).
- Splice closure and splicing locations utilisation.
- OLT types splice closures (locations are given).

5.3 *Problem statement*

Keeping in mind the structure as well as complexities of complete problem, in our research description of its formulation is split in to four (4) problems that are depicted in Figure 6 as a square. We decided that these partial problems interlinked. The semantics of each variable that link to specific couples of partial problem is drawn by the shape of oval.

Figure 6 Block diagram of proposed structure for OLT



First part of problem is the *bundle layer dimensioning denoted by* Δ^{Bl}. Its purpose is that at assessing number with all types of splitters that are installed and at selection number of OLT cards to be installed at Central Office (CO) nodes as well. Delivered resolution promises that all accessing nodes, irrespective of their distance to the CO, delivered with requisite optical signal of appropriate power.

The second part of problem is *cables which is denoted by* Δ^{I}_{cab}. It defines number of cables of all types that are installed at every infrastructure segment. Installed cables are to provide fibres in numbers sustaining requests of bundle layer dimension problem.

Splices are the third part of problem. *It is denoted by* Δ^{I}_{Spl} which calculates number of optical closures and splices of all types which are essentially installed in every infrastructure node for supporting of solutions assessed in first two problems.

The fourth part of problem is *site dimensioning. It is denoted by* Δ^{I}_{Sit}; its goals are selecting a site type and number with all types of hardware cabinet that are installed in each infrastructure location.

5.4 *Problem objectives*

Key objective of $\mathcal{P}$ problem is to decrease the total cost is expressed by all partials of the $\mathcal{P}$:

$$\Delta = \Delta^{Bl} + \Delta^{I}_{cab} + \Delta^{I}_{spl} + \Delta^{I}_{sit} \tag{1}$$

In equation (1) Δ depicts overall cost. The symbols Δ^{Bl}, Δ^{I}_{cab}, Δ^{I}_{Spl}, and Δ^{I}_{Sit} are depicting cost of individual parts of $\mathcal{P}$ that are bundle layer, cables, splices and site dimensioning respectively.

5.5 *Description layout of problem*

To simplify the overall layout, we split the problem in to two portions. The first part is the model part that is described in Sub-section 6.1 which presents architectures with important notions that expresses overall organisation of FTTH-OAN. The second part is equipment catalogue that is described in Sub-section 6.2. This part describes a catalogue set which identifies all equipment types. For every type, a set of critical parameters such as capacity, cost.

6 Model of model of FTTH-OAN

This section presents a comprehensive model of all resources of FTTH-OANs which is shown in Figure 7. It is appropriate for the requisites of formulation of the optimisation problem. This model shown in Figure 8 by dividing it into two fragments those are:

1 Network

2 Equipment

The network fragment consists of equipment needed for installation in infrastructure nodes and segments such as cables, segments preparation types, hardware cabinets, OLT devices and cards, cable closures, splitters, etc.

Figure 7 FTTH-OAN basic network

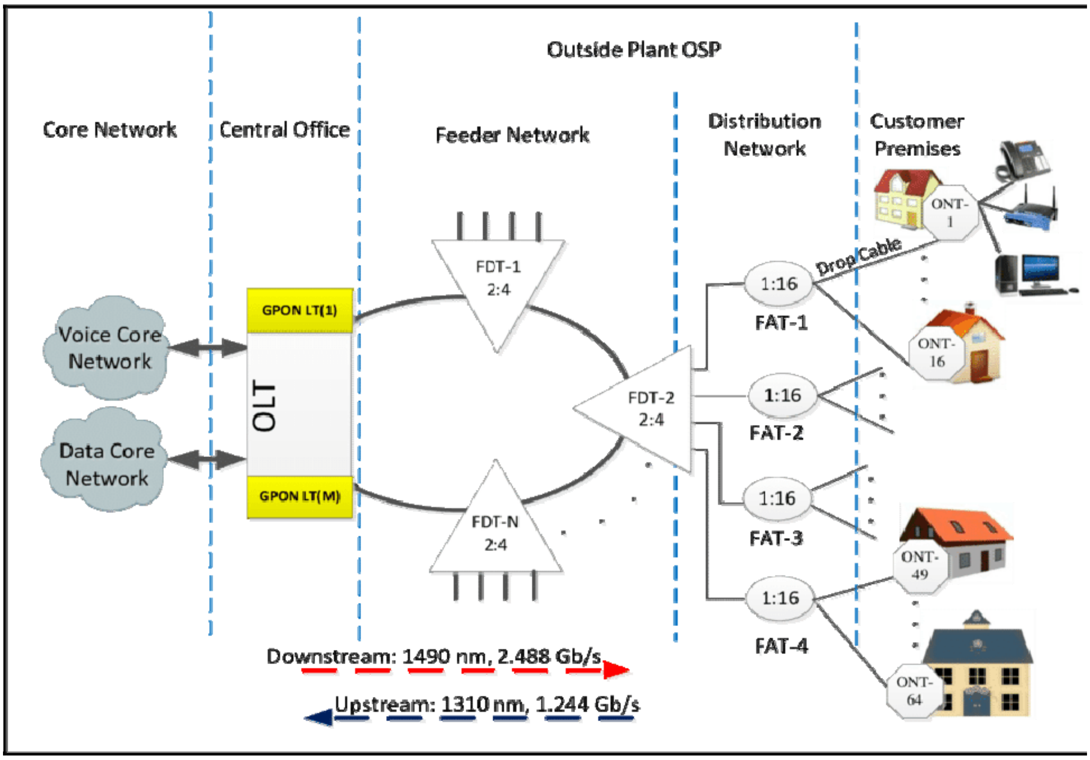
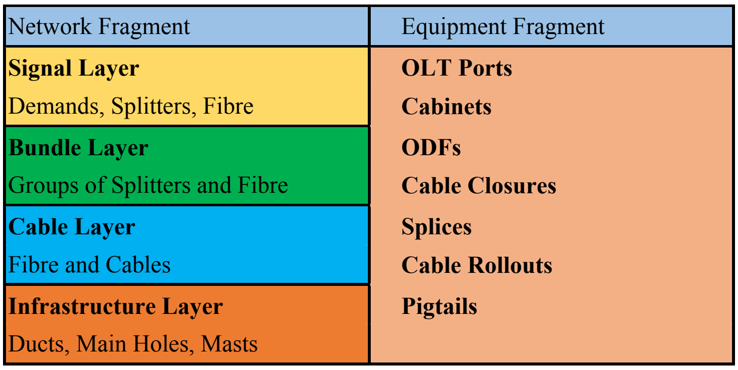


Figure 8 Model fragments



Network Fragment	Equipment Fragment
Signal Layer Demands, Splitters, Fibre	**OLT Ports** **Cabinets**
Bundle Layer Groups of Splitters and Fibre	**ODFs** **Cable Closures**
Cable Layer Fibre and Cables	**Splices** **Cable Rollouts**
Infrastructure Layer Ducts, Main Holes, Masts	**Pigtails**

6.1 *Network fragments*

According to telecommunication modelling rules, we split networks fragment in to stack of layers. In these layers every pair of neighbouring layers, upper layer which is client, gains the benefits of all resources provided by the lower layer which is server. We differentiate the four (4) layers starting from *signal*, *bundle*, *infrastructure and cable layer*.

Descriptions start from signal layering model. It contains an essential base for our optimising methodology. It classifies components of signal nodes and links that are needed for delivering signal networks links in ONT and OLT devices. Unluckily, signalling model differentiates each individual component. Its direct application in formulation of optimising problem leads to unsatisfactorily great optimisation problem instances. To deal with this issue, we present a layer of aggregated bundle model. It takes collections of signal nodes and connections as a bundle instead of distinct ones. As there is intricate relation in layers hence we settled their descriptions in an order which does not follows layers' order.

6.1.1 *Model of infrastructure layer*

This layer characterises network of channels that are connected through staves which can accommodate optical cables that supports multiple ODNs. Network needs to be linked therefore at least one link in Central Office and all ONT must be existing nodes.

Figure 9 shows the infrastructure layer topology. Topologies of the infrastructure layers are molded by an undirected graph $G^{IL} = \left(\mathcal{N}^{IL}, \mathcal{L}^{IL}\right)$, with group of *infrastructure nodes denoted by* $\mathcal{N}^{IL}$ and group of undirected *infrastructure links denoted by* $\mathcal{L}^{IL} \subseteq \mathcal{N}^{IL} \times \mathcal{N}^{IL}$. Infrastructure node that is denoted by n which is belongs to $\mathcal{N}^{IL}$, signifies a position, like a staves or a pole, in which optical wires sacked. The infrastructure link that denoted by $l \in \mathcal{L}^{IL}$ which signifies a place-holder, such as channel in pair of infrastructure node. All links can accommodate different optical wires.

We differentiate a set $\mathcal{N}^{ILS} \subseteq \mathcal{N}^{IL}$ of infrastructure sites such nodes which furnished to hold either signal splitters or active devices. These locations depend on their positions in service area of networks, apportioned in to central office sites $\mathcal{N}^{ILSO} \equiv \left\{n^{ilso}\right\}$, distribution point sites $\mathcal{N}^{ILSD}$ which are specified by *DP*, point of access locations $\mathcal{N}^{ILSA}$ that are indicated by *AP* while the customer premise sites $\mathcal{N}^{ILSP}$ are depicted through *CP*.

Finally, we describe a set $\mathcal{P}^{IL} \subseteq \mathcal{L}^{IL}$, that is the all *infrastructure links* with a suitable subset $\mathcal{P}^{ILS} \subset \mathcal{P}^{IL}$ of *infrastructure trails*; through supposition, for a couple $n_1, n_2 \in \mathcal{N}^{ILS} \times \mathcal{N}^{ILS}$ of infrastructure locations. There is selected maximum one infrastructure link that denoted by $p \in \mathcal{P}^{IL} : p \in \mathcal{P}^{ILS}$ denoted the infrastructure trail of this pair.

6.1.2 *Model of cable layer*

The infrastructure trail maintenances several parallel concentrating *fibre links in* a pair of its end infrastructure locations. Every fibre link contains a series of directed segments of *fibre* that are linked permanently or temporarily at the infrastructure node as optical splices or ODFs. Fibre and cable segments are shown in Figure 10.

Figure 9 Infrastructure layer topology

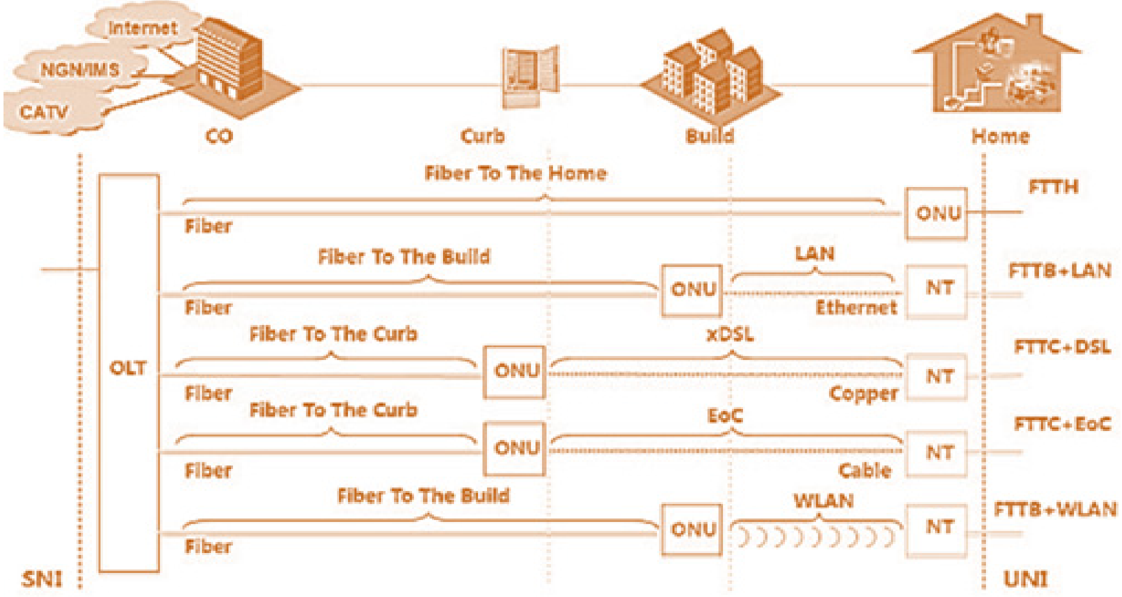
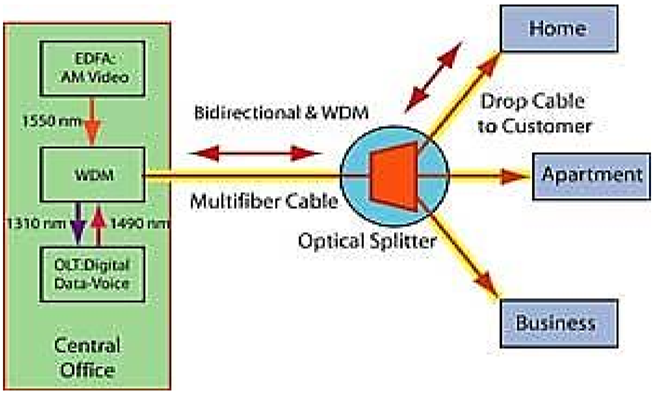


Figure 10 Fibres and cable segment



Lastly, optical cables segments are incessant segment of optical cables that is installed in infrastructures route containing single or multiple infrastructure segments.

6.1.3 *Model of signal layer*

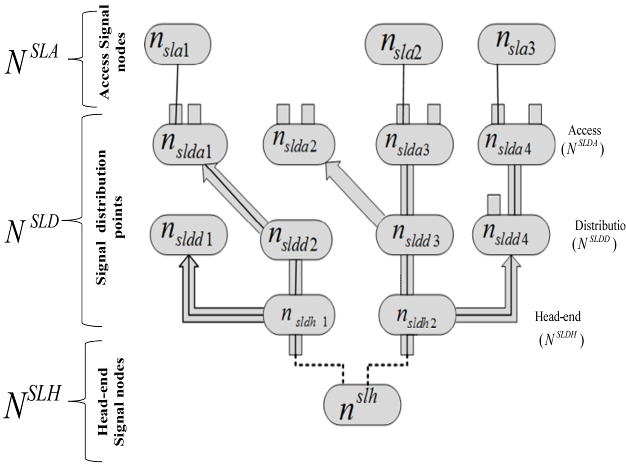
Signalling layer gives a group of descendent signal network links in OLT devices ports, ONT terminals and group of parallel ascendant network links which links ONTs to OLTs for a single FTTH-OAN. These links are provided through the passive ODNs containing a set of signal splitters connected by dual directional fibre optic routes.

Signal layer topology is signified by a graph. This graph is denoted by G^{SL} which is equal to signal node and group of directed signal connections. It is containing a group of signal nodes that are denoted by $\mathcal{N}^{SL}$ and group of directed signal connections denoted by $\mathcal{L}^{SL}$. Figure 11 shows the signal nodes with links and connection. The signal nodes show that signal transporting functions are done through active as well as passive devices. The signal connections signify in turn distinct fibre optic routes interrelating couples of signal nodes. The $\mathcal{N}^{SL}$ is divided in to set head end nodes that is denoted by $\mathcal{N}^{SLH} \equiv \left\{n^{slh}\right\}$, set of access nodes denoted by $\mathcal{N}^{SLA}$, and set of signal distribution points denoted by $\mathcal{N}^{SLD}$. The set $\mathcal{N}^{SLD}$ is also divided into sets of distribution, head end and access signal distribution points that are denoted by $\mathcal{N}^{SLDH}$, $\mathcal{N}^{SLDD}$ and $\mathcal{N}^{SLDA}$, respectively. This division reveals level that engaged by specific splitters within network links. The $\mathcal{N}^{SLA}$ are real source of signal demand of specific access node n *which belongs to* $\mathcal{N}^{SLA}$. The $h^{sl}(n)$ is the number of network links that requires.

A signal node n *belongs to* $\mathcal{N}^{SL}$ depends on its class either $\mathcal{N}^{SLH}$, $\mathcal{N}^{SLDH}$, $\mathcal{N}^{SLDD}$, $\mathcal{N}^{SLDA}$, or $\mathcal{N}^{SLA}$ is defined a subset of infrastructure location types either $\mathcal{N}^{ILSO}$, $\mathcal{N}^{ILSD}$, $\mathcal{N}^{ILSA}$, or $\mathcal{N}^{ILSP}$ it can be installed in. For viable allocations, we used a function *si_site(n)* : $\mathcal{N}^{SL} \rightarrow \mathcal{N}^{ILSL}$, that for signal node $n \in \mathcal{N}^{SL}$, defines its presenting infrastructure location $sl \in \mathcal{N}^{ILS}$. By assumption following assignments are viable:

- Single head end signal node n^{slh} that belongs to $\mathcal{N}^{SLH}$ essentially be allotted to single CO site n^{ilso} that belongs to $\mathcal{N}^{ILSO}$, where $si\_site\left(n^{slh}\right) \equiv n^{ilso}$,
- Every distribution signal distribution point s, can be allotted to CO site n^{ilso} or any DP site s that belongs to N^{ILSD} that is "$_{n\hat{\imath}}$ N^{SLDD}, $si\_site(n) \in \left\{n^{ilso}\right\} \cup \mathcal{N}^{ILSD}$,
- Each head end signal distribution point n belongs to $\mathcal{N}^{SLDH}$ essentially be allotted to single CO site n^{ilso}, that is $\forall_{n\in}\mathcal{N}^{SLDH}$, $si\_site(n) \equiv n^{ilso}$,
- Every access signal distribution point n that is belongs to N_{SLDA} can be allotted to any type of an infrastructure site however CP, that is, $si\_site(n) \in \mathcal{N}^{ILSO} \cup \mathcal{N}^{ILSD} \cup \mathcal{N}^{ILSA}$,
- Lastly, every access signal node n that belongs to $\mathcal{N}^{SLA}$ essentially be allotted to any of CP infrastructure locations s that is belongs to $\mathcal{N}^{ILSP}$

Figure 11 Signal nodes with links and connections



6.1.4 *Model of bundle layer*

The model of signalling layer recognises each distinct component must deliver signal network links in OLT and ONT. In our work we presented aggregate model, by the name of *bundle layer*. It deliberates groups of signal nodes and links as a substitute of individual ones.

This model contains directed graph that is denoted by G^{BL}, $\mathcal{L}^{BL}$. The bundle nodes are denoted by $\mathcal{N}^{BL}$ while $\mathcal{L}^{BL}$ is group of bundle connections. G^{BL} organises a contraction of a graph $G^{SL} = \left(\mathcal{N}^{SL}, \mathcal{L}^{SL}\right)$ of signalling layer, each bundle node $n_{bl} \in \mathcal{N}^{Bl}$ signifies subset $\mathcal{N}_{bl}^{sl} \subseteq \mathcal{N}^{sl}$ of signalling nodes. All bundle layer links $l_{bl} \in \mathcal{L}^{BL}$: $l_{bl} \in \delta\left(n_{bl}\right)$ occurrence of bundle node n_{bl} signifies in turn group

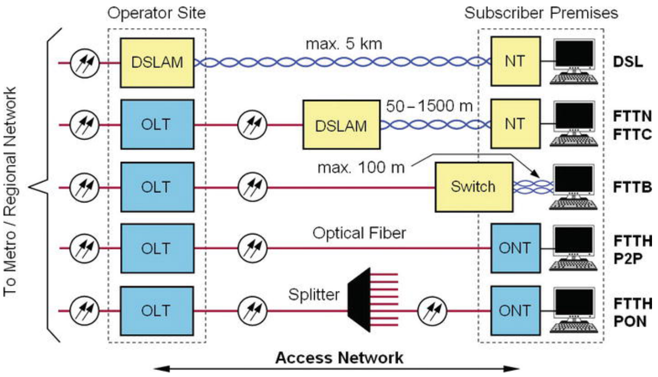
$\mathcal{L}_{bl}^{sl} = \left\{ l_s \in \mathcal{L}^{sl} : l_{sl} \in \delta\left(\mathcal{N}_{bl}^{sl}\right)\right\}$ of each signalling link occurrence to this selected subset of signalling nodes. For simplify mapping in signalling and bundle layers model, we present functions $bs\_nmap\left(n_{bl}\right) : \mathcal{N}^{BL} \mapsto 2\left|\mathcal{N}^{SL}\right|$. This function expresses subset of signalling nodes $\mathcal{N}^{SL}$ amassed to bundles node n_{bl} ∈ $\mathcal{N}^{BL}$ and function $bs\_lmap\left(ln_b\right) : \mathcal{L}^{BL} \mapsto 2\left|\mathcal{L}^{SL}\right|$ which states subset of signalling links denoted by a bundle link l_b.

Following is categorisation of bundle nodes:

Singleton set that represent by $\mathcal{N}^{BLH} \equiv \left\{n^{blh}\right\}$ which masses the head end signal node n^{slh}. Each head end signalling distribution point $n_{sldh} \in \mathcal{N}^{SLDH}$, which is placed in CO infrastructure location n^{ilso}. Mentioning to sample network single bundle head-node n^{blh} masses head end signal node n^{slh} and two head end signal distribution points n_{sldh1} and n_{sldh2}; set $\mathcal{N}^{BLD}$ of distribution bundle nodes. Every distribution bundle node n_{bld} ∈ $\mathcal{N}^{BLD}$, agrees to CO or a DP infrastructure location n_{ils} ∈ $\mathcal{N}^{ILSO}$ ∪ $\mathcal{N}^{ILSD}$ and groups each distribution signal distribution points n_{sldd} ∈ $\mathcal{N}^{SLDD}$: $si\_site\left(n_{sldd}\right) = n_{ils}$, positioned in that location. In sample network, there are two distribution bundle nodes n_{bld1}, n_{bld2} that collective, respectively, a subset of distribution signalling distribution points $\left\{n_{sldd1}, n_{sldd2}, nsn_{sldd3}\right\}$, and $\left\{n_{sldd4}\right\}$; – set $\mathcal{N}^{BLA}$ *o*f accessing bundle nodes. Every accessing bundle node n_{bla} ∈ $\mathcal{N}^{BLA}$, related to an infrastructure location n_{ils} ∈ $\mathcal{N}^{ILS}$, and aggregates every access signal distribution point n_{slda} ∈ $\mathcal{N}^{SLDA}$: $si\_site\left(n_{slda}\right) = n_{ils}$ as well as each accessing signalling node n_{sla} ∈ $\mathcal{N}^{SLA}$: $si\_site\left(n_{sla}\right) = n_{ils}\, nis$ positioned at this location. In sample network as shown in Figure 12, in which three access bundle nodes represented by n_{bla1}, n_{bla2}, n_{bla3}, respectively. We proposed $c(n) : \mathcal{N}^{BLD} \mapsto 2|\mathcal{N}^{BLA}|$ function that for every distribution bundle node n ∈ $\mathcal{N}^{BLD}$ distinguish subset $\left\{m \in \mathcal{N}^{BLA} : \exists l \in, b\_a(l) = n \wedge b\_b(l) = m\right\}$ of bundle accessing nodes linked to that distribution node through a bundle connection; referred by *distribution cone* of n distributing nodes.

Bundle links denoted by $\mathcal{L}^{BL}$ are further divided into *trunk bundle* and *distribution bundle links that are represented by* $\mathcal{L}^{BLH}$ *and* $\mathcal{L}^{BLD}$*, respectively*. With support of $bb\_a(l) : \mathcal{L}^{BL} \mapsto \mathcal{N}^{BL}$ and $bb\_b(l) : \mathcal{L}^{BL} \mapsto \mathcal{N}^{BL}$ functions that recognise, correspondingly, start and end bundle nodes of a directed bundle link denoted by l ∈ $\mathcal{L}^{BL}$, these two can be properly define as, $\mathcal{L}^{BLH} = \left\{l \in \mathcal{L}^{BL} : bb\_a(l) \in \mathcal{N}^{BLH}, bb\_b(l) \in \mathcal{N}^{BLD}\right\}$ and $\mathcal{L}^{BLD} = \left\{l \in \mathcal{L}^{BL} : bb\_a(l) \in \mathcal{N}^{BLD}, bb\_b(l) \in \mathcal{N}^{BLA}\right\}$, respectively,. Sets $\mathcal{L}^{BLH}$ and $\mathcal{L}^{BLD}$ organise the segregating of set $\mathcal{L}^{BL}$.

Figure 12 Bundle nodes and bundle links



The actual demands for signals network connections are generated in accessing bundle nodes $\mathcal{N}^{BLA}$; demand h_n^B of every distinct accessing bundle node n ∈ $\mathcal{N}^{BLA}$ is calculated by given below expression:

$$h^B\left(n\right) = \sum_{\substack{s \in \mathcal{N}^{SLA}, \\ s \in bs_{nmap(n)}}} h^s\left(s\right), n \in \mathcal{N}^{BLA} \tag{2}$$

6.1.5 *Concluding remarks of network fragment*

The direct bundle link l that is belongs to $\mathcal{L}^{BL}$, of bundle layer maintained through a group of similar fibres links in *si_site*(*bb_a*(*l*)) and *si_si te*(*bb_b*(*l*)) infrastructure locations.

By supposition, each fibre link used identical infrastructure trail $bi\_p(l)$ ∈ $\mathcal{P}^{ILS}$ where function $bi\_p(l) : \mathcal{L}^{BL} \mapsto \mathcal{P}^{ILS}$ expresses an infrastructure trail that is taken by each fibre link supportive bundle link.

Let directed trunk bundle connection from group $\mathcal{L}^{\mathrm{BLH}}$. Each fibre link which supports that link is known as trunk fibre link. It uses a trunk infrastructure trail which contains trunk fibre segments. All cable segments that have trunk fibres denoted as trunk cable segment. Conferring to stated rules, we introduced group of trunk infrastructures trails representing by $\mathcal{P}^{\mathrm{ILSH}}$ and group of distribution infrastructure trails that represented by $\mathcal{P}^{\mathrm{ILSD}}$. We signify group of trunk infrastructure segment and distribution infrastructure segment through, respectively, $\mathcal{L}^{ILH} \subseteq \mathcal{L}^{IL}$ and $\mathcal{L}^{ILD} \subseteq \mathcal{L}^{IL}$; we focused on sets $\mathcal{L}^{ILH}$ *and* $\mathcal{L}^{ILD}$ that normally don't organise segregating of set $\mathcal{L}^{IL}$. We assumed that each trunk infrastructure trail from $\mathcal{P}^{ILSH}$ which use single trunk infrastructure segment from $\mathcal{L}^{ILH}$ traverses segment in identical direction. Therefore, trunk and distribution, infrastructure segment can be considered as directed. $ii\_a(l) : \mathcal{L}^{IL} \mapsto \mathcal{N}^{IL}$ and $ii\_b(l) : \mathcal{L}^{IL} \mapsto \mathcal{N}^{IL}$, functions expresse respectively, start and ending infrastructure nodes of infrastructure segments. The trunk segment in $\mathcal{L}^{ILH}$ creates a directed tree by root at CO location n^{ilso}, whereas distribution segments in set $\mathcal{L}^{ILD}$ create a forest of directed trees, all rooted at a location which hosts distribution bundle node from $\mathcal{N}^{BLD}$ set. Hence, for every trunk segment *l that belongs to* $\mathcal{L}^{ILH}$ there is just one or none predecessor trunk segment *ii_ah*(*l*). Likewise, for every distribution segment *k that belongs to* $\mathcal{L}^{ILD}$ there is just one or none predecessor distribution segment *ii_ad*(*k*).

7 Conclusion and future work

The increasing demand for broadband internet services requires adaption of novel fibre base technologies. To attract new customers, fixed access network operators have to substantially increase the speed and quality of internet services. This can only be achieved by bringing the fibre as close to the customer as possible. This requires extensive planning in terms of cost, time and infrastructure. In this paper, we have presented a model of automating FTTH planning considering OAN. Different features, planning phases and model fragments have been identified and discussed, both theoretically as well as mathematically. In our future work, we will present formulation in term of optimisation for FTTH cost effective deployment. Real world experiment will aid in formulation as well as validation.

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