A Taxonomy-based Comparison of FTTH Network Implementation Costs

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ABSTRACT:
Hundreds of millions of homes worldwide already have Fiber-to-the-Home (FTTH) broadband connection since this technology holds many advantages over current technologies. The need for higher bandwidth by customers persist the network providers to upgrade their networks. FTTH is the use of fiber optic cords to deliver communications signals from an operator's central network to individual houses, buildings, and residences, changing old copper infrastructures to provide higher bandwidth to customers. Recently NG-PON capabilities has opened new approach in optical fiber networks creation. Operators are trying to use a single infrastructure in access layer for fixed and mobile (4G/5G) services. However, the FTTH implementation is a challenging for network operators in consideration of a large amount of investment, including Capital Expenditure (CAPEX) and Operational Expenditure (OPEX). The review and classification of the most relevant approaches about cost reduction of FTTH implementation is done in this paper based on a novel taxonomy.

KEYWORDS: Fiber to the Home (FTTH), Cost Estimation, Capital Expenditures (CAPEX), Operating Expenditures (OPEX)

1. INTRODUCTION

Stunning demand on bandwidth (Fig. 1) has led the Information Communication Technologies (ICT) industry to build the suitable infrastructures in access layer. FTTH and 4G/5G technologies are the latest achievement.

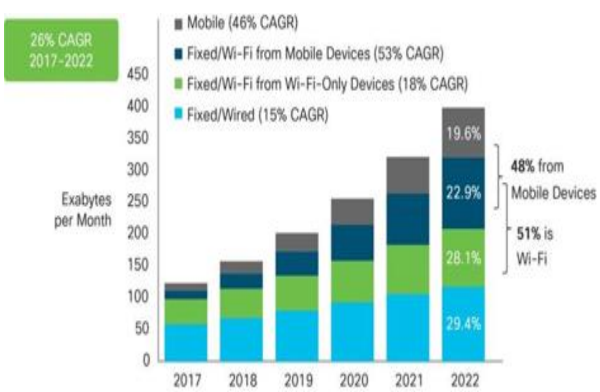

Fig. 1. IP Traffic by Access Technology [1].

Across the world, the improvement of broadband access quality and capacity is on the agenda of numerous operators. They are trying to deliver broadband services at an optimal cost and to balance the short-term investment and long-term goals. In order to define the advantages and disadvantages of the various networks available in the market and potential investors are undertaking techno-economic evaluations. FTTH is a future-proof fixed-access network, which offers a much higher transmission capacity than copper cable networks. Internet traffic constantly is experiencing tremendous growth owing to the proliferation of bandwidth-hungry applications, including on-line gaming and video streaming.

The major traffic produced by mobile devices and the growing deployment of Internet of Things (IoT) systems needing the machine to machine communication [2]. The demand for broadband access is constantly increasing with the popularity of bandwidth-intensive services. This has led telecommunication firms to regard other technologies to the prevailing Digital Subscriber Line (DSL) infrastructure to accommodate the upcoming subscriber's demands. The FTTH solution is the only one among access network technologies that may presently meet those needs. In the last 50 years, fiber optics technologies take up a unique position in the world of ICT. They are the only available option in transmission links at a high bit rate in particular for the end users. It offers a distinct advantage as regards high achievable data rates. On the other side, the high costs of maintenance and initial deployment necessities are as the heaviest impediment [3]. At the FTTH Council, experts claim fiber connections to be the best technology with adequate bandwidth to manage projected consumer demands over the next decade cost-effectively and reliably. Fiber holds almost infinite bandwidth coupled with a long reach, making it “future safe”.

There are usually two kinds of connections used in the implementation of FTTH networks: Point-to-Multipoint (P2MP) and Point-to-Point (P2P). On the other hand backhaul is the most important challenge in 4G/5G, while convergence between fixed and mobile services will provide new attractions for users. Operators are encouraged to use the fiber access network to expand 4G/5G networks.

Deploying a FTTH network needs considerable upfront capital investments. For an operator, it is undeniably important to make a detailed network in an affordable model and select the right technology that optimizes its capital and operation expenses, together with the payback period [4]. A challenge related to FTTH deployment is the high cost of the passive infrastructure and, specifically, of the civil works which correspond to almost all of the total investment. The FTTH implementation, however, is challenging for network operators in the light a great deal of investment, such as CAPEX and OPEX. Moreover, demand forecast, migration time duration, expected revenue as regards technologies or bandwidth have to be considered [5].

Several design factors should be considered, which make the optical network planning is a challenging process. In this case, an intelligent network planning system is needed to be able to minimize both the time and cost of network requirements creation in various topologies [6], network modeling and solutions. Thus, need to be tailored to specific service providers’ situations.

Despite the great success of the existing solutions in minimizing OPEX and CAPEX costs, they still lack comparative studies and statistical analyses. This paper provides a taxonomy of cost reduction approaches in FTTH implementation.

The rest of the article is structured as follows: Section 2 argues the general principles in FTTH design and implementation, along with its main components. Section 3 explains popular FTTH implementation technologies, including GPON and TWDM-PON. Cost challenges are discussed in Section 4. Section 5 presents the taxonomy of FTTH cost reduction solutions, together with their methods, targets, advantages, and disadvantages. This section includes FTTH usage for 4G/5G backhaul and involves a statistical review of existing methods. Section 6 concludes the paper.

2. FIBER-TO-THE-HOME

Fiber has been already became a dominant medium in backbone networks. Fiber-to-the-Home is an umbrella term applied for emerging access networks, using an optical fiber in the first/last mile. The privilege of FTTH networks over other telecommunications networks, in a techno-economic sense, is their extensive reach and capacity. Fiber has a practically unlimited bandwidth capacity; thus, it is capable of meeting the traffic demand increment for multimedia services. Accordingly, it offers a future-safe medium that outperforms all other known media. Each FTTH network, in an ideal world, would be designed from scratch to cover all future eventualities. In many cases, however, the existing network infrastructure is available (either the operators own or third party capacity to be accessed), implying that beginning again would be much more expensive. The problem with this hybrid approach is that maintenance costs may rise as different equipment, of varying ages, is made to work together, and it cannot meet future requirements.

Active Optical Network (AON) and Passive Optical Network (PON) are two main topologies in FTTH. Cost components differ depending on the chosen technical solution. PON cost components resemble that of hybrid fiber copper, whereas the needed investment for an active star includes the following main components:

1- Customer Premises Equipment: An ONU (Optical Network Unit) that terminates the optical signals at the user side. Based on the solution and services provided, other equipment can be required.

2-Fiber Access Network: Cable, duct, and civil work that are needed to connect each home to an aggregation node.

3-Aggregation Node: Cabinet and switch, which terminates the fiber connection and aggregates them towards a central exchange.

4-Fiber Backbone Network: Cable, duct, and civil work that are needed for aggregation nodes connection to a central office.

5-Service Node Equipment: Core equipment (switches, routers) for backbone connection. Also, the management system, as well as a broadband remote access server, is required.

Owing to all the hardware spread nearby the implementation area (i.e., in aggregation nodes), the OPEX of an AON is higher than that of PON. Fig. 2 shows various FTTH network architectures in a comparative model [7]. The abbreviations are; Customer Premises Equipment (CPE), Remote Node (RN), Central Office (CO), and Arrayed Waveguide Grating (AWG); Ethernet equipment is marked with blue, TDM equipment is red, and passive optical components are green.

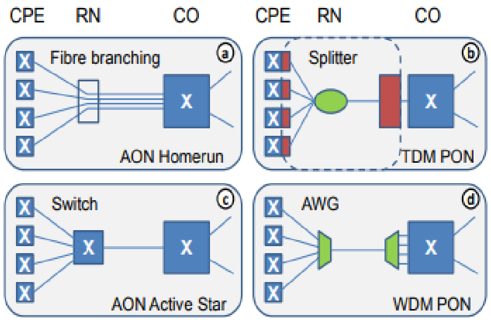

Fig. 2. Different FTTH architectures overview [7].

The transmission medium that presently leads from the cabinets to the homes are normally twisted pairs or coaxial cable in mature markets, particularly in western countries. In these markets, most service providers have selected to install fiber to the curb distribution hub and apply copper/coaxial to the premise as, in the early stages, performance is good enough and, it still makes sense to maximize the user value of the existing (and previously paid for) infrastructure. However, faster internet speed demand is not compatible with current copper/coaxial cables; thus, the pressure is growing on operators to expand the FTTH network. For construction implementation, it is important to consider the geographical conditions. Also, it is vital that consumers are not inconvenienced at any point throughout an FTTH implementation. No consumer wants their property to be at the center of a major civil engineering project. Fig. 3 shows the expected growth of the bandwidth connection in the world, FTTH/Fiber technology will be dominant with 60% in 2025 [8].

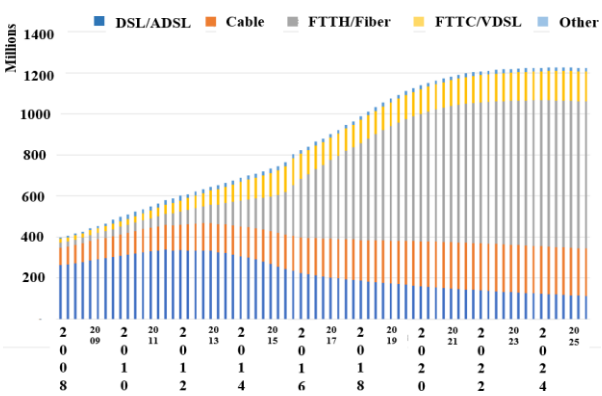

Fig. 3. Global Forecast by Technology [8].

3. GIGABIT PASSIVE OPTICAL NETWORK (GPON)

GPON is based on the ITU-TG.984.x standard for the new generations of broadband passive optical access. GPON offers an unprecedented high bandwidth downlink rate of up to 2.5 Gb/s as compared to the other PON standards; It provides the QoS full business protection, at the same time carries. TDM traffic can be mapped to the GEM frame, 8 kHz using a standard frame able to support TDM services. Also, GPON, as a carrier-grade technology standard, offers access network-level protection mechanism and full OAM functions. In FTTH networks, GPON is broadly deployed. According Fig. 4 it can develop into XG-PON, XGS-PON and WDM-PON.

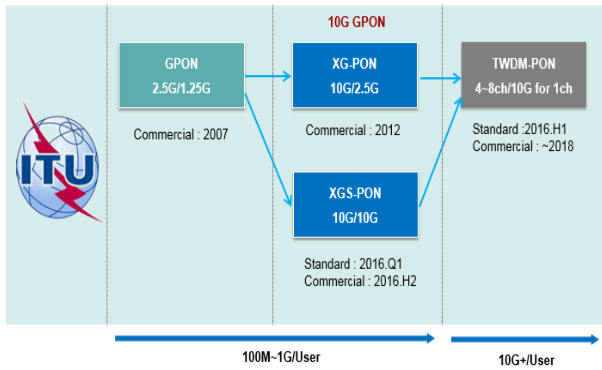

Fig. 4. GPON scenarios [9].

Dedicated 1/10/100 Gb/s services for a customer at a moderate price are accessible in WDM-PON and can sustain usage traffic pattern. A single wavelength, in this strategy, is redirected to CPE from the OLT through a passive wavelength router positioned in the outside plant. The power splitter/combiner, in this case, is replaced by a wavelength selector filter, typically an array waveguide grating. Thus setting up a single wavelength with symmetric bandwidth between each CPE and OLT.

Practically XGS-PON can provide the symmetric bandwidth required by mobile 4G/5G and it is easier to upgrade to WDM-PON.

4. COST CHALLENGES FOR IMPLEMENTING FTTH NETWORKS

Competition profit margin in FTTH projects is low because the infrastructure and equipment expenditure is high. For the decision of which network topology suits the best in a particular area, an accurate estimation of the demanded and available bandwidth, expected tariff structure, as well as investment costs, are essential for the business case. Hence, in the following sections, a survey of cost reduction and estimation approaches is provided. These costs can be divided into CAPEX and OPEX.

4.1. CAPEX and OPEX Costs

Capital expenditure or CAPEX are funds applied by a firm to obtain, upgrade, and keep physical assets, including property, industrial buildings, and equipment. Often, that is applied to undertake new projects or investments by the company. This type of financial outlay is also made by firms to preserve or increase the scope of their operations. It is the money spent on the purchase and improvement of fixed assets.

An operational expenditure, OPEX, is the money a firm spends on an ongoing, day-to-day basis to run a business or system. Such expenses, depending upon the industry, may range from the ink applied to print documents to the wages paid to employees.

One of the most important issues in implementing FTTH networks is its high cost. While designing and implementing infrastructure. There are generally decision parameters, which may critically affect the network cost. One of these, for FTTH, is the average length of fiber in the aggregation part. There is a fiber distance, depending on the cost of fiber and aggregation node equipment, which minimizes the cost of deployment. This length differs for various settings and scenarios. There is a tradeoff between the protection cost and the service reliability level as improving reliability coefficient by network resources duplication (and CAPEX) can be too expensive. The major contributions of this paper consists of offering a universal method for CAPEX and OPEX evaluation to be used to any fiber access network considering changed component cost in time and variable take rates, and comparing the total cost.

The goal, while maintaining acceptable service reliability, is to offer a guideline for the design of the most cost-effective protection. The planning phase cost will perhaps be proportional to the total cost of the entire project (deployment, service migration, and up or running over the entire project lifecycle). In the following studies, some optimization platforms for FTTH network design are presented. A platform is capable of minimizing the CAPEX and indirect OPEX of network deployment by optimizing locations of optical equipment, signal splitters, and cable cabinets, together with optimizing cable routes, types of cables, as well as the number and types of optical cards and splitters [10]. CAPEX and OPEX both require to be minimized in order to meet this requirement. In light of this, the fiber access network evolution is presented. The aim is to choose the best potential combination of equipment, which minimizes a network's final total cost. At the same time, a network's final cost is optimized in all regarded final states, taking the weighted cost of the achieved results as the expected final cost of a network. The ways the demands of various states met are virtually independent of each other.

5. TAXONOMY OF FTTH IMPLEMENTATION COSTS

Some of the studied articles are considered in urban and suburban areas in different countries. Most of them are from the top articles in the past ten years unless their content is very close to our subject. The purpose of each paper and its proposed solution to reduce the cost of CAPEX and OPEX in implementing FTTH networks are outlined.

The proposed solutions can be categorized as follows:

1- Cost Model
2- Algorithm and Mathematical Modeling
3- Network Analysis and Review
4- Infrastructure and Implementation Factors
5- Geographical and Environmental Parameters
6- 4G/5G Backhaul

5.1. Cost Model

The following articles, with the definition of a generic model called cost model, seek to find the lowest cost for fiber-optic network implementation.

Table 1 summarizes these approaches based on their methods and solutions.

There is a general reference to the definition of the cost model, and these articles also design other models by changing the parameters and topics discussed; the cost function in economic model for GPON in FTTH access network design can be defined [23]:

$$Cost(t) = \sum_{t}\sum_{j=0}\left\lceil \frac{d_c(t)}{g_c} \right\rceil . p_c(t) \quad (1)$$

With parameters c: types quantity of equipment or trenches, d_c: the required capacity of c installed in time t (years), g_c : the granularity of c, e.g., km fiber-cable wound on a reel, number of ports per OLT-card, and p_c: the price of c at the given granularity.

Cost for P2P and P2MP:

$$C_{P2P}(t) = \sum_{t=1}^{T} \begin{bmatrix} C^{rack}(t).\frac{N(t)}{f_g^1} + C^{port}(t).\frac{N(t)}{f_g^2} \\ + C^{shelf}(t).\frac{N(t)}{f_g^3} + L_{trench}.C^{fiber}(t).N(t) \\ + L_{trench}.C^{trench}(t).N(t) + C^{\mathrm{mod}em}(t).N(t) \end{bmatrix} \quad (2)$$

$$C_{P2MP}(t) = \sum_{t=1}^{T} \begin{bmatrix} C^{rack}(t).\frac{N(t)}{f_g^1} + C^{port}(t).\frac{N(t)}{f_g^2} \\ + C^{shelf}(t).\frac{N(t)}{f_g^3} + \frac{L_{trench}.C^{fiber}(t).N(t)}{64} \\ + \frac{L_{trench}.C^{fiber}(t)}{64} + L_{trench}.C^{trench}(t).N(t) \\ + C^{\mathrm{mod}em}(t).N(t) \end{bmatrix} \quad (3)$$

N(t): number of subscribers, f_g^1, f_g^2, f_g^3: granularity of the rack, card and shelf, L_{trench}: the average length of the trench, C^{fibre}: the price of the fiber, $C^{rack, port, shelf}$: the price of the rack, port, shelf, and *T*: the time of implementation

Table 1. Cost Model.

Ref.	Year	Target	Solution	Technique
[23]	2015	CAPEX Evaluation and Minimizing	Total Cost Calculatio n	Comparison between P2P and P2MP (GPON)
[24]	2015	Cost-Effective FTTH Scheme	BER and Power Budget Measuring	Simulation in Various Topologies
[25]	2014	Network Sharing Scheme in FTTH/PON Architectures	Cost Model in Different Geotypes	CAPEX & OPEX Comparison in GPON, XG-PON, TWDM-PON, and AWG-based WDM-PON
[26]	2013	Active Ethernet and GPON Migration to NG-AON and TWDM-PON	Techno-Economic Model	Modeling what Includes all Costs and Makes the Distinction between CAPEX & OPEX
[5]	2010	FTTH Dynamic Planning	ILP-based VBA Cost-Revenue Calculatio n	Migrating Steps Containing Green Field, ADSL, FTTC, FTTB, and FTTH
[27]	2007	FTTH and FTTN Rollout Comparison	Cost Model	Calculating the Finished Price for each Technology

This part discusses the studies that used a cost model to reduce OPEX and CAPEX of fiber-optic network implementation. These approaches advantage is minimizing network deployments cost. On the other hand, the reuse of current passive infrastructure does not bring technical privilege as compared with the stand-alone scenario; however, it helps to decrease the total cost per home connected [25].

5.2. Algorithm and Mathematical Modeling

In the following articles, the FTTH implementation is examined in mathematical analysis, as well as modeling with some algorithms. These articles are also important as regards reducing the costs of implementing and using fiber optic networks. Table 2 shows these approaches based on their methods and solutions.

Advantages:

- Handling huge volumes of highly aggregated IP traffic.
- Not restricting the bandwidth that cannot be delivered to the end users.
- Minimizing the network deployment cost.

Disadvantages:

- Almost all of the research published in the field of FTTH design either does not regard uncertainty or just consider in preliminary design phases.

The values used in the calculations are based on estimated cash inflows, and as with any estimation, has the possibility of being far from the actual value.

Table 2. Algorithm and Mathematical Modeling.

Ref.	Year	Target	Solution	Technique
[18]	2017	FTTH Cost Reduction	MIP-based Multi-state Optimization (MuSO)	Selecting the best Possible Combination of Equipment
[19]	2016	FTTH Modeling, Mathematical Planning	Mixed Integer Linear Programming (MILP)	Max. NPV Min. CAPEX Opt. Topology CPLEX Graph
[20]	2015	Effective FTTH Planning	Genetic Algorithm, BIP	Automatically Generation Duct and Cable Layers and Equip. Locations
[21]	2015	Service Diversity in Hybrid Fiber Copper Networks	Automated Service Provisioning Mechanism OSS	Systems to Minimize Cost & Complexity, G.fast on Copper
[3]	2013	CAPEX Minimization in PON/P2P FTTH	Fiber and Trenching Costs Assessment	A* and SMT Algorithms
[22]	2012	DSL and GPON Comparison	Techno-Economic Analysis	Calculating Deployment Costs Divided Pure and Metro Access Networks

5.3. Network Analysis and Review

The following articles have introduced the network and implemented systems with the best way to reduce costs, as well as ease of deployment. Considering the implemented solutions, it can be stated that one of the most practical solutions is the implementation based on GPON. Table 3 summarizes studied approaches based on their methods and solutions, which have the following specifications.

Advantages:

- Fault tracking and its location determination.
- Simplifying a problem.
- Network design cost reduction.
- FTTH easier deployment, which yielding potentially significant saving in CAPEX and OPEX.

Disadvantages:

- Tractability of approaches.
- The reuse of existing passive infrastructure does not bring cost benefit in comparison to the stand-alone.
- FTTH requires high-bit-rate connections for broadband services.

5.4. Infrastructure and Implementation Factors

The following articles discuss the implementation of fiber-optic networks, as well as the cost of each of its equipment. In this section, reducing the initial cost and maintaining each sector will reduce the total cost and bring some advantages in resource management.

Table 4 summarizes these approaches, along with their targets and technics.

Table 4. Infrastructure and implementation factors.

Ref.	Year	Target	Solution	Technique
[20]	2015	GPON FTTH Planning in Greenfield	Hybrid Optimization	Minimizing Network Deployment Cost
[28]	2013	P2P and P2MP Deployments Comparison	FTTH Solutions Analysis	Telemach P2MP, Multi-Operator Open-Access
[29]	2011	Passive Optical Components Technologies	PDS (Passive Double Star)	Model For Conventional P2P Transmission
[30]	2010	Protected PON Schemes in Optimum Cost	CAPEX and OPEX Comparison	Different Architectures Deployment Consideration

It is known that all-optical access networks have several advantages as compared to copper networks, together with being the final solution in broadband access technologies. Other benefits are from the viewpoint of productivity and cost. It is being rather easy and low-cost to upgrade the basic PON, with no protection) to achieve protection functionality.

Fiber access networks require high-bit-rate connections for broadband services.

Table 3. Network Analysis and Review.

Ref.	Year	Target	Solution	Method/Technique
[11]	2017	Validating Power Budget and Cost	GPON Technology	Evaluating and Minimizing the Implement Costs
[12]	2015	CAPEX Minimizing	Optimizing Platform Network Design	Decomposing Optimization Process into Phases
[2]	2015	Minimizing Design Cost	GPON FTTH	Intelligent Network Planning System
[13]	2014	Implementing a Protected GPON FTTH	Survey then OSP Design	Optical Power Budget Calculation
[14]	2008	FTTH Cost Reduction	PON Deployments Monitoring	Different Cost Models Analyzing
[15]	2009	Evaluating FTTH & Reliability Performance	Hybrid WDM/TDM PON	Cost per User Minimization in PON FTTH
[16]	2008	Preparing Unlimited Bandwidth	Automated Fiber Managemen t (AFM)	Enabling the Service Provider to Configure Connections Remotely
[4]	2008	Defining Key Parameters which Impact FTTH Economics	CAPEX and OPEX Modeling	GPON, EPON Comparison in Different Scenarios
[17]	2008	Centralized Monitoring and Self-Protection	SANTAD System	Failure Detection, Automatic Recovery, and Survivability Increasing

5.5. Geographical and Environmental Parameters

These papers examine the environmental factors for the implementation of fiber-optic networks in the regions concerning the climate. In this section, it is tried to reduce the cost of implementation due to geographical items..

GIS is an information system, which is applied to input, store, manipulate, recover, analyze, and produce referenced or geospatial data geographically. Using in decision-making for planning and management of telecommunication, natural resources, land use, urban services and facilities, transportation, environment, as well as other related administrative affairs.

Table 5. Geographical and environmental items.

Ref.	Year	Target	Solution	Technique
[11]	2017	Optimizing Network and Reducing the Cost of Fiber-Optic Component	GIS Systems	Providing more Accurate Planning by Considering Geographical Conditions
[31]	2016	Focusing on Delivering Symmetrical 1 Gb/s Access	Strategy of Wavelength Division Multiplex (WDM)	Fiber to the Node/Cabinet Deployments
[32]	2016	Proposing a Modified Backfilling by Stabilizing the Conduit and Non-Shrink Grout in the Base Layer	Micro Trenching Technology	Micro Duct Installation in Trench and Backfilling and Sealing to Speed up the Project

PON technology brings new approaches in the ICT to provide high-speed internet and triple play bundled services, such as voice, data and video streaming. In most countries, the service providers are offering broadband services on traditional copper network. High-speed internet and broadband demand is increasing rapidly. It is desired with great need to migrate from traditional copper-based access network to PON base.

Given the geographical requirements, a scalable fiber access network is needed that may be optimized as per user requirements and demands with high-speed bandwidth efficiency, involving the minimum losses and with ideal CAPEX.

With GIS, the developed platform for migration from copper to PON-based fiber has been studied, planned, and then simulated on a selected geographical area with physical execution that showed better and efficient results with a reduction in capital and operational expenditures. A factual plan, without ambiguities, assists the operators in analyzing or forecasting bandwidth requirements of a region, optimized network planning, together with the on-time and efficient deployment [10]. Table 5 summarizes these approaches that bring the advantage of allowing operators to offer symmetric-rate services. This approach is good, but it's weak against climate change, and is limited for a specific geographic area.

Table 6. FTTH as 4G/5G backhaul.

Ref.	Year	Target	Solution	Technique
[33]	2019	Comprehens. Analysis about FMC	Hardware Collocation and Fiber Sharing	Different Solution Technical Evaluation
[34]	2018	FMC Common Platform	WR WDM-PON	CAPEX Comparison in Different Scenarios
[35]	2018	FMC Packet-Optical Network	SDN/NFV	Implemented and Experimentally Result Analysis
[36]	2017	FWA, Fixed Wireless(5G) Access	XG-PON CWDM	Different Transport Systems Cost Comparison
[38]	2017	Economical Optic Fiber	ViRCA Control Plane	Power Consumption and QoE
[37]	2016	Minimum Cost Design for 5G	TWDM-PON	K-means Cluster Algorithm, Nodes & Cable Conduit Sharing
[39]	2014	Energy Consumption 4G FTTH	WDM BBU Placement	ILP , Aggregation Infrastructure Power (AIP) Assessment
[40]	2014	FMC Framework	Access Resource Sharing	Statistical Analyzes (COMBO Project)

5.6. 4G/5G Backhaul

New generations of mobile network are designed for wireless broadband services. A large-scale and high-capacity distribution network is the success key in their deployment. FTTH is the best techno-economic candidate for 4G/5G backhaul. Table 6 provides samples of some studies which have been done on different aspects of using a single and flexible network. It will have many benefits for operators and customers.

Advantages:
- 4G/5G deployment cost reduction
- OPEX minimization
- A single service portfolio
- Fixed and mobile network convergence

Disadvantage:
- Interference in maintenance and troubleshooting procedures

5.7. Essential Parameters for Implementation

FTTH deployment is increasing globally; as studied here, it has emerged as the best option for offering both higher speeds and longer reach peace of mind about future network requirements. The decisions for implementing involves splitter locations, connecting methods, future upgradability, long term maintenance, and cost (first, operating, and total costs). Certain parameters, on the other hand, can overlap throughout the network planning process, important areas that ultimately drive architecture decisions, such as business case, pre-deployment considerations, geographical location, as well as future-proofing.
Understanding any unique challenges posed within these areas, including required take rates, population densities, advantages and disadvantages of connection choices, as well as ease of migration to next-generation technologies, will assist service providers in selecting an optimal FTTH architecture.

5.8. Statistical Review of Studied Approaches

As seen in recent decades, the issue of reducing the cost of implementing fiber-optic cables has always been a concern to be regularly investigated. According to studies, the impact of cost-effective solutions has been on CAPEX. Referring to studies, it further can be concluded that in the area of reducing fiber-optic implementation costs, the focus is on categorization based on system analysis and evaluation. There is no reference simulator in design and simulations; this discussion can be further investigated in the future. As seen, the amount of study on the network analysis and review category is more. Considering the above studies, as well as the globalization of FTTH in the whole world and its increasing advances, the research on the implementation of fiber-optic networks can be outlined as follows from 2007.

6. RESULTS AND CONCLUSIONS

The present focus of research and development is on servicing a range of user demands and decreasing regional disparities in service levels. In this research, optical access technology is discussed for broadband services in the form of the GPON system, installation technology, and wireless access technology. With this review focused on incremental networks, it is important to note any previous studies conducted, and the results gained thereof, thus providing a frame of reference for comparison purposes. Lastly, practical factors play a vital role in network design. Some may greatly affect the design of the network, while others may not. However, to have a successful network, the design should consider as many practical factors as possible [19].

In this paper, some solutions are presented to reduce costs in implementing FTTH networks. A detailed FTTH design approach is provided for an intelligent network planning system, which minimizes the cost of network design while considering the practical scenarios. The short computational time clearly illustrates that such an approach can be employed to automate the design process and produce optimal results that cannot be achieved manually. Large savings are possible at such a considerable cost, and thus, detailed modeling is required to make the best upfront decisions. In order to construct such a model, it is impossible to rely on a detailed CAPEX model alone; however, a relatively integrated model, including all facets of the costs, is required [14].

The article shows that if a service provider wants to keep up with the growing user traffic pattern, in the long run, only TWDM-PON may offer Gb/s nearly guaranteed at a moderate cost concerning the fully dedicated 1 Gb/s point-to-point connection accessible in WDM-PON technologies [31]. A general cost function, in this study, is determined as an objective function that is derived from the difference between CAPEX and OPEX, respectively and the revenues. The capital cost of the FTTH rollout is dominated by the cost of installing fiber in the distribution areas to the homes. This represents about 60% of the total capital cost. Much of this cost is driven by labor and is not declining at the rate of the costs for fiber-based components [27].

It is showed that for a high number of subscribers, the GPON-based FTTH has a lower CAPEX than that of AON-based FTTH. FTTH, on the other hand, has a fairly higher CAPEX before the number of subscribers reaches a critical mass. Another general method for CAPEX and OPEX analysis considering changed component cost in time and variable take rate is suggested, followed by the calculations made for certain representative architectures.

Fiber is a structural, fundamental part of both fixed access and 5G mobile networks and there is a market opportunity to converge and share infrastructure. This is very important when we suppose that the civil works to deploy fiber underground or overhead can be a substantial part of the costs of new mobile and fixed networks implementation [33].

Future work in this topic can evaluate different aspects of dual-purpose (Fixed and Mobile) fiber access deployment. In addition to technical and economic issues, considering marketing indicators can increase the efficiency of models.

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