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A study on FTTH implementation and migration in Nepal

Naba Raj Khatiwoda[1], Babu R Dawadi[2,*]

[1] *Wireline and Customer Service Directorate, Operation and Maintenance Department, Nepal Telecom*

[2] *Department of Electronics and Computer Engineering, Institute of Engineering, Tribhuvan University, Nepal*

**Corresponding email: baburd@ioe.edu.np*

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Abstract

The increasing demand of high speed data results into extensive enhancement on different telecommunication technologies through wireline and wireless technologies. Optical Fiber technology is being popular for fixed broadband technologies and for backhaul network data for network convergence and media device interaction. Fiber to the home (FTTH) is gaining momentum of deployments in many countries all around the world. Passive optical network (PON) utilizes point to multipoint (P2MP) topology and is becoming suitable, cost effective, and promising solutions as compared to existing copper based telecommunication infrastructure. PON architecture is cheaper than other architectures due to dynamic bandwidth allocation and common resources that can be used by different subscribers and especially for home subscribers. This paper presents a study on the effective deployment of PON based FTTH network at Nepal by referring the deployment scenario of Nepal Telecom (NT), while this network design, deployment, and implementation provides a lesson learn for cost effective deployment of such network to other stakeholders of developing countries having similar territory and implementation challenges.

Keywords: *Broadband; FTTH, network deployment; PON; telecommunication.*

1. Introduction

Information and communication technology (ICT) enables us to exchange information instantly from any part of the world. However, there are several challenges for a developing country like Nepal to have robust and high capacity telecommunication services for its people due to poor telecommunication infrastructure, where less than three percentage (2.43%) people of total population have access of landline infrastructure (NTA, 2021). There is limited availability of broadband services in most of the areas of the country. Mobile communication is available to almost all the citizens, but only the voice communication service is available. Mobile broadband (3G, LTE/4G) is being expanded rapidly in the country, but it is not enough for all citizens and for all parts of the country.

In Nepal, there is well planned fixed telephone network in limited area only and most parts of the country have poor telecommunication infrastructure. But the government owned organization such as Nepal Telecom (NT) and other private internet service providers (ISPs) are working massively to expand FTTH service and building FTTH infrastructure. About 6,00,600 subscribers are using copper based telephone lines and still time division multiplexing (TDM) switches are in operation (NTA, 2021). NT is the service provider for landline phone in Nepal. It is working aggressively to replace the TDM or legacy switches and copper based networks by the next generation network (NGN) IP switches and optical fiber network basically FTTH network.

It is a great challenge to expand telecommunication facilities in all parts of the country, because there is difficult and adverse territorial structure such as mountains, hills, lack of physical infrastructure such as roads, electricity, and lack of proper planned residential structure (Dawadi et al., 2019). Fixed landline is limited to urban and some parts of the sub-urban area and district headquarters with limited places in rural areas. Digital divide is a prevalent in the country. In this paper, design and implementation of FTTH technology is discussed and cost effective implementation of FTTH and migration of FTTH from copper based network is analyzed and different models for different territories are discussed and recommended. This design and implementation method to deploy FTTH network would provide a lesson learn for the cost effective deployment of such network in the developing countries. The FTTH network architecture can be modified in different capacities with slight modification of Fiber distribution cabinet (FDC) and Fiber access point (FAP), and can be used at different sites depending on the population distributions.

The rest of the paper is organized as follows. In section 2, the background of FTTH technology and its benefits with related work on network deployment are discussed. Section 3 presents methodology of PON based FTTH deployment considering network deployment of NT. Section 4 presents the results and analysis of implementation including capital and operational expenditure (CAPEX and OPEX) calculation of network deployment. Section 5 provides discussion with possible recommendations, while section 6 concludes the paper.

2. Background and Related Work

FTTH is an advanced technology transmitting signal in the form of light through the Fiber cable medium to provide an ultra-high speed, reliable communication, high quality voice, data, and video transmission. The transmission of voice, data, and video through the same medium and at the same time is called triple play. Besides having higher investment in the initial stage, optical Fibers are effective and suitable substitutes of existing copper cable based telephony and cable TV networks. Optical Fiber is replacing copper cables due to its various advantages. It provides higher bandwidth (Tera bit per second - Tbps vs. 10Gbps in copper wires) and longer distance transmission (around 50 km vs. up to 5 km in copper wires). It is lighter in weight (weighs around 10 times less than copper cables) and has longer lifetime and much less attenuation (Khatimi et al., 2019). Optical Fiber is used for transmitting a volume of data at a higher speed with lower cost. Optical Fibers are costly at the initial stage of deployment, but their durability minimizes the overall cost in a long run. Optical Fibers are recently widely used in various types of networks such as backhaul network, computer network e.g. wide area networks(WANs), metropolitan area networks (MANs) as well as local area networks(LANs) with Ethernet-optical interface standards and in access network ('the last mile and 'will complete all-optical-network-evolution') as well. Optical Fibers are also used in data transmission in various fields like surgery, automobile industry, space, military applications, decorations, and lighting (Babani et al., 2014).

The copper based telecommunication network is not capable to cope up with the huge demand of data transmission required for the reliable data service. The evolution of advanced telecommunication technologies and the rapid increase in data usage in different fields resulted into a huge demand of data speed. Online classes, e-learning, telemedicine, online video conference, online business, online payment, online shopping, and live streaming need reliable and high speed Internet service. FTTH is the only complete solution for such type of applications. The combination of Fiber and copper network as a hybrid technology is also possible. NT is also using these hybrid combinations using IP switches and copper based access network. But this hybrid combination is also not suitable due to limitations and problems of copper cable as compared to optical Fiber networks.

In FTTH, the Fiber is directly connected from an exchange or switching office to the subscriber's home. Generally, the exchange offices are called central offices (CO) and the Fibers from a CO are connected to different subscriber's premises. The connection mechanisms and approaches are different based on the FTTH network design. FTTH network design is carried out differently based on the types of subscriber's premises, i.e. the size of building, number of residents in the building, number of building in a community, etc. Thus, general term of FTTx is frequently used, where the term 'x' refers to a node, curb, home, premise, or business (Sahu et al., 2019). Fig. 1 shows the general architecture of FTTH. The major components of the architecture are briefly summarized here.

Optical line terminal (OLT): OLT is located in CO and it is the end point of internet service providers. It controls the bidirectional data flow from subscribers' end to backbone transmission network and vice versa. OLT takes voice, data, and video from backbone transmission network and broadcast to all subscribers, while there is flow of information in the downstream direction. When upstream information flow takes place, OLT accepts the traffic from subscribers and forwards to the backbone transmission network.

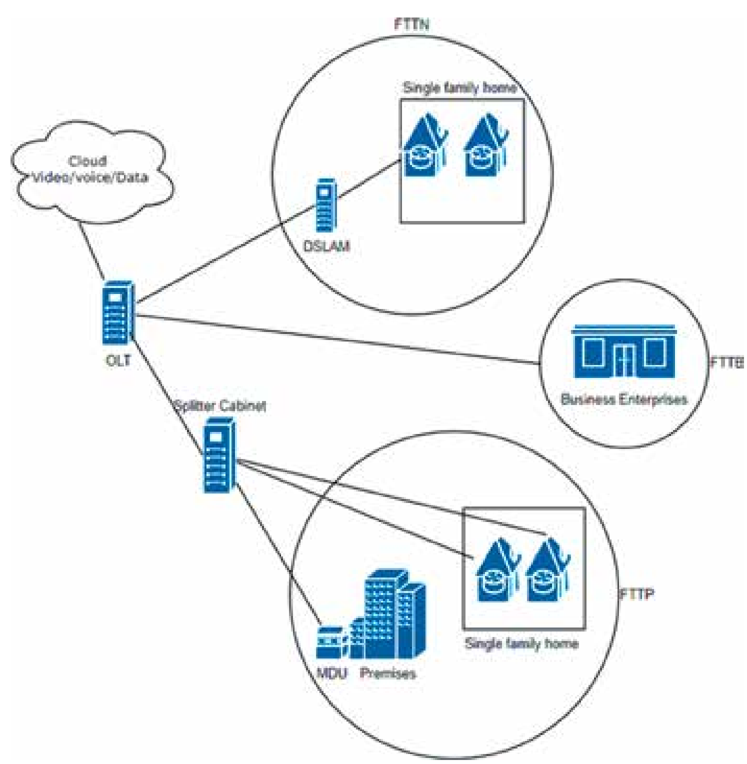

Figure 1: FTTH general architecture

Fiber to the business (FTTB): FTTB is designed for enterprises subscribers or business houses. The Fiber is directly connected from OLT to the active devices located inside the enterprises and they have access dedicated resources such as bandwidth.

Fiber to the node (FTTN): An active switching equipment i.e. node such as digital subscriber line access multiplexer (DSLAM) is placed near the subscribers' premises. Copper access network can also be used. FTTN is suitable at a distance of about 1.5 Km.

Fiber to the premises (FTTP): FTTP is designed for larger number of subscribers in a single building or premises. Multi dwelling unit (MDU) are placed at the premises and the network is connected to individual subscribers through the MDU. The premise can be a single family house or group of single family house within a large building (Rigby, 2014).

Cloud: This is the network structure that connects all the network elements through Internet protocol (IP) and multi-protocol level switching (MPLS). It connects the server related to voice, data and Video.

DSLAM: DSLAM is a switching equipment that aggregates traffic from different digital subscriber line (DSL) and aggregates the traffic using multiplexing techniques and sends to backbone transmission network. De-multiplexing is carried out for the downstream traffic.

Splitter Cabinet: it is a cabinet containing optical splitter inside it. Optical splitters are passive devices which divides the optical signal into numerous optical signals. The split ratios are 1:2, 1:4, 1:8, and 1:16 and so on. The splitters make the different subscribers use the same optical resource from OLT to splitter (Lokhande & Singh, 2017).

2.1 FTTH Network Architecture

Optical Fiber network can be deployed in two ways: Active Optical Network (AON) and Passive Optical Network (PON).

2.1.1 Active optical network

AON architecture as the name suggests uses the active or powered equipment such as routers or switches. It uses electrical switching equipment for data routing. It has dedicated optical Fiber terminated to the subscriber's premises and the subscribers get the dedicated Fibers and bandwidth. The AON network structure is point-to-point (PTP) and can provide data transmission at a distance of around 100 Km (Abdel et al., 2018). This network is costly and has frequent power issues due to active equipment, but generally considers high quality of service (QOS) network due to dedicated network and suitable for corporate users. It is also considered as a high security network. Fig. 2 shows the network architecture for AON system. The different components of the AON architecture are:

Ethernet switches: These are the active devices such as router or switches that have capable of switching and forwarding the incoming and outgoing traffic to the desired destination.

Optical Network Terminal (ONT): ONT is an active device used at or inside the subscriber's premises. ONT de-multiplexes the incoming signal (downstream) into voice, data, and video, then sends to appropriate destination i.e. voice to telephone set, data to computer or mobile, and video to TV set. Similarly ONT aggregates upstream traffic from triple play devices and forwards to CO (Mata, 2014).

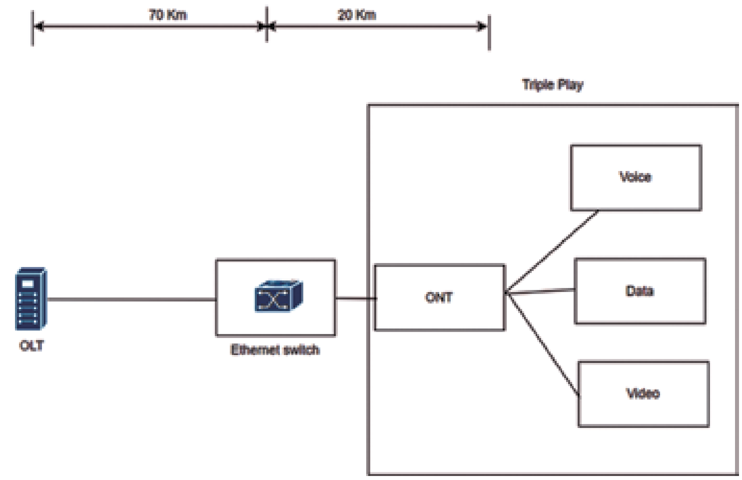

Figure 2: AON architecture

2.1.2 Passive optical network

PON uses passive equipment or non-powered equipment from CO to outside of customers' premises. The passive devices are basically PON splitters. PON architecture has point to multipoint (P2MP) structure and the Fibers and bandwidth are shared by the different subscribers. It does not use active components such as amplifiers, repeaters, and shaping circuits. Due to the high bandwidth of optical Fiber, the shared resources are not of much interest but it makes sensitive for quality service when there is high traffic and much more active subscribers at a time. A single Fiber is connected from central office to splitter and the splitter splits the Fiber and connected to different subscribers, thus sharing the Fiber from CO to a splitter by the connected subscribers. Fig. 3 shows the PON based system architecture.

In the central office, optical line terminator (OLT) is located and optical Fiber is connected from OLT to an optical splitter through optical distribution frame (ODF). As discussed earlier, the OLT generally performs bandwidth allocation and data routing. It manages bidirectional traffic from OLT to customer's premises and vice versa. Optical splitters are the passive splitters that split an optical signal equally into several low power signals. One of them is selected on the basis of the communication service requirements. Splitters are capable of multiplexing and de-multiplexing the optical signals from and to the connected ONTs. Splitters are capable of transmitting the traffic in both direction i.e. both upstream and downstream. An optical splitter or PON splitter is used inside the subscriber's premise or it can be also used outside of the premises. PON splitter is also used inside FDC. PON splitter can be used in different stages. If they are used in first stage, they are generally called as L1 or S1 splitter and in second stage, as L2 or S2 splitters. L2 or S2 splitters are used inside a FAP. Basically FDC and FAP are passive optical splitters.

Splitters are connected between ONT and OLT and there may be more than one stage of splitter connections. Basically, there is optical network unit (ONU) connected at customer's premises and it communicates other ONTs, but ONU and ONTS are considered the same device. The ONT has the interfaces to connect triple play devices such as RJ-11 interfaces for telephone set, LAN interfaces for data and video. The PON network is suitable for the distance at around 20km for quality data transmission and it uses wavelength range of 1310 nm for upstream at speed of 1.25Gbps, 1490nm at 2.5Gbps for downstream, and 1550nm for video transmission (Horvath et al., 2020).

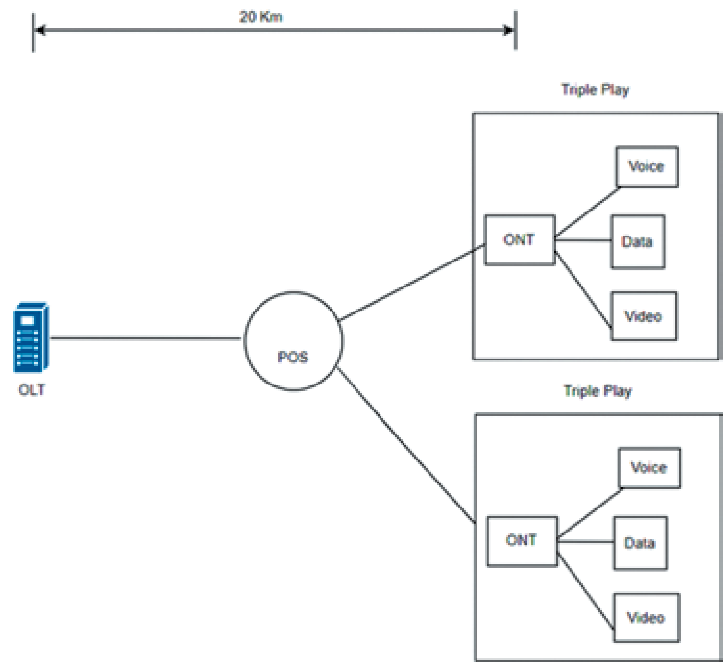

Figure 3: PON architecture

2.1.3 AON vs. PON

As every system has both benefits and shortcomings, AON and PON systems have the same. On the basis of some key parameters, for example, signal distribution, equipment, cost and coverage distance, here is comparison between these two systems. Table 1 shows the difference between these two systems (Larsen et al., 2010; Mahloo et al., 2015).

Table 1: Comparison between AON and PON

Parameters	**AON**	**PON**
Coverage distance	100Km	20Km
Bandwidth	Dedicated, same as bandwidth of OLT port	Sharing
Signal distribution	Unique signal	Same signal to all
Cost	Expensive due to dedicated resources	Cheaper
System failure and maintenance	Complex due to active components if there is frequent power failure	Simpler due to passive devices
Network modification	Easier due to dedicated resources	Complex as there are shared resources

In AON networks, subscribers can use dedicated Fiber optic and bandwidth, while in PON networks, there is sharing of optical Fiber and bandwidth by using PON splitter. Optical Fibers from OLT are shared using L1 splitter and further can be shared by using L2 splitter before reaching to customers premises as well. Due to the dedicated resources, tracing of problems would be easier in AON network, while it is somewhat difficult in PON network. Since, there are powered or active equipment in AON network, there may be more issues of power if somewhere fails the power. In PON network, no such issues take place due to the passive Fiber optic except in two end terminals. AON devices are costlier than PON and AON devices that need frequent maintenance than PON devices due to the necessity of power. In AON system, network can be extended up to 90 to 100km from OLT i.e. central office, while in PON system it is up to 20km only. If there are subscribers closer to the central source of the data, the deployment is easier (Larsen et al., 2010). Apart from these reasons, AON networks are industry standards, more reliable than PON networks, easier to add new devices, and are suitable for corporate customers. Due to the shared bandwidth and resources causing slow in busy hours but are cheaper than AON network and suitable for household customers.

2.1.4 PON standardization

PON network is basically designed for shared usage, due to this, it is cheaper. It uses multiplexing/de-multiplexing techniques to transmit many user's data through the same Fiber. The multiplexing mechanism is based on time division multiple access and time division multiplexing. The Institute of electrical and electronics engineers (IEEE) and the study groups of ITU's telecommunication standardization sector (ITU-T) have developed the different series of PON standards. The full services access network (FSAN) group has developed technical specifications that have been the basis for ITU-T standards. Table 2 summarizes the different PON standards (ITU-T Q2 / Study Group 15, 2018; Muciaccia et al., 2014).

Table 2: PON standards

Technology (Standards)	Features
BPON(G.983.1/G.983.5)	It is the first complete standard of PON, enhanced version of APON based on the ATM protocol with dynamic bandwidth allocation and protection functions. BPON (G.983.1/G.983.5) is standardized in 2005 and has bit rate of 155/622 Mbps (upstream/downstream).
EPON (IEEE 802.3ah)	Adopts P2MP structure and PON transmission. It is the most effective communication method to realize the "three networks in one" and "last mile" due to its cost effective deployment. It has symmetric bandwidth of 1.25 Gbps.
10G-EPON (IEEE 802.3av)	Provides for 10/1Gbps (downstream/upstream) bitrates is the most common Standards.
GPON (ITU-T G.984)	GPON supports multiuser through PON splitter and has high bandwidth, but it is more expensive and complex. It has the bit rate of 1.25/2.5 Gbps. (upstream/downstream)
XG-PON (ITU-T G.987)	XG-PON standard introduced in 2010 provides bit rate of 2.5-10/10Gbps) with highest number of end-users (64-128 Gbps (upstream/downstream) and longer reach (20-60KM).
NG-PON2 (ITU-T G.989.1)	Introduced in 2013, provides bit rate of greater than 10/40Gbps (upstream/downstream) with highest number of end-users (>128) and longer reach (40-60KM).
High speed PON (G.Hsp.x)	Provides high speed of 50Gbps. It is under development.

2.1.5 Telecommunication service scenario

Total population of Nepal is 29,876,531 (NTA, 2021), the telecommunication penetration in Nepal is 130.34%, among them 127.9% are of mobile users. It shows that the number of mobile users is more than the total population of the country. It is due to the fact that more than one mobile phone lines are subscribed by a person but not all citizens are using the mobile. There is no or limited network coverage at far rural part of the country. As discussed earlier, the share of basic telephony is about 2.43%. In most part of the country, the fixed telephone or landline network availability is limited (NTA, 2021).

Fig. 4 shows the broadband share in Nepal for different technologies. Broadband penetration is mainly from mobile network, it is around 74.09%, remaining are from wired and wireless fixed broadband.

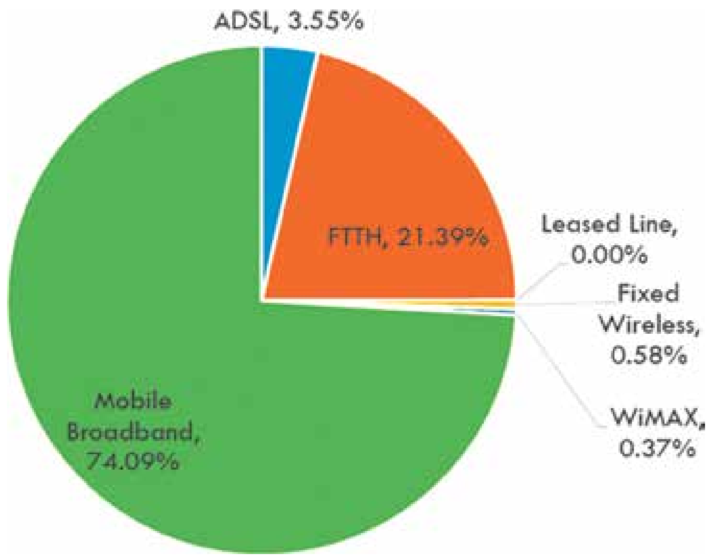

Figure 4: Broadband share in Nepal (source: NTA)

Due to the lack of fixed telephony network infrastructure, the fixed broadband network in Nepal is limited to only about 22.46% of the Nepal's total Population. Fixed broadband technologies include ADSL, FTTH, and lease lines (including copper, optical, and connected by microwave links). Though only 22.46% of Nepal's total Population are having access of fixed broadband, FTTH has the larger share of 86.64 % and it is growing day by day (NTA, 2021). It is due to the optical Fiber deployment by NT and other private ISPs. Fig. 5 shows the share of fixed broadband services in Nepal.

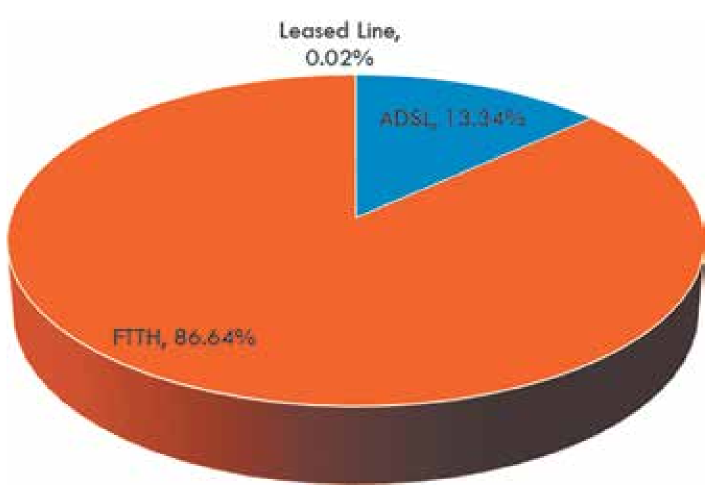

Figure 5: Fixed broadband in Nepal (source: NTA)

NT is migrating copper based ADSL system to optical Fiber broadband technology. Project work for FTTH infrastructure is under deployment. Still, NT has dominant number of ADSL subscribers and they are getting lower due to migration process. Fig. 6 shows the proportion of ADSL, migrated FTTH subscribers from copper cable network, and new FTTH subscribers in NT. The figure is based on the data of NT's ADSL, FTTH subscribers as of august 2020.

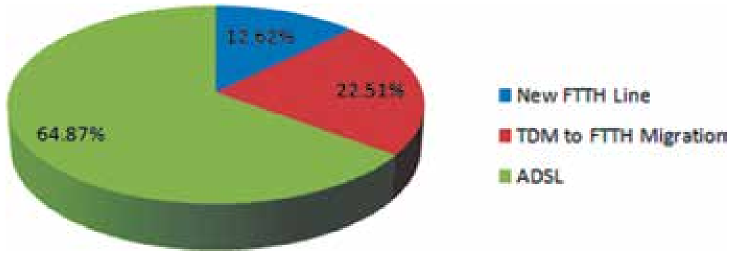

Figure 6: Fixed broadband users in NT (source: NT)

Since, only NT is providing the fixed landline service in Nepal, it has been planning to replace the legacy system with the FTTH service. Fig. 7 shows that 43.47% of the existing total subscribers are having TDM legacy switch and NT is working to replace the legacy switch with NGN IP/IMS switches very soon.

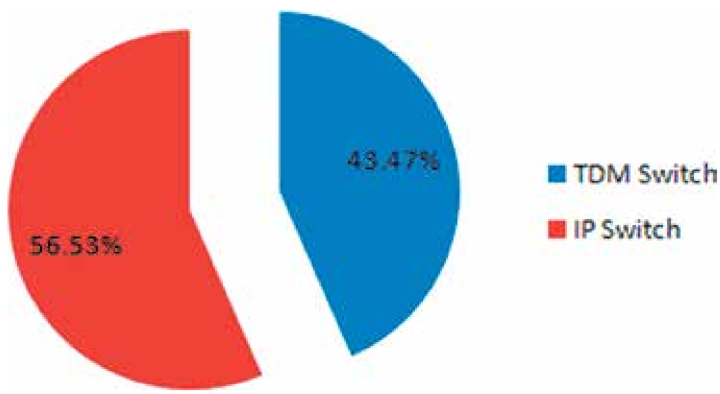

Figure 7: TDM switch vs. IP-based switch (source: NT)

2.2 Related Works

Some related works for the implementation of PON based FTTH architecture are very fruitful and carried out in Nepal and other countries. For reliable optical Fiber high speed data communication, there should be robust telecommunication infrastructure available for the service. Because the existing legacy system cannot support high bandwidth data transmission. There is a pressure for network service providers to upgrade the network infrastructure to meet their demands. The high speed data transmission capability of optical Fiber is instrumental for the world to realize the concept of smart city, smart payment, smart transportation, Internet of things, and smart of everything.

A cost effective design and implementation of GPON based network is presented for Baghdad/Al-Gehad city. Wavelength division multiplexing (WDM) based FTTH solution results in minimization of CAPEX and allows for flexibility and adaptability (Kadhim & Hussain, 2013a).

A GPON based architecture is proposed by the authors for Kosovo (Caka & Hulaj, 2011). The concrete possibilities for practical realization of FTTH network are analyzed based on the territorial structure of Kosovo. A model network for ten houses were used for analysis.

Innovative ideas are developed in Europe for infrastructure sharing. In France, rules for duct sharing are defined and agreed in 2008 and different operators shared the common duct infrastructure of France telecom. Tools for installing optical Fiber in domestic water pipe is developed and used in Germany (FTTH Council Europe, 2014).

FTTH can be a milestone for efficient and fast health care system in rural areas. Hypothetical structuring equation models have been proposed and the test has been carried out in India (Bag et al., 2019). It shows the implementation of FTTH systems results in enhancing the efficiencies of emergency health care system.

Authors of (Khabzli et al., 2019) proposed a PON-based FTTH network architecture for Pekanbaru Citraland housing in Indonesia. The simulated results show that the link budget value has met the IEEE 802.3 standard. In this paper, we present a design and implementation process for PON based FTTH for Nepal considering network deployment of NT.

In Nepal, the project for optical Fiber project for backhaul data transmission is expanding all over the country. NT and other private telecommunication service providers are building Fiber infrastructure in the Terai region and expanding towards hilly region rapidly. Fig. 8 shows the copper network and optical FTTH network reachability status by NT. Copper network is expanded to all district headquarters but there is no uniform expansion to other places. NTA is also building optical Fiber transmission network expansion utilizing the rural telecommunications development fund (RTDF) (NTA, 2018).

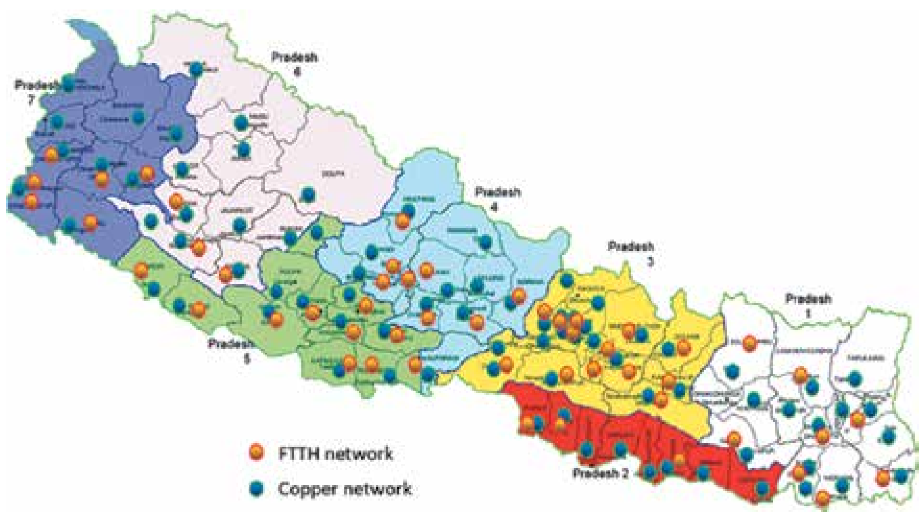

Figure 8: Copper and optical network reachability by NT (map source: ncthakur.itgo.com)

There are challenges to deploy optical Fiber, aerial as well as underground (UG) and all-dielectric self-supporting (ADSS). ADSS is the aerial optical Fiber used for transmitting data that are used on electric utility power lines or high voltage transmission lines (Efficiency, 2015). Tensile element is provided with nonmetallic reinforcement and it does not need messenger wire.

There should be a close coordination among various types of physical infrastructure providing agencies such as road department, drinking water supply department, and electrical authority. The coordination process is happening frequently, but lack of proper communication results in breakdown of optical Fiber, while construction and maintenance work of road, electricity, and drinking water. So, complete synchronization is yet to be realized and there should be proper planning to expand the Fiber through bridges, overhead bridges, and poles.

3. Methodology

A study of design and implementation of PON based FTTH for 500 subscribers capacity is carried out in NT. Its capital expenditure (CAPEX) as well as operational expenditure (OPEX) is estimated and possible payback period is also calculated.

Let us discuss on first design aspect of PON FTTH network. Data collections and analysis have been carried out from the field survey. The location and capacity of OLT, ODF, the length and types of feeder cables, the FDC capacity, the length and types of aerial or distribution cable and types of FAPs are calculated based on precisely collected survey data. The location of FDC and FAPs are fixed accurately with proper survey data. The residential density that may include the number of building, capacity of building, the number flats etc. the possibility of expansion of residential area also considered precisely. The structure of road, highways, drinking water, and pole structure of electricity, where it is to be shared are analyzed and coordinated properly. The proper route of feeder, aerial cable according to the residential structure are identified. The geographic information system (GIS) application becomes the effective tools to solve the problems with field survey data. The network ring also designed correctly for redundancy purposes in case of main link fails. Generally, OLT and ODF sites are in CO. Fig. 9 shows the summary of design steps of FTTH network using bottom up approach i.e. from subscriber residents to CO.

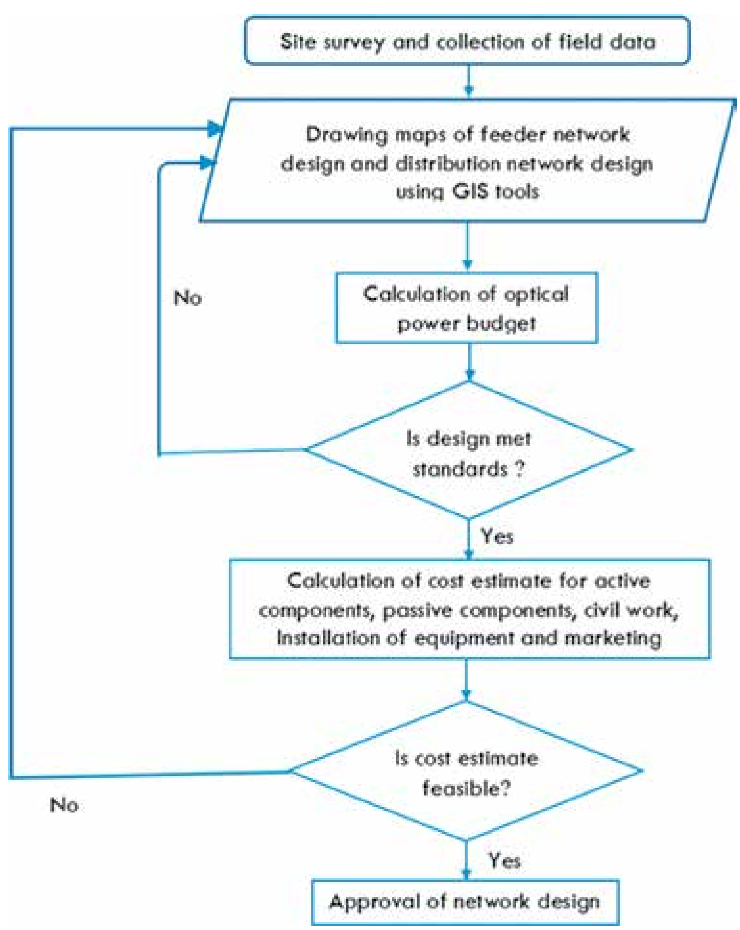

Figure 9: Design steps of PON based FTTH network

Fig. 10 shows FSA, CSA and DSA service are boundaries in design aspect (Lokhande & Singh, 2017).

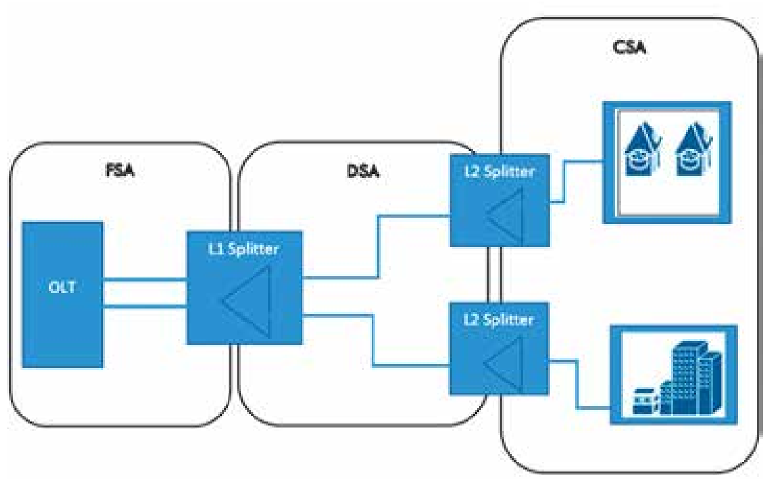

Figure 10: Service area boundaries

Feeder service area (FSA) design: FSA is planned in such a way that it covers the maximum home/customer to meet the key performance indicator (KPI) and design from OLT to first stage designer.

Customer service area (CSA) design: Planning the CSA/S2 splitter cluster requires building information, open plots, under construction building information, and land base data, which contains building, roads, streets parks, playground etc. Design from 2nd level splitter onwards covers 10-40 subscribers.

Distribution service area (DSA) design: Fiber route planned between L1 splitter to L2 splitter is called as distribution route. Distribution sections connect neighboring buildings from L1 splitter locations in its designated cluster.

Feeder and distribution Fiber: Feeder Fiber is used to connect ODF and FDC. After completing the site for OLT, feeder laying design is carried out and possible locations of FDC and FAP are designed accurately from field survey data by using GIS tools. Generally, 12/24/48/96/144 core Fiber cable is used. It is underground (UG) Fiber cable and designed accordingly. Distribution Fibers are aerial Fiber of 12/24/48 core that are used to connect FDC and FAP depending upon choice of different their capacities.

Drop Fiber (DF) and ONT: Drop Fiber cable is used between FAPs and ONT. It can be one- or two-core Fiber. The length of DF is calculated according to the distance between FAP and subscriber's home. The FAP is placed in a location such that the total length of DF can be minimized. ONTs are installed inside the home premises of the users. DF with built-in connector is used and connector can be made according to the choice of the required length of the DF. Generally, the length of DF is up to 50m and if there is longer distance i.e. greater than fifty meters, outdoor terminal box can also be used for signal repetition and generation purposes. Fig. 11 shows the FTTH architecture for 512 capacity FDC of ODN Network. In this network, L1 splitter or FDC has 1:8 split ratio resulting 64 Fiber access points (FAPs) from 8 cores of Fiber. Each FAP or L2 splitter has 1:8 split ratio further thus resulting 512 connection port for subscribers. For copper based telephone migration, exchanges up to the capacity of 2000 to 5000 subscribers and such type of FDC is suitable for cities such as Itahari, Mahendranagar, and Surkhet. The network architecture for ODN shown in Fig. 11 can be modified and applied for FDCs with the capacities of 256 and 1024 subscribers. The major differences are the number of feeder cable, split ratio of L1 and L2 splitter. Table 3 shows the comparisons of the three types of ODN architecture. Fig. 12 summarizes the implementation and deployment steps of PON based FTTH network.

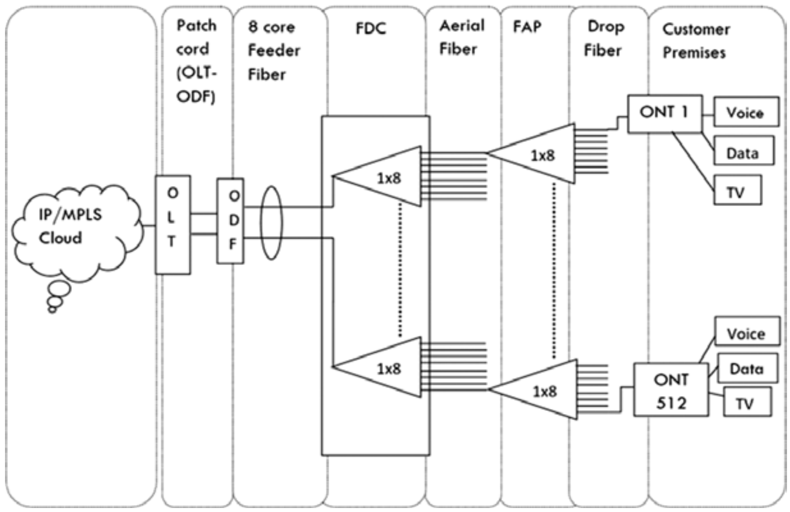

Figure 11: ODN architecture for FDC capacity of 512

Civil works: Trenching, digging and basement of FDC, laying of duct for Fibers are carried out. In NT, civil department coordinates the design and implementation of civil related works. The major challenges for this type of work is to establish coordination with the related other offices such as road department, urban development department, electricity authority, and other related departments (Nyarko-Boateng et al., 2020).

Table 3: Comparison of different ODN architecture

Parameters	FDC-512	FDC-256	FDC-1024
Number of OLT Ports	8	4	16
Number of L1 Splitter	8	4	16
L1 Split ratio	1:8	1:16	1:4
Number of L2 Splitter	64	64	64
L2 Split ratio	1:8	1:4	1:16

4. Implementation, Results, and Analysis

CAPEX is related to the cost associated with the infrastructure such as physical assets, building, network equipment, and software (Schneir & Xiong, 2014). OPEX refers to the cost associated with day to day activities or business for running and maintaining the system continuously and preventing from failures. In this paper, we consider cost estimation for ODN basically from OLT to ONT and analyze for best optimization combination of CAPEX and OPEX. CAPEX includes mainly three types of costs, these are infrastructure setup cost, system network equipment cost, and customer's premises equipment cost. The infrastructure setup cost includes the cost of ODF, Fiber (e.g., feeder, aerial, splicing cost, and drop Fiber), POS splitter (e.g., FDC and FAPs), in-house infrastructure in the subscribers premises, and related other components. The cost also includes the civil work cost like trenching, digging, and ducting for underground Fiber laying. System network equipment cost refers to the cost associated with network equipment for routing and switching. Switches, routers, OLT, and related cards and accessories, racks, power equipment such as UPS, air conditioning, and rectifiers. Customer premises equipment (CPE) cost includes the cost related to ONT (e.g., CPEs, telephone interfaces, LAN cables and interfaces, radio interface, and power backup for CPEs. (Rokkas et al., 2012; Wang, 2017).

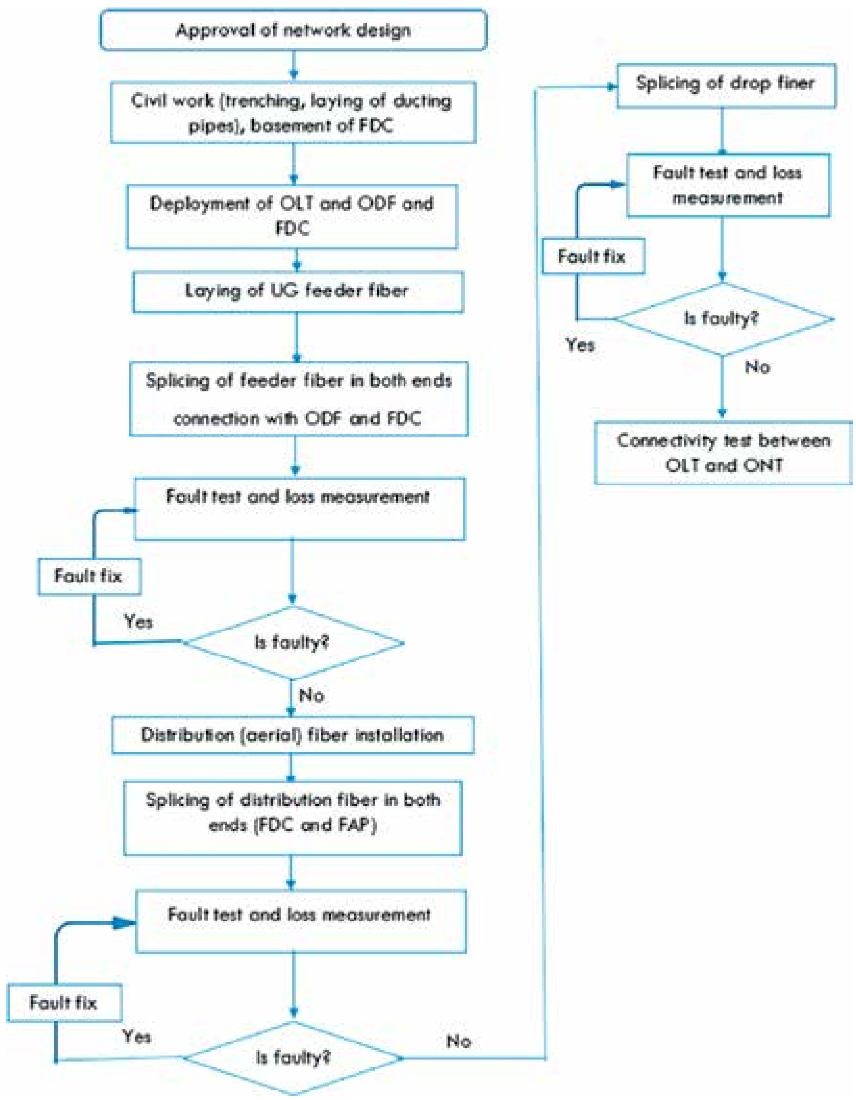

Figure 12: Implementation and deployment steps of PON based FTTH network.

OPEX is the cost incurred by business in its day to day business for smooth operation and maintenance of the FTTH system. OPEX includes wages and salaries of employees, travelling expenses, preventive and corrective maintenance cost. The major OPEX for FTTH operation and maintenance is the service provisioning cost. This is about provisioning of subscribers' services such as addition, removal and editing service profile of the subscribers. Service profile includes details of subscribers such as name, address, documents, types of service package etc. Service provisioning is carried out by the network management system (NMS). It includes Fiber management (such as splicing and patch cord management), and fault management such as failure detection and recovery through system, card and other components replacement and repair. Energy consumption cost covers the power consumption by active equipment and air-conditions. Maintenance cost includes the maintenance of physical infrastructure, preventive and corrective maintenance cost. Floor space management cost includes mainly the cost associated with space leasing for setting up equipment (Kadhim & Hussain, 2013b; Kulkarni et al., 2008).

4.1 Network Life Cycle of a Typical FTTH

The cost breakdown can be well depicted by examining the following project life cycle of typical projects, which will be fruitful for cost breakdown. A typical network lifecycle consists of the following five stages:

- Planning phase
- Implementation phase
- Migration phase
- System power up and running phase
- Dismantle phase

Planning phase: It includes analysis of demographic as well as geographical factors which affects costs for deployment stage. Survey of entire network, calculation of number and location of network equipment, estimation of CAPEX and OPEX, developing business model, choice of proper technology, and choice of proper work order are to be finalized in planning phase.

Implementation phase: In this phase, the project is deployed. For FTTH, all civil related works e.g. trenching, digging, and lying of ducting can be carried out. The installation of network equipment, laying down of Fibers, installation and testing of PON splitter, and testing of all equipment should be carried out in this phase. Larger amount of cost and resources are needed in this phase.

Migration phase: After the deployment phase is over, migration phase should be carried out. Database collection of all subscribers, their service status are collected, rearranged and updated according to the new service. If there is a mismatch, then proper migration cannot be performed. The cost is related to activity based cost. It includes basically customer's equipment cost such as cost of CPEs and accessories and administrative and CPE installation cost while migrating.

System power up and running phase: This phase includes mainly operation and maintenance. Proper preventive and corrective maintenance procedure are analyzed and carried out. The main cost includes OPEX cost like equipment maintenance, splicing and patching (for operations and maintenance), parts repaired and replacement costs. Marketing and promotions, and continuous fixed costs are also included in this phase.

Dismantle phase: In this Phase, all the existing subscribers are migrated into new service and all the old network equipment will be dismantled (Casier et al., 2008).

4.2 CAPEX and OPEX calculation for ODN

The CAPEX calculation presented in this paper is only for an ODN network of an urban area having 500 subscribers. The other costs like backbone transmission and core network are not included. The CAPEX includes OLT and core equipment, UG feeder Fiber, aerial distribution Fiber, FDC, FAP, drop Fiber, customer premises equipment (CPE), implementation cost and civil work cost. By calculating all the costs, the CAPEX per subscriber is come out to be NPR 9937.17(≈9938). This is calculated for specific time period and it may vary with time due to the changes in the prices of Fibers and labors and other equipment. The calculation is based on ODN architecture for 512 subscribers. The estimated values are assumed based on the current market values and considering previous different quotations and tender. Table 4 shows the values of each parameters. The calculation is carried out using the following formula.

Cost per subscriber for OLT and core equipment (1024 Capacity)

$$= \frac{\text{Total cost for OLT and core equipment (1024-capacity)}}{\text{Number of subscriber}} = \frac{650000.00}{1024} = 634.77$$

The total quantity is specified for UG feeder Fiber, aerial distribution Fiber, FDC, and FAP. Implementation cost is just enough for 512 subscribers.

$$\text{Cost/subscriber for UG Fiber} = \frac{\text{Total cost for UG feeder fiber}}{\text{Number of subscriber}} = \frac{300000.00}{512} = 585.94$$

Each subscriber need one CPU, so the unit cost is kept same.

Total cost =∑(Total cost for each parameter)+ Overhead cost (15% assumed)

Table 4: CAPEX calculation for ODN

Parameters	Quantity	Total cost(NPR)	Cost per subscriber (NPR)
OLT and core equipment (1024 capacity)	1 Set	650000.00	634.77
UG feeder Fiber	1000 meters	300000.00	585.94
Aerial distribution Fiber	4000 meters	280000.00	546.88
FDC	1 set	25000.00	48.83
FAP	64 set	96000.00	187.50
Drop Fiber	1 set	600.00	600.00
CPE	1set	2500.00	2500.00
Implementation cost	Calculated total cost	275000.00	537.11
Civil cost		1000.00	1000.00
Installation and marketing		2000.00	2000.00
		Total cost	8641.02
		Overhead cost(15% assumed)	1296.15
		Total investment (CAPEX)	9937.17

Fig. 13 shows the different cost and their contributions in percentage. The CAPEX would increase in suburban and rural area due to the transportation cost and labor cost. CAPEX is estimated for urban, sub-urban, and rural area. Fig. 14 shows the CAPEX for urban, sub-urban, and rural areas. CAPEX increases in rural area due to heavily increase in transportation cost.

Similarly, OPEX includes operation and maintenance cost, customer care cost, International bandwidth for voice, IPTV, data and other VAS services, and interest of investment. Analyzing and calculating OPEX, the OPEX per subscriber per month is estimated to be NPR 532.81. The calculation is carried out based on current international bandwidth price, operation and maintenance cost as 10% of total revenue, and considering interest of investment as 10%. Income is assumed based on the current average income of voice, data, and TV subscription rate. Fig. 15 shows the different contribution share for OPEX per month in percentage.

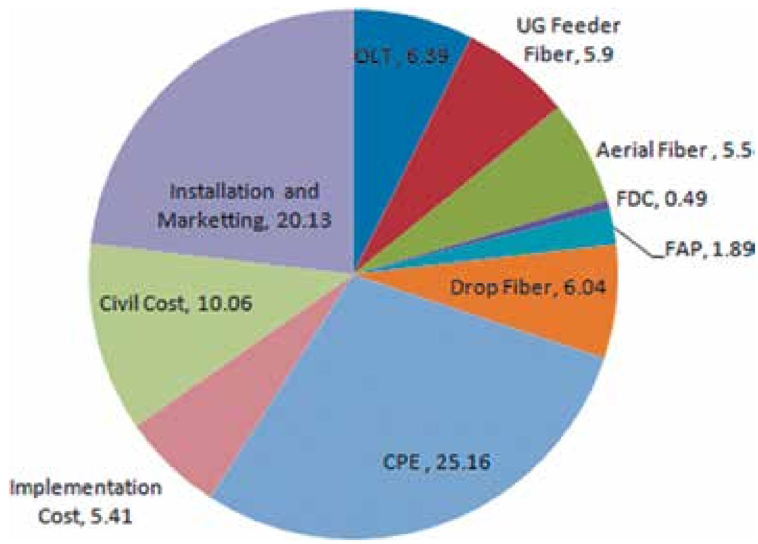

Figure13: Investment share in percentage

Internet revenue per month = NPR 800.00

IPTV revenue per month = NPR 200.00

Voice revenue per month = NPR 250.00

Total revenue per month = NPR 800.00 + NPR 200.00 +NPR 250.00 = NPR 1250.00

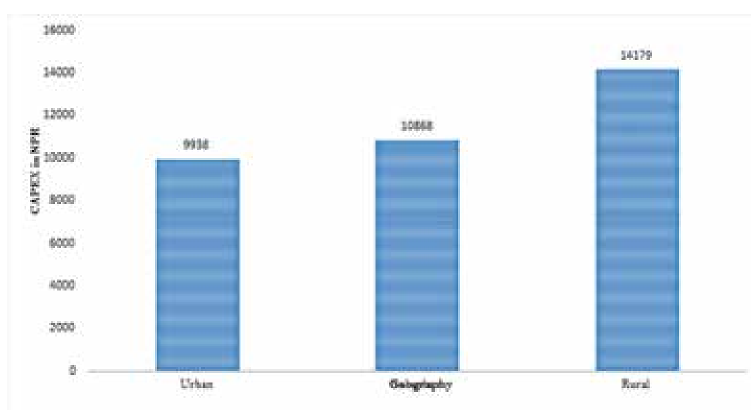

Figure14: CAPEX for different terrain

Expenses are assumed as,

International bandwidth (20% of total consumption) per month = 0.2* NPR800 =NPR160.00

IPTV per month (70%) = 0.7 x 200.00 = NPR 140.00

Voice (10%) per month = 0.1 x 250 = NPR 25.00

Operation, maintenance, and customer care cost per month = 10% of total revenue = 0.1 x 1250 = NPR 125.00

Interest of investment per month = 10% of total investment = 0.1x $\frac{9937.17}{12}$ = NPR 82.81

Total investment per month = NPR160.00 + NPR 140.00 + NPR 25.00 + NPR 125.00 + NPR 82.81 =NPR 532.81

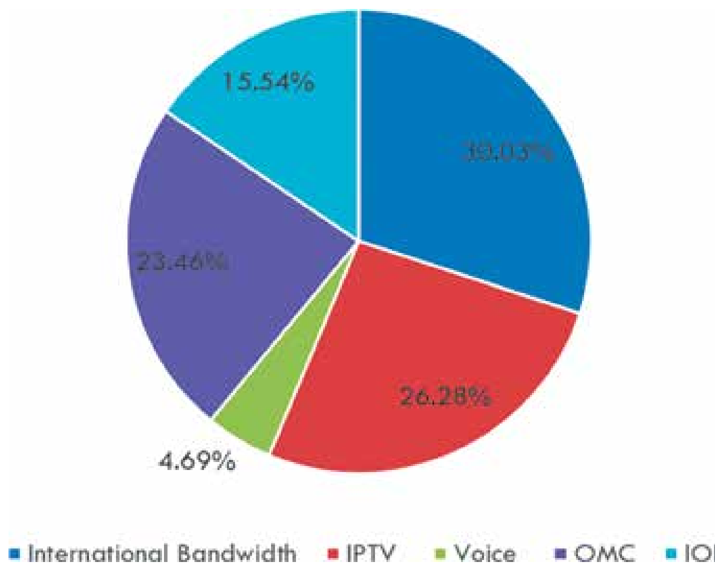

Figure 15: OPEX contributions in percentage

Payback period: Analyzing CAPEX, OPEX, and revenue calculations, the payback period for urban area is about 20 months. It is considered that the network utilization ratio is 0.5. Fig. 16 shows payback period for different geography. The payback period is longer (38 months) for rural areas due to high transportation, carrying, and labor cost. In some area, transportation is to be carried out by helicopters, aero planes.

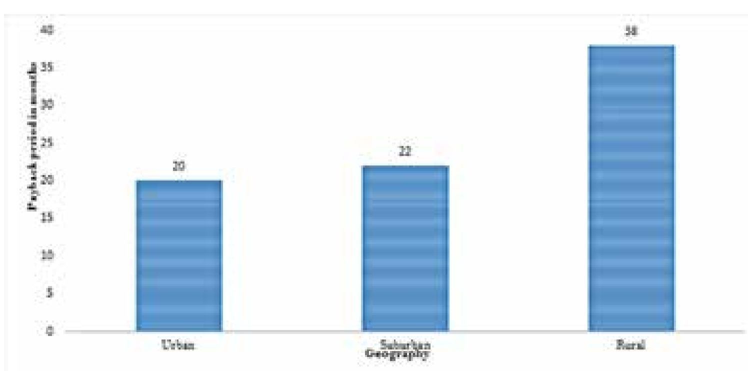

Figure 16: Payback period for different geography

4.3 Implementation of GIS Tool for Optical Network Planning

A GIS tool is very fruitful to design FTTH network due to its availability, much more functional abilities, and openness of software (Matrood et al., 2014). GIS software tools are very fruitful for effective design of FDCs, FAP, feeder Fiber and aerial Fiber, and for estimation of drop Fibers. Fig. 17 shows network design for both feeder Fiber and FDC, FAPs, and aerial Fiber. For the accurate Fiber network planning for both aerial and feeder Fiber, GIS tools is very effective. Fig. 18 shows a sample figure of network diagram drawn using GIS tool (CableCad) for aerial cable and FDC location and a feeder.

Table 5: Power loss measurement from OLT to L1 splitter (source: NT)

Port No.	Signal Power loss OLT to ODF(dBm)	At input of L1 splitter (FDC no. 1)(dBm)
1	3.3	1.1
2	4.4	0.46
3	2.41	0.6
4	2.94	1.49
5	2.36	0.5
6	3	1.96
7	3.12	1.54
8	3	1.17
	Average Power loss = 3.06625 dBm	Average Power loss = 1.1025 dBm

Table 6 shows the measured values of output of L1 splitter, input and output of a particular FAP or L2 splitter of 1:8 split ratio. The average value of power loss is -8.72375 dBm and -18.23 dBm respectively. So the values are satisfactory for network deployment. The value of loss is -8.88dBm at input of L2 splitter. Similarly, the maximum value of loss is -18.3dBm and minimum value of loss is -18.16dBm at output of L2 splitter. The above values suggest that the network deployment is satisfactory.

Table 6: Power loss measurement from L1 splitter to L2 splitter (source: NT)

Port No.	Output of L1 splitter (FDC No. 1)(dBm)	Input of L2 (FAP1) (dBm)	L2 output (FAP1)(dBm)
1	-8.88	-8.88	-18.2
2	-8.69		-18.22
3	-8.7		-18.25
4	-8.69		-18.28
5	-8.77		-18.18
6	-8.72		-18.16
7	-8.65		-18.25
8	-8.69		-18.3
	Average power Loss = -8.72375 dBm		Average power Loss = -18.23 dBm

4.4 Loss Measurement

The practical optical Fiber loss of up to -22dBm for the last mile or end devices from ODF is considered to be sufficient. The power loss from OLT to ODF is 4dBm. Table 5 shows the measured values from OLT to ODF. The average value is 3.0663 dBm. Similarly, the power at the input of a sampled FDC or L1 splitter of

1:8 split ratio is also measured and the average value turn out to be 1.1025 dBm. This measurement is taken of feeder cable up to the length of 3km the distance between FDC and FAP is up to 1km. Optical power meter (OPM) is used for loss measurement, optical time-domain reflectometer (OTDR) is used for finding Fiber cable's fault, and splicing machines are used to splice the optical Fiber whenever there is requirements to ensure quality of optical Fiber.

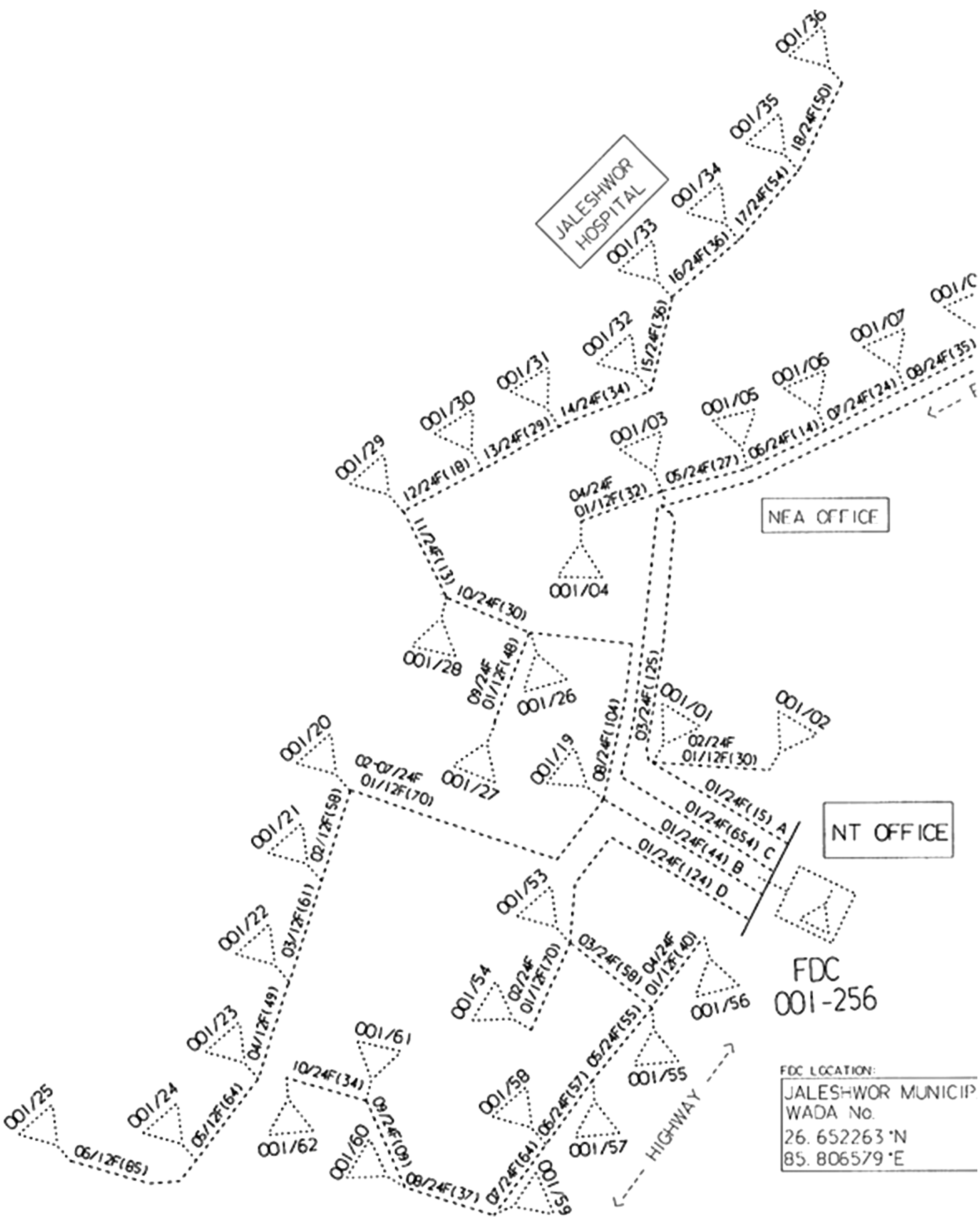

Figure 17: FDC, aerial fiber and FAP design map by GIS tools-CableCad (source: NT)

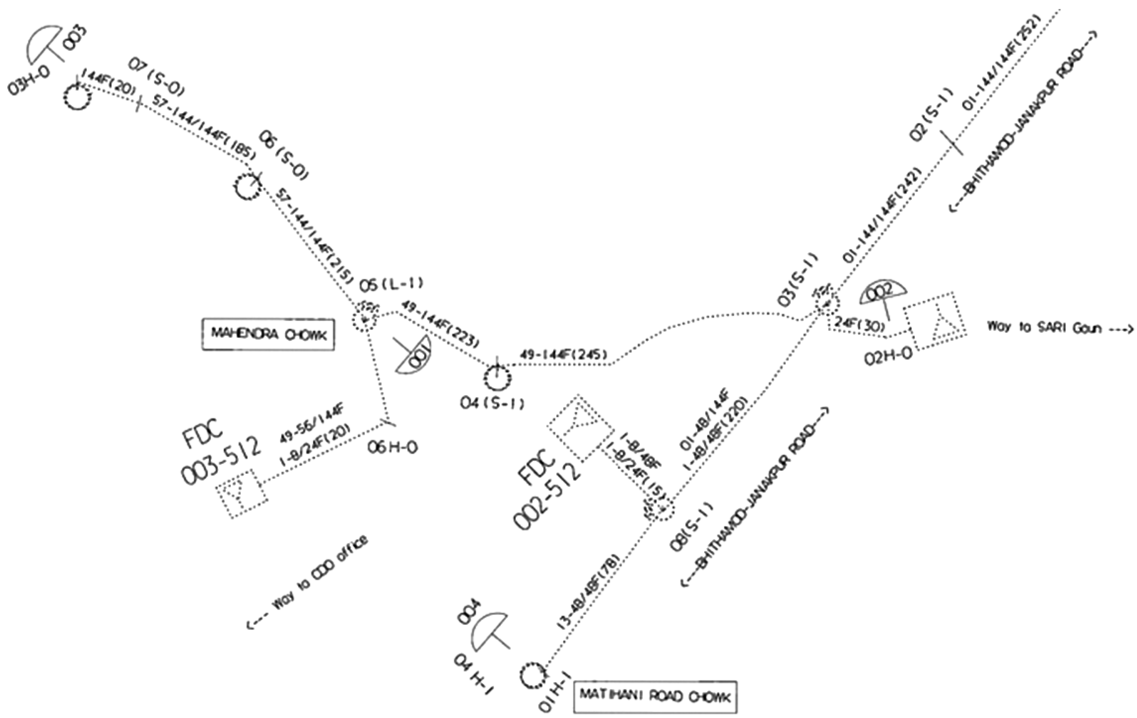

Figure 18: Feeder fiber design layout by GIS tools (source: NT)

5. Discussion and Recommendation

In this paper, the PON architectures are discussed and implementation in the context of Nepal is analyzed. The different architectures are suitable in different terrain structure in Nepal. It is considered to have reliable optical Fiber backhaul link across all parts of the country. Microwave links should be updated to higher capacities. Based on the CAPEX and OPEX discussion, the following different architecture is recommended in different terrain.

- For corporate customer, AON is suitable, PON architecture can also be used for that purpose too.
- For densely populated area, PON having capacity of 1024 and higher is suggested that reduces CAPEX and OPEX.
- For sub-urban area, PON architecture with capacity of 512 is recommended.
- For rural area, where there is dispersed inhabitation around 200 to 400 population in small market. For sub-urban area PON architecture with capacity of 256 is suitable.

For remote area, where there may not be Fiber transmission network, there should be improvement of microwave transmission network and PON having capacity of 64 or 32 is recommended, but it is too costly for implementation. RTDF fund can be utilized for such scenario as Government of Nepal has a policy to use the fund for the rural areas.

6. Conclusions

In this paper, the FTTH implementation scenario in the context of Nepal is presented. Cost effective implementation approach is also discussed and some architectural approaches are recommended that are suitable based on demographic condition of Nepal. Backhaul transmission network with optical link is mandatory for better quality service of FTTH network. Based on the territory, the discussed architectures can be modified and designed in future. High capacity FDCs are proposed for high density area to replace copper network. Microwave link should be upgraded to avoid bottleneck of data traffic. Integrated planning is necessary for building telecommunication infrastructure. While planning for road infrastructure, planning for electric poles, ADSS, underground cable, Fiber laying on the side of bridges is to be carried out jointly. The discussed design and implementation methodology would be a lesson learn to other stakeholders of the developing nations like Nepal.

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Conflict of Interests

Authors declare no conflict of interests.

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