Escola d'Enginyeria de Telecomunicació i Aeroespacial de Castelldefels

UNIVERSITAT POLITÈCNICA DE CATALUNYA

# MASTER THESIS

**TITLE: Design of a Network Access Based on FTTH for Sao Tome and Principe**

**MASTER DEGREE: Master in Science in Telecommunication Engineering & Management**

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# Overview

Telecommunication infrastructures constitute a key point for development of a society. A robust infrastructure for telecommunication services enables competitiveness of a country, power its economic growth and promote welfare of his population. On the contrary, a weak infrastructure is responsible for low penetrations in the access of broadband services, low productivity and, at the end, higher life cost.

The present project proposes a technical solution for a new telecommunication infrastructure in Sao Tome and Principe based in Fiber to the home – FTTH technology, as the best way to overcome the problem related with low penetration of Information and Communication Technology (ICT) and high cost of those services currently registered in this country. Studies have shown that price and penetration of fixed broadband services are quite related, and FTTH is the only technology able to provide all those services at low cost for at least next 50 years without necessity of replacement and the revenue for the companies are ensured.

The project is complemented by an economic assessment of the technological solution based on current equipment prices in the market. However it worth to consider that for its implementation the business model based on a phased strategy is the best solution, taking as the starting point the area where there is the highest number of companies and users, as a way to achieve the goals and get success without the need for large investments a priori.

# Resumen

Las infraestructuras de telecomunicaciones constituyen el punto clave para el desarrollo de una sociedad. Una infraestructura de telecomunicaciones robusta proporciona la competitividad del país, potencia su crecimiento económico y promove el bienestar de su población. Al contrario, una infraestructura débil es la responsable por la baja penetración en el acceso a los servicios de banda ancha, baja productividad y el alto costo de vida.

En el presente proyecto se propone una solución técnica para una nueva infraestructura de telecomunicaciones para Sao Tomé y Príncipe basada en la tecnología Fibra hasta el hogar – FTTH como la mejor forma de superar los problemas de baja penetración en los servicios de Tecnologías de Informaciones y Comunicación (TIC) y el alto costo de estos servicios verificados actualmente en el país. Los estudios han demostrados que el precio y la penetración de los servicios fijos de banda ancha están íntimamente relacionados, y FTTH es la única tecnología capaz de proporcionar todos estos servicios a bajo costo sin la necesidad de ser sustituido por otras tecnologías en los próximos 50 años y los ingresos por parte de las compañías están garantizados.

Además se ha hecho una valoración económica de todo el proyecto basado en los precios actuales de los equipos en mercado, pero consciente que para su implementación una estrategia basada en un modelo de negocio por etapas sería la mejor solución, tomando como el punto de partida la zona con mayor número de empresas y de usuarios como forma de alcanzar los objetivos y obtener sucesos sin la necesidad de grandes investimentos a priori.

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# Acronyms

A - Availability
ACE- Africa Coast to Europe
ADSL – Asymmetric Digital Subscriber Line
AES – Advanced Encryption Standard
AG – Agua Grande
AGER - Autoridade Geral de Regulação (General Authority of Regulation)
AON - Active Optical Networks
ATM – Asynchronous Transfer Mode
ATU-C - ADSL Terminal Unit-Central
ATU-R - ADSL Terminal Unit-Remote
AWG - Arrayed Waveguide Gratings
BER – Bit Error Rate
BW – Bandwidth
CATV – Cable Television
CO - Central Office
CST – Companhia Santomense de Telecomunicações
DAB - Dynamic Allocation of Bandwidth
DSLAM - Digital Subscriber Line Access Multiplexer
EPON - Ethernet Passive Optical Networks
ESON - Ethernet Switched Optical Network
FSAN – Full Service Access Network
FTTC – Fiber to the Curb
FTTH – Fiber to the Home
GEM - GPON Encapsulation Method
GNI p.c – Gross National Income per capita
GPON – Gigabit Passive Optical Networks
GUE - Guiché Unico para Empresas (One-stop Shop for Businesses)
HDTV - High Definition Television
HFC – Hybrid Fibre-Coaxial
IBP - ICT Price Basket
ICT – Information and Communication Technology
IDI – ICT Development Index
INE - Instituto Nacional de Estatística (National Statistics Institute)
ISP - Internet Services Provider
ITU – International Telecommunications Union
LAN - Local Area Networks
LC – Local Center
LLID- Logical Link Identifier
MAC - Media Access Controller
Man - Metro Area Networks
MIS - Measuring the Information Society
MPCP - Multipoint Control Protocol
OAM - Operation, Administration and Maintenance
OLT - Optical Line Terminal
OMCI **-** ONT Management and Control Interface
ONT - Optical Network Terminal
OPEX – Operational Expenditure

P2M – Point-to-Multipoint
P2P – Point-to Point
PON - Passive Optical Networks
STP – Sao Tome and Principe
TDM – Time Division Multiplex
TDMA - Time Division Multiple Access
TDMA - Time Division Multiplex Access
WACS - West Africa Cable System
WDM - Wavelength Division Multiplex
U – Unavailability
USA – United State of America

# Introduction

Sao Tome and Principe (STP) are two small Islands located in West of Africa where the public telecommunications infrastructure is based in Asynchronous Digital Subscriber Line (ADSL) based in DSLAM technology. The level of ICT penetration is quite low mainly because of high price practiced in the provided services as the consequence of the telecommunications infrastructure used. Being STP an island, where the connections with the world is performed by satellite, together with the monopoly awarded to a company up to two years, make STP one of the country where the users pay more in the world to access broadband services. As the consequence of this, the level affordability is quite low. However, an important recent deployment has been the landing in STP of major cable systems on African continent: specifically, Africa Coast to Europe (ACE) in May 2012.

The constant demand growing of bandwidth in the world is an evidence which cannot be ignored, and although there are wide progresses in development of different types of the Digital Subscriber Line (DSL) technologies, they are really limited when distance increase. Today, the looming bandwidth needs are so large, and all studies forecast that the innovation will continue and the needs for more bandwidth will further increase. Services which require broadband access like High Definition Television (HDTV), Video on Demand (VoD) or streaming media, require more bandwidth than the one that can be provided by DSL. Since the optical fiber system has come now to STP, the design of a robust network which allows providing broadband services can be realized; this way, an infrastructure for broadband services can be built, being at lower cost than satellite-based one. Fiber to the home (FTTH) technology is able to support he required bandwidth, taking into account both current and future needs.

The present project, analyze the actual telecommunications infrastructure in STP, provide several alternatives based on optic fiber and present the solution that best fits the characteristics of STP; it , has been structured into 4 chapters.

In the first chapter, is addressed the history of telecommunications in STP such as their existent infrastructures and level of services penetration. Also in this chapter a new infrastructure based on FTTH is proposed to overcome the limitation of the existing one. Later, on the second chapter a deep study based on the proposed infrastructure is performed, its advantages and the reason and why it was selected is analyzed. The chapter three makes a study of the bandwidth which will be required for the subscribers: considering big, medium and low size companies as well as urban and rural residential users. The chapter 4 is aimed to design of networks, equipment' deployment, fibers selections and installations cost of the infrastructure.

# Chapter 1: Actual telecommunication infrastructures

**Summary**
Sao Tome and Príncipe (STP) are two small islands located in Guinea Gulf in West of Africa where the penetrations of broadband services is quite low mainly because the cost of the services. In this chapter, it will be provided an overview of the state of ICT services in STP, the existent infrastructures, such as ICT Development Index (IDI) and ICT Price Basket.

## 1.1. General contents

Telecommunication services in STP were launched on January 1, 1990 by a consortium between the Sao Tome government and Portugal Telecom. This consortium is called “Companhia Santomense de Telecomunicações” (CST). At the beginning, the only service provided by this company was fixed phone services until around year 2000 when they started to provide mobile telephone services and Dial-up internet access through Modem of 56Kbps capacity.

Some years later, that technology had been replaced by ADSL, which has remained until today, to provide better fixed internet service to the users. The fixed internet service in Sao Tome is quite expensive and as a result, the services are limited to a few numbers of people. More frustrating is the fact that, users cannot contract a bandwidth over 12Mbps because the company does not have the capacity to provide more than this bandwidth to its customers.

In 2012, the project Africa Coast to Europe (ACE) laid an optical fiber to the islands arriving from France to South Africa with connections through some countries of southern Africa including Sao Tome. However, currently it is not possible to verify some enhancement on the communications services. The price still remains quite high, one of the most expensive in the world.

In April 2012, through General Authority of Regulation (Autoridade Geral de Regulação – AGER), the government decided to end the monopoly of CST, conceding the second telecommunication license to a new company, UNITEL, which is expected to start operation in the first half of 2014.

Actually, there are 179.200 inhabitants in Sao Tome and Principe, but only around 8000 has fixed broadband internet connections, distributed between residential and business customers, which corresponds to just 4,5% of the total population of the country. Nowadays there are some people who are using mobile internet which was released two years ago. As can be observed, the number of users of fixed internet connections is very low; the main reason for this small number of users is the price applied by Internet Services Provider (ISP) which had been enjoying monopoly of the telecommunications sector up to two years ago without any market competition. The following tables show the current price of internet, fixed and mobile, respectively applied for that company.

**Table 1.1.** Current price applied by CST for ADSL services [1].

| Upstream (Kbps) | Downstream (Kbps) | Value / Months | Ceiling traffic (Gb) | Excess Traffic value |
|---|---|---|---|---|
| 256 | 512 | 34,69$ | 4 | 0,0114$ / Mb |
| 512 | 1024 | 55,50$ | 8 | 0,0114$ / Mb |
| 1024 | 2048 | 111,00$ | 20 | 0,0114$ / Mb |
| 1024 | 4096 | 222,00$ | 40 | 0,0114$ / Mb |
| 1024 | 12288 | 381,56$ | Unlimited | |

Apart from this fee which is charged per month for the fixed internet services, an additional $81,86 is charged being the cost for installations.

**Table 1.2.** Current prices applied by CST for mobile internet services [1].

| Bandwidth (Mbps) | Valoe / Months | Ceiling Traffic (Gb) | Excess Traffic/months |
|---|---|---|---|
| 1 | 34,69$ | 2 | 0,0278$ |
| 2 | 55,50$ | 4 | 0,0278$ |
| 3,6 | 90,19$ | 8 | 0,0278$ |
| 7,2 | 138,75$ | 16 | 0,0278$ |

## 1.2. Existing Telecommunications Infrastructures

Telecommunication is a productive sector, key factor to economic development of countries, although the income is not in the short term, after the initial inversions the profits will be ensured. Therefore the company cannot be afraid to invest in that sector by deploying modern broadband infrastructures and equipment which constitute the critical points of developments. The following figure shows the general investment diagram of a telecommunication company.

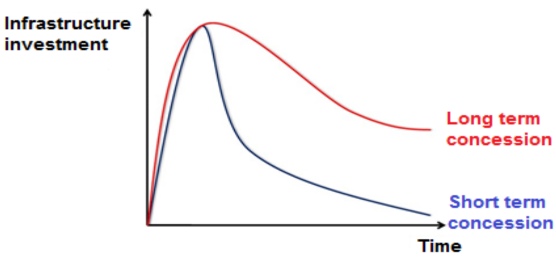



**Fig.1.1:** General investment in Telecommunication Company.

As can be verified, the main expense of the company is only at the beginning; after that, the expenses are minimal. The only thing that depends on the investment scenarios is the duration of the concessions. If it is considered that the area under the curve represents the amount invested in the infrastructures, it means that concessions at long durations imply more inversions. The national infrastructure of telecommunications installed actually in Sao Tome is composed by international Central Office (CO) which can be considered also as the primary center and several small regional Central Offices located in each district throughout the country which can be considered as Local Center (LC) as showing in the figure bellow.

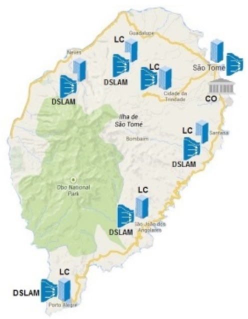



**Fig.1.2:** Current telecommunication infrastructure.

The technology used to provide fixed broadband internet services is Digital Subscriber Line Access Multiplexer (DSLAM) which provides the users access to the ADSL services over the existing copper telephone lines which connect subscriber´s home or offices to Central Offices in the company. The bandwidths provided by the company to the users are shown in the following table.

**Table 1.3.** Bandwidth provided by CST.

| Upstream (Kbps) | Downstream (Kbps) |
|---|---|
| 256 | 512 |
| 512 | 1024 |
| 1024 | 2048 |
| 1024 | 4096 |
| 1024 | 12288 |

As it is well-known, in a copper pair, the attenuation per unit length increases as the frequency of signals transmitted increases, and more distance means more signals attenuations. It can be explained that the best performance achieved using this technology are quite affected by the distance as showing in the following table.

**Table 1.4.** Bandwidth vs distance.

| Upstream (Kbps) | Downstream (Kbps) | Maximal distance (m) |
|---|---|---|
| 256 | 512 | 5400 |
| 512 | 1024 | 3000 |
| 1024 | 2048 | 1500 |
| 1024 | 4096 | 500 |
| 1024 | 12288 | 200 |

ADSL has the disadvantage that it is a distance sensitive technology. As the connections length from the user to the DSLAM increases, the signal quality decreases and the connections speed goes down. The next graph shows that limitations.

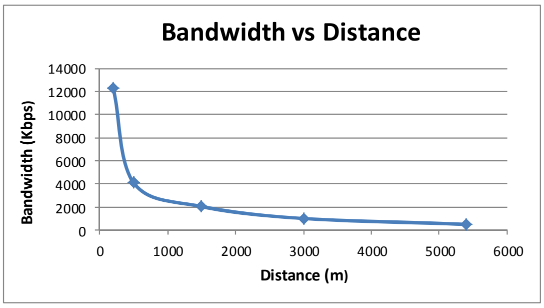



**Fig.1.3:** ADSL bandwidth vs. distance

Really, only the users located within 300 meters from the Central Offices are able to establish connections near the maximal contracted speed regardless of bandwidth. After 1500 meters the connection speed decreases considerably as showed in the graphics above.

## 1.2.1. DSLAM

A DSLAM is a Multiplexer located on the Central Office that provides ADSL access services to subscribers over fixed telephone line. The communications between DSLAM and Modem ADSL is done between an interface ATU-R (ADSL Terminal Unit - Remote) located in the client side and ATU-C (ADSL Terminal Unit - Central) located in the service provider side integrating a large number of cards inside, each of them containing several modems ATU-C [2]. Their structure integrates several cards and each one support 48 ADSL modems which mean that only one card can provide service to 48 subscribers. In front of them, ATU-R and ATU-C, there is a splitter, that is the filter whose objective is to separate the low (voice) and high (data) frequency signals. DSLAM handle high speed digital data coming from several subscribers ADSL modem and aggregate it into a single high capacity link. The following picture represents a general structure of DSLAM network architecture.

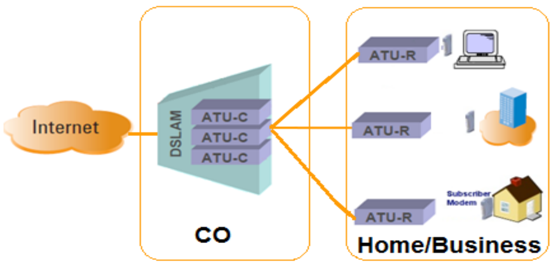



**Fig.1.4.** General structure of DSLAM network architecture.

The local Central Office connects to the business or home through pair of copper and the telecommunications companies use it to provide internet services through ADSL technology. They are using DSLAM with 48 ports for more populated area and 32 ports for less populated area.

### 1.2.2. Penetrations

It is evident that the cause of the low penetration of telecommunication services in STP is due to high tariff levels and low quality of the services as the result of technology used. The internet spread very fast, the informatics applications still continuous to be developed and the user request more and more bandwidth. Considering these challenges, every company has to take advantage of the new technologies in order to provide better solutions to their customers and be more competitive to get more market share. With that high tariff applied for the internet services, most people cannot to have access to the fixed internet connections and this situation reflects directly on the productivity of the people, the competitiveness of the country and also on the social welfare. The more important issue in the deployment of telecommunications infrastructure is the penetrations increment and the huge generated jobs. The fast spread of internet, the adoption of mobile media and the constant development of several applications serve to demonstrate how they have become a strategic technology.

According to the ITU report from 2013 [3], the bandwidth medium price of fixed connections between 2008 and 2012 has dropped down around 82% because the developed countries which where the price was decreased 30% each year from 2008 to 2011. In 2012 the medium price per megabyte of speed was $19,50, which mean a fourth part that cost in 2008 [3]. However, as was shown in table 1.1, the actual price in STP per megabyte is more than twice of the medium one. It is believed that, it is a big challenge to reduce that figure in near future.

The level of penetrations can be measured by considering the total amount of people in STP, which is 179.200, according the National Statistics Institute (Instituto Nacional de Estatística - INE) from 2013 and knowing the number of people that have the fixed internet is around 8.000. It was obtained that only 4,5% of peoples have fixed internet connections at home/business which is a very worrying situation in this era. This level of penetration is mainly due to a steady increase in recent years of the number of new businesses created, which has helped to raise this figure. The following graph shows the amount of new companies in lasts three years.

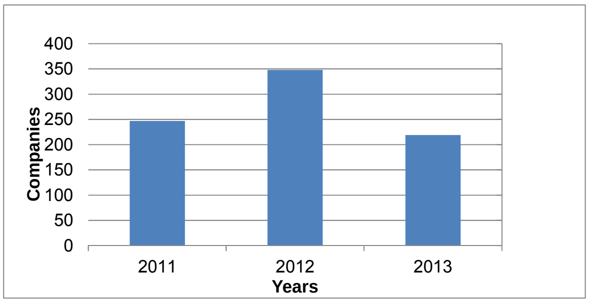



**Fig.1.5:** Numbers of new companies in last three years.

Looking at the graphs, it is clear that from 2011 to 2012 the increment was so significant, about 41%, rising from 248 companies in 2011 to 348 in 2012. In 2013 that amounts decrease up to 219, which could be because of political instability.

The ITU Measuring the Information Society (MIS) report, which has been published annually since 2009, featured two benchmarking tools to measure the information society: the ICT Development Index (IDI) and the ICT Price Basket (IPB). The IDI captures the level of ICT developments in 168 economies worldwide and compares progress made during the last year. The IPB combines the consumer prices for (fixed and mobile) telephone and internet broadband services for 168 economies into one measure and compares these across countries, and over time. Unfortunately no data available from STP concerning to IDI, but there are available data for IPB, which situate the country in place 161 of the ranking with IPB equal to $163,10 from 2012 [3] which mean that it is the country whose ICT is the seventh most expensive in the world.

### 1.2.2.1. The ICT Development Index (IDI)

The ICT Development Index (IDI) is a composite index combining 11 indicators into one benchmark measure that serves to monitor and compare developments in Information and Communication Technology (ICT) across countries. The IDI was developed by ITU in 2008 and first presented in the 2009 edition of Measuring the Information Society. It was established in response to ITU member states request to develop an ICT index and publish it regularly. It aims to capture the evolution of the information society as it goes through its different stages of development, taking into consideration technology convergence and the emergence of new technologies [3].

The main objectives of the IDI are to measure:

- The level and evolution over time of ICT developments in countries and relative to other countries;
- Progress in ICT development in both developed and developing countries: the index should be global and reflect changes taking place in countries at different level of ICT development;

- The digital divide, i.e. differences between countries with different levels of ICT development;
- The development potential of ICTs or the extent to which countries can make use of ICTs to enhance growth and development, based on available capabilities and skills.

The ICT development process, and a country´s transformation to become an information society, can be depicted using the following three stage model:

- Stage 1: *ICT readiness* (reflecting the level of networked infrastructure and access to ICTs).
- Stage 2: *ICT intensity* (reflecting the level of use of ICTs in the society).
- Stage 3: *ICT impact* (reflecting the result/outcome of efficient and effective ICT use).

IDI values ranged from a low possible (theoretical) range of 0 to 10. Indeed, economies with the highest level of ICT use and uptake are increasingly focusing on exploiting the latest technologies, optimizing regulatory frameworks and pushing for increasingly fast and better ICT services. High speed Internet access at home has become one of the common measures of success [3]. For example, in the Republic of Korea, where ICT continues to be a key priority area, by 2012 nearly all households had high speed internet access and the country enjoyed one of the highest average advertised broadband speeds in the world. ICTs have helped the Republic of Korea to become a robust economy, and overcome the 2008 financial crisis. They have driven growth and innovation, increased transparency and made the country one of the key ICT exporters in the world. [3]

### 1.2.2.2. IDI in Africa and STP

With regards to Africa, Seychelles and Mauritius are the top ranked countries in that region. They are the only African countries with an IDI above the global average. The African regional IDI of 2.0 is by far the lowest of all regions, and apart from Seychelles and Mauritius only South Africa and Cape Verde have IDI values above the developing country average. All remaining countries lie below that average and rank very low globally as shown in the following figure.

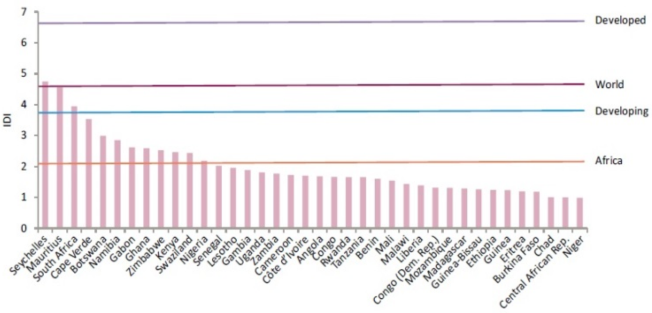



**Fig.1.6:** IDI comparison in Africa [3].

The bottom nineteen countries in the IDI 2012 are all African countries, with Niger in last position globally with an IDI of 0,99. The strongest growth in international Internet bandwidth per Internet user was recorded in Kenya, where the figure shot up from just 4,5Mbps in 2011 to 24Mbps in 2012 [3]. That report does not publish the information about STP, but they mentioned that only countries like Seychelles, Mauritius, South Africa and Cape Verde have IDI values above the developing country average, so it is easy to conclude that STP is not in a good position on the ranking.

### 1.2.2.3. The ICT Price Basket (IPB)

ITU has been presenting the results of the IPB annually with the objective of measuring the cost and affordability of the key ICT services: fixed telephony, mobile cellular (voice and SMS) and fixed broadband. The IPB has proved to be a useful benchmarking tool for the international comparison of ICT prices covering more than 160 countries. In the broader context of ICT developments, the IPB helps in identifying those cases where prices constitute a barrier to ICT uptake, and points to best practices and bottlenecks that have an impact on the cost of ICT services [3].

Fixed broadband prices have been collected by ITU through the annual ICT Price Basket Questionnaire since 2008. Countries are ranked according to the price of fixed broadband as a percentage of GNI p.c. The lower the percentage, the lower the relative cost of the service. Globally, analysis of fixed broadband prices from 2008 to 2012 dropped from 115,1 per cent of GNI p.c. in 2008 to 22.1 per cent in 2012. The biggest drop occurred in developing countries, where fixed broadband became much more affordable [3].

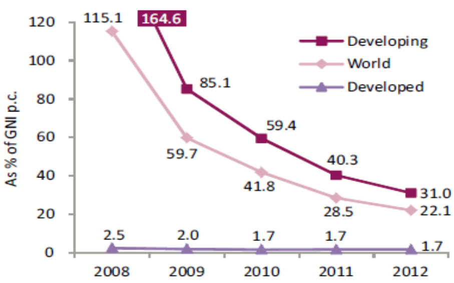



**Fig.1.7:** Fixed broadband prices, as a percentage of GNI p.c. 2008-2012 [3].

In developed countries, where fixed broadband services were already relatively affordable, prices (relative to GNI p.c.) have dropped at a much more moderate rate (17% to 19% annually from 2008 to 2010). Since 2010, the average cost of fixed broadband services has stabilized at around 1.7 per cent of GNI p.c. on average, and even increased slightly, by 1.4 and 1.9 per cent in 2011 and 2012, respectively. In most cases, however, an increase in price comes with both a higher data allowance and faster speeds. The price of a fixed broadband plan is often determined by speed [3].

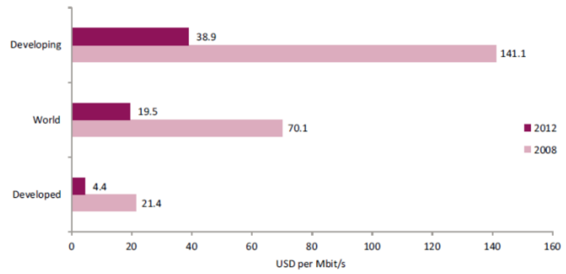



**Fig.1.8:** Fixed broadband median price per Mbps, in USD, 2008 and 2012.

The graph above shows that the price per unit of speed (Mbps) also decreased significantly between 2008 and 2012. Globally, the median price was $19.50 per Mbps in 2012, almost a quarter of the price in 2008. The drop in prices per Mbps is visible in both developing and developed countries, where median prices in 2012 stood at $38.90 and $4.40 per Mbps, respectively. These numbers show that people in developing countries pay considerably more per Mbps. The results of the 2012 fixed broadband price analysis, which includes 169 economies for which 2012 price data were available, show significant differences in the price and affordability of fixed broadband subscriptions. The cost of an entry level fixed broadband subscription ranges from 0.21 per cent of GNI p.c. in Macao (China) to 386.9 per cent of GNI p.c. in Cuba [3].

### 1.2.3. IPB in Africa and STP

A shortage of international internet connectivity and a lack of broadband infrastructures are common in the Africa region, and represent major barriers to price decreases. As pointed out above, an increase in international internet bandwidth often has a positive effect on prices.

An important development in 2012 was the landing of two major cable systems on the African continent: West Africa Cable System (WACS), which went live in May 2012, and Africa Coast to Europe (ACE), which launched services in a first set of countries in December 2012.  WACS links South Africa to the United Kingdom with landing points in Namibia, Angola, Democratic Republic of the Congo, Republic of the Congo, Cameroon, Nigeria, Togo, Ghana, Cote d'Ivoire and Cape Verde. With the landing of ACE, the Gambia, Guinea, Equatorial Guinea, Liberia, Sao Tome and Principe and Sierra Leone was for the first time connected directly to an international submarine cable [3]. The figure 1.9 gives more details about this last system.

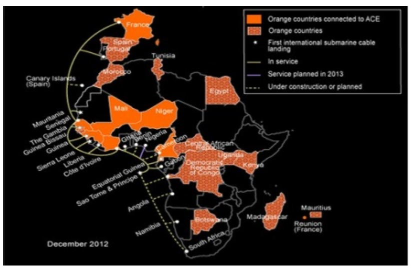



**Fig.1.9:** Africa Coast to Europe system.

Since shortage of international connectivity constitutes a major bottleneck in Africa, the direct connection of these countries to international traffic routes could drive fixed broadband prices down significantly, provided that local ISPs Companies can benefit from competitive prices to connect to the international gateways [3]. The following graphs shows the Purchasing Power adjusted fixed broadband prices in the Africa region from 2012.


**Fig.1.10:** Fixed broadband prices in the Africa region, 2012.

Looking to above graphs which include just twenty eight countries of Africa, it can be perceived that STP has the highest fixed broadband prices in the African region with purchasing power parity (PPP$) around $160,00 when the lower price belong to Mauritius with $20,00. The difference between them is eight times. Relating with the price in the world, the difference is extremely misadjusted. The countries with the least affordable fixed broadband prices are commonly all low developed countries. This underlines the strong link between income/development levels and affordability in those countries.

To summarize it is important to note that the main cause of high price of fixed broadband services in Sao Tome and Principe is related with several factors which are highlight below:

- The closed telecommunication´s market during more than twenty years by only one company that has been the monopoly of all telecommunications market without any kind of competition.
- Its geographical insularity which leads the use of satellite to connect Sao Tome and Principe to the world.
- The actual telecommunications infrastructure used to provide services to the users are other factors that contribute to high price charged, such has been explained before, income/development levels and affordability such as infrastructure/price is closely related.

It is expected that with the arrival of these two major cable systems, WACS and ACE, on the African continent, the next years these situations will be overcome and Africa, specifically Sao Tome and Principe, can provide social welfare to their people assuming that fixed broadband continues to be a fundamental service for achieving the full benefits of the internet as a development enabler, because it remains the primary means of accessing high speed, high capacity and reliable internet services. Infrastructure upgrades should be carried out with a long-term view, taking into account the expected lifetime of the network.

It is clear that the penetration in STP is increasing and the numbers of new enterprises created in the last years are constantly growing, spite of a fall in 2013 as shown in the figure 1.5, and the need of more bandwidth are quite evident. Furthermore, the price per Mbps has been decreasing considerably, for instance it was actualized in January 2014. Moreover, a further growth in the number of people requiring broadband access is forecasted. It is for sure that FTTH is future proof network architectures, and it has been clearly identified as the target solutions for wireline broadband networks. Fiber is precious; no other physical medium can carry more data over greater distances. According to all these factors a new broadband infrastructure based on Fiber to the home - FTTH technology is proposed in this project.

# Chapter 2. Fiber to the Home – FTTH


## Summary

Once, FTTH is the selected technology to overcome the existent shortage of telecommunications infrastructure in STP, in this chapter it will be provided an explanation about FTTH, its benefit and importance. Furthermore, it will be presented some FTTH architectures such as their protocols. This is to help to select the best solution, according to the characteristics of STP, considering also the protection mechanisms to provide a guaranteed service.


## 2.1. Definition

Fiber to the Home, commonly known as FTTH, is defined as an access network technology that delivers the highest possible speed of internet connection through optical fiber that runs directly into the home, building or office. The optic fiber communications path is terminated on inside the subscriber´s homes for the purpose of carrying communication services to a single subscriber. FTTH is unique, because it removes all the bottlenecks that slow the performance of other types of network. With FTTH, are possible download files at least 10 times faster than like, for example, ADSL networks [5].

## 2.2. Advantages of FTTH

There are several advantages associated with FTTH that are highlighted:

- FTTH features local battery backup and low power consumption.
- FTTH is reliable, scalable and secure.
- The FTTH networks are a future proof architecture.
- Signals travel a long distance inside fiber cable without degradation up to 20 Kms or more under some circumstances.
- They provide a thousand times more bandwidth than typical broadband service using DSL over copper wire, and 200 times more than typical broadband over cable TV coax [6].

## 2.3. Why FTTH is needed

Because is the only type of fixed line access network solution that is truly proofed against all future developments and eventualities, therefore it is the only one that it makes sense to invest in, when a new network is being deployed. FTTH offers vastly higher bandwidth and better access to new types of service than other access options, and is the only network option suited to deliver the future economic growth that the information led economies and communities demand. It is furthermore more reliable and cheaper to operate than alternatives. The following picture shows the estimations of bandwidth needed in the world up to 2030.

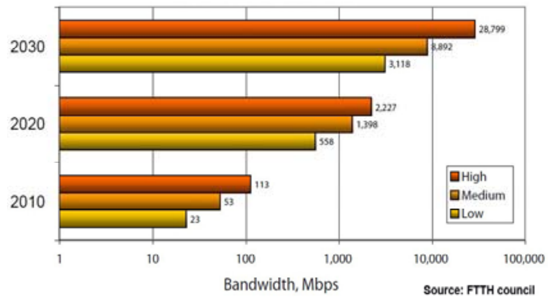



**Fig. 2.1:** Estimated bandwidth needed by typical home in the World [6].

FTTH is the only solution that offers the bandwidth and symmetry necessary to allow the development of all required services and applications that make a difference to the way how the people live and work. According to FTTH council, the aggregate bit rate requirements of all the applications in world in a “connected home” could easily exceed 1 Gbps by 2020 and 8 Gbps by 2030, assuming three video and voice streams, one gaming stream and one data/e-mail stream per home, simultaneously [6].

With consumer demand for high speed bundled services, FTTH has been recognized as the ultimate solution for providing these services to the end users. Twisted pair, coax and hybrid fiber /coax (HFC) networks are not as robust or future proof as FTTH technology. And with the continue declining costs of optical equipment, FTTH has proven to be a technology to focus as it gains the interest of services providers.

## 2.4. FTTH Architectures

FTTH are disposed over two main architectures. In particular, active and passive are the two commonly used architectures for FTTH deployment. Active Optical Networks (AON) architecture is also called as Point to Point architecture (P2P) and Passive Optical Network (PON) architecture is called Point to Multi Point (P2M). Choice of active or passive architectures for deployment depends on the type of services to be delivered, cost of the infrastructure, current infrastructure and future plans for migrating to the new technologies [7].

### 2.4.1. PON Architectures

With PON, each customer is connected into the optical network via a passive optical splitter, therefore, no active electronics in the distribution network and bandwidth is shared from a single fiber out among the separate fiber which feeding, individual subscribers. This is the reason why they are called passive. The advantage of FTTH PON is the fact that they use purely optical passive components, so there are no electronics at all between the provider’s central office and users. This dramatically minimizes the networks maintenance, costs and requirements, as well as eliminating a need for a dc power network. It is a single fiber to the end user, providing revenue generating services with standard user interfaces, including voice, high speed data, analog or digital CATV and video on demand. PON architecture can reduce the cable cost as it enables sharing of each fiber by many users [7]. Typical PON architecture is shown in the figure 2.2.

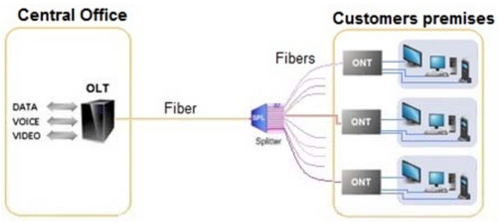



**Fig.2.2:** Typical PON network architecture.

With PON privacy is ensured by time shifting and personal encryption of each subscriber traffic. Upstream traffic is enabled by Time Division Multiplex Access (TDMA) synchronization. Fixed network and exchange costs are shared among all subscribers. This reduced the key costs per subscriber metric [6]. The most important aspect of PON architecture is its simplicity. Although PONs can exist in three basic configurations (tree, bus and ring), the tree topology is favored due to smaller variation in the signal power from different end stations.

#### 2.4.1.1. PON´s Components

Optical Line Terminal (OLT) is the main element of the network and it is usually placed in the central office and puts the pulses on the fiber in the first place. It is the engine that drives FTTH system.

Optical Network Terminals (ONTs) are deployed at customer’s premises. They are the devices at the customer end that turn the light pulses back into electrical signals. Usually, customers will have equipment such as computers that expect an Ethernet connection. This is a standard way of networking that’s used around the world. The computers, and perhaps the little home Wi-Fi system, all use Ethernet. So a typical ONT turns the light pulses into Ethernet signals. ONTs are connected to the OLT by means of optical fiber and no active elements are present in the link. A single ONT can serve as point of access for one Fiber to the Home customers.

Splitter is a passive element which, in the downlink, distributes the input power equally for all the branches connected at the output for reaching the connections to the ONTs. The final splitting ratio can be achieved using a single splitter device, a single 1x32 splitter or a cascaded series, such as 1x8 + 1x4 or 1x16 + 1x2. To split the incoming signal from the Central Office to subscribers, the passive optical splitter needs to have the following characteristics [7]:

- broad operating wavelength range;
- low insertion loss and uniformity in any conditions;
- minimal dimensions;
- high reliability;

- support network survivability and protection policy;

In the PONs, the transceiver in the ONT is used to transmit the data between the customer premises and the central office OLT. WDM triplexes module separates the three wavelengths 1310nm, 1490nm and 1550nm. ONT receives data at 1490nm and sends burst traffic at 1310nm. Analogue video at 1550nm is received. Media Access Controller (MAC) controls the upstream burst mode traffic in an orderly manner and ensures that no collision occurs due to upstream data transmission from different homes.

#### 2.4.1.2. Wavelength Division Multiplexing Access (WDM – PON)

Wavelength Division Multiplexing (WDM) uses multiple wavelengths to transport signals over a single fiber. WDM breaks white light passing through optic fiber cable into all the colors of the spectrum, like light passed through a prism, creating a rainbow. Every wavelength carries an individual signal that does not interfere with the other wavelengths. In simple terms: WDM creates virtual fibers; the best and simplest way to multiply fiber capacity. Fully transparent to any bitrate and protocol, WDM is the natural integration layer for modern networks. This allows networks to become more manageable, operate more efficiently and transport considerably higher bandwidth for huge volume of data transmission. In WDM-PON each home is assigned its own wavelength and has continual use of the fiber at that wavelength. An overview of a WDM-PON network is illustrated in following figure.

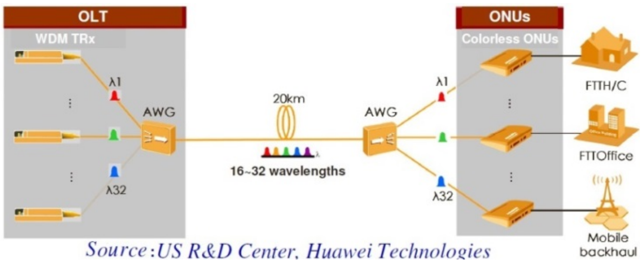



**Fig.2.3:** Typical WDM-PON architecture [4].

The first requirement that the passive 1x32 power splitters is to be replaced by passive 1x32 channel multiplexers, typically athermal Arrayed Waveguide Gratings (AWGs) as shown in figure 2.3. This multiplexer allows the 32 different wavelengths can be transmitted down the common fiber, and then each home is allocated its own wavelength. The end result of WDM-PON is a wavelength to each subscriber [8].

#### 2.4.1.3. DWM-PON advantages over traditional PON

There are several advantages to the WDM-PON architecture over more traditional PON systems; among them, the most important are [8]:

- More bandwidth available to each subscriber.

- Provide better security and scalability, since each home only receives its own wavelength.
- MAC layer in a WDM-PON is simplified, since they provides Point-to-Point (P2P) connections between OLT and ONT and does not require the Point-to-Multipoint (P2MP) media access controllers found in other PON networks.
- Each wavelength in a WDM-PON network is effectively a P2P link, allowing each link to run at different speed.

The main challenge with WDM-PON is the cost. Since each subscriber is assigned his own wavelength this suggests that the OLT must transmit on 32 different wavelengths versus one shared wavelength as found in more traditional PON systems. Likewise, it requires that each of the 32 homes on a link operate at a separate wavelength suggesting that every ONT requires an expensive tunable laser that can be tuned to the correct wavelength for a particular home.

The athermal AWG splits one wavelength to each home and their athermal design requires no power. This allows the athermal AWG to replace the 1x32 power splitter in the same outside enclosure, so that, the fiber infrastructure in a WDM-PON deployment is identical to that in a more traditional PON system [8].

### 2.4.2. AON Architectures

Active Optical Networks, also called Ethernet Switched Optical Network (ESON) architecture provides a dedicated fiber to the side from the Central Office to the customers premise. Since the fiber is dedicated, Operation, Administration and Maintenance (OAM) of the content and troubleshooting become easy. When the distances of the central node and remote sites are known, estimation of power budget, troubleshooting the faults in the network would be easier. Transmission in AON configuration is more secure, because all transmissions are physically separated by fiber. Only the end points will transmit and receive information, which is not mixed with that of any other customer. Their architecture is a very simple network design [7]. A typical connectivity diagram of active technology in the access network is shown in figure bellow.

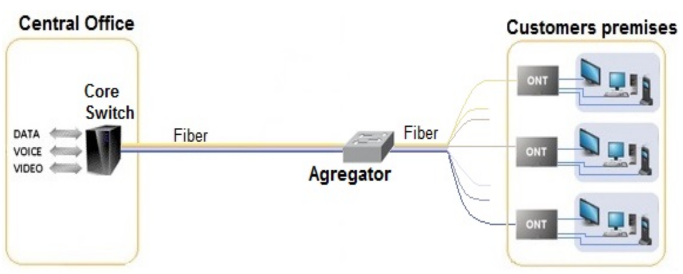



**Fig. 2.4:** AON typical Architecture.

#### 2.4.2.1. AON´s Components

Core switch, Aggregation Switch and Optical Network Terminal (ONT) are the main building blocks of a P2P network. The Core Switch is a high capacity Ethernet switch that communicates to Aggregator Switches using standard GbE optical signals. The Aggregator Switch interfaces this data stream to multiple premises Gateways called Optical Network Terminals (ONT). Each ONT interfaces a 100Mbps signal in a standard 100 BaseFX format, which is 100 BaseT Ethernet format on an optical fiber. The Core Switch interfaces multiple content and service providers over an MPLS-based Metro or Regional network to deliver data, video, and voice services to the users on the access network [7].

The switch aggregator is electrically powered switching equipment, to manage signal distribution and direct signals to specific customers. This switch opens and closes in various ways to direct the incoming and outgoing signals to the proper place. In such a system, a customer may have a dedicated fiber running to his house. Active Optical Networks, however, also have their weaknesses. They require at least one switch aggregator for every 48 subscribers. Because it requires power, an active optical network inherently is less reliable than a passive optical network [21]. In a P2P network, each customer is served by at least one dedicated fiber. Each fiber (and thus each customer) has its own laser to generate the pulses of light. In a “passive” optical network, one central office laser might serve up to 64 customers [6] or even more.

### 2.4.3. PON-FTTH Protocols

#### 2.4.3.1. EPON

Ethernet Passive Optical Networks (EPON) is an optical access network technology that carries native Ethernet traffic. The maximum bandwidth offered to the users depends on the number of ONUs that hanging each OLT. They provide a good performance, simplicity, and facility to deployment. One of the key in this type of networks is the Dynamic Allocation of Bandwidth (DBA) to the users in the EPON network standard. It provide the symmetric bandwidth of 1,25 Gbps.

**Traffic Administration**
At begin when an ONU is connected to the OLT, they are administrated by them, the registration process is produced which is assigned the LLID (Logical Link Identifier) associated with each MAC (Media Access Control) to the ONTs.

**MPCP (Multipoint Control Protocol)**
Upstream traffic: Multiple MACs operating in a shared medium, so only one ONU can send traffic at a given time using the method of Time Division Multiple Access (TDMA) to prevent transmission collisions. Downstream traffic: Because the PON is a broadcast medium, the traffic reaches all ONUs, but they can only receive from whom it is intended.

EPON is fully compatible with other Ethernet standards, so no conversion or encapsulation is necessary when connecting to Ethernet-based networks on either end. The same Ethernet frame is used with a payload of up to 1518 bytes. Since Ethernet is the primary networking technology used in Local Area Networks (LANs) and in Metro Area Networks (MANs), no protocol conversion is needed.

#### 2.4.3.2. GPON

Gigabit PON is the standard networks protocol with over 1Gps of speed. Is the most widespread PON FTTH networks protocol in Europe and USA such as the one recommended to Africa FTTH council by ITU-T.

##### 2.4.3.2.1. Objective of GPON

- **Multiservice transport:** TDM voice, synchronous transport SONET/SDH, Ethernet (10/100 BaseT), ATM, etc.
- Multirate: Support for multiple bitrate with the same protocol, including symmetrical speeds of 622Mbps, 1.25Gbps, 2,5Gbps, 10Gbps and asymmetric of 155Mbps/1.25Gbps, 622Mbps/1.25Gbps, 155Mbps/2.5Gbps, 622Mbps/2.5Gbps and 1.25Gbps/2.5Gbps respectively in upstream and downstream [9].
- Maximum range of 20 km, although the standard has been prepared to get up to 60 km.
- OAM (Operation, Administration and Management) end to end.
- The maximum number of users that can hang from the same fiber is 64, but the system is prepared to give up to 128 users [10].

**Features and Techniques:**
Multiplexing Information: both channels of information (downstream and upstream) traveling in the same optical fiber by using different wavelengths.

**Downstream Direction:** TDM (Time Division Multiplexing) technology is used. All data is transmitted to all ONTs. Each ONT filters the received data and is only able to access data that are directed towards it [10].

**Upstream Direction**: TDMA (Time Division Multiple Access) is used. The OLT controls the upstream channel, assigning time slots to each ONT transmission. Pointer mechanism controls the transmissions of the ONTs through pointer information sent by the OLT. MPCP protocols are required to avoid collisions and to distribute the bandwidth among users. Perfect timing of ascending to the OLT is able to reconstruct the GPON frame packs is required. For this reason it is necessary that the OLT knows the distance from each ONT to reflect the delay experienced by the data since the user [10].

**User ID:** GPON provides a mechanism that allows the OLT to identify each of the ONT presented in the same fiber network. Therefore, each ONT has unique serial number which is known by the OLT [10].

**Remote configuration of the ONT's**: One of the main challenges which GPON had solved is the remote management of user equipment. In this way a considerable saving of costs of maintenance is achieved since the intervention in the client's home is not necessary. GPON standard has developed a protocol called OMCI (ONT Management and Control Interface). This protocol allows remote configuration of ONTs. For each ONT, a channel between OLT and ONT is established for management purposes between them, which includes management, performance, alarm monitoring and fault detection. The OMCI protocol is one of the key aspects to ensure interoperability between manufacturers [10].

**Transport Protocols:** The GPON standard provides two possibilities concerning the transport protocols that can be used: ATM: used by APON and BPON and GEM (GPON Encapsulation Method) is a new protocol defined to use in GPON [10].

#### 2.4.3.3. EPON vs. GPON

EPON and GPON are popular versions of passive optical networks (PONs) and useful for high speed internet access, Voice over Internet Protocol (VoIP), and digital TV delivery. The main differences between them lie in the protocols used for downstream and upstream communications and remote configuration of ONTs. The following tables highlight the more important differences between them.

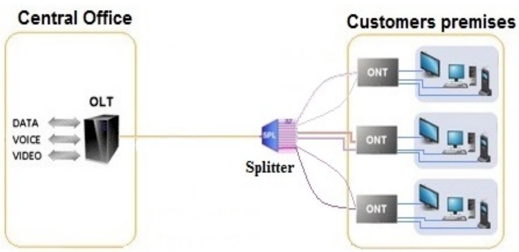
**Table 2.1:** EPON vs. GPON

| | Sym. Data rate (Gbps) | | Split rate | | Mux | Wavelength (nm) | | | Range (Km) | BER | MAC | Transport Protocol |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dw | Up | Typ | Max. | | Dw | Up | TV | | | | |
| **EPON** | 1,25 | 1,25 | 32 | 64 | WDM | 1490 | 1310 | | 20 | $10^{-12}$ | TDMA | Ethernet |
| **GPON** | 10 | 10 | 64 | 128 | WDM | 1490 | 1310 | 1550 | 20 | $10^{-10}$ | TDMA | GEM |

For data format, the GPON packets can handle ATM packets directly. Recall that ATM packages everything in 53-byte packets with 48 for data and 5 for overhead. GPON also uses a GPON Encapsulation Method (GEM) to carry other protocols. It can encapsulate Ethernet, IP, TCP, UDP, T1/E1, video, VoIP, or other protocols as called for by the data transmission. Minimum packet size is 53 bytes, and the maximum is 1518.

#### 2.4.3.4. PON´s Protections Schemes

The FSAN Group’s G.984 specification allows several types of redundancy within PON´s network. They have defined four types of protection topologies that offer varying levels of protection. The basic protections topologies in PON are listed on the following figures:



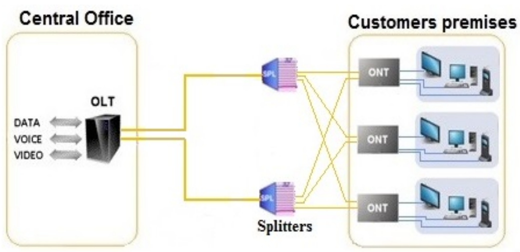
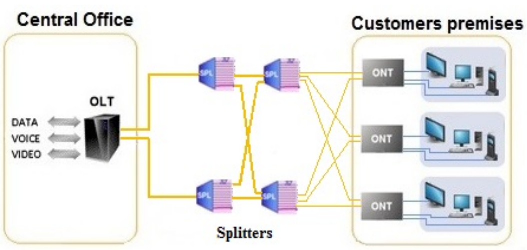




**Fig.2.5:** Redundant branches.

**Fig.2.6*:*** Redundant tree.



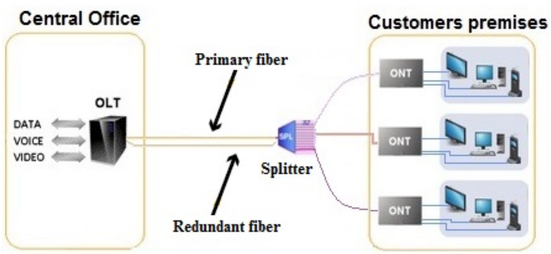




**Fig.2.7:** Redundant trunk and branches.

**Fig.2.8**: Redundant trunk.

The objective of protection scheme is to protect the networks against communications' interruption, so that, interruption time is almost inexistent since link failures do not cause connection interruption and the end user is not affected once that any failure on the fiber, the communication go through a redundant fiber. The total cost can be reduced due to the diminution of the OPEX related to the failure management. The use of one or other protections scheme depends on the use foresees for the network and the corresponding cost. The following table shows the advantages and disadvantages of each scheme.

**Table 2.2:** Advantages and disadvantages of PON´s protections scheme

| Protection Scheme | OLT | Splitter | Trunk fiber | Branches fiber | Efitiency | Cost of Deployment |
|---|---|---|---|---|---|---|
| **Redundant branches** | Not protected | Not protected | Not protected | Protected | Low | Medium |
| **Redundant tree** | Protected | Protected | Protected | Protected | Very High | High |
| **Redundant trunk** | Protected | Protected | Protected | Not protected | High | Medium |
| **Redundant tree and brnaches** | Protected | Protected | Protected | Protected | Very High | High |

The per cent of affected users depends of the network area where the failure is produced. For instance if the failure occur in a GPON card, trunk fiber or in splitter the amount of affected users will be considerably high, however, if the failure occur in branches fiber or in the ONT, few users will be affected, in case they network are not protected.

# Chapter 3. FTTH BW requirement

**Summary**
The bandwidth (BW) that each district will require is important because those data provide an overview about the real needs of the country. In this chapter it will be presented the actual state of FTTH in Africa, the used protocols and their benefit. On the other hand, the geographical distributions of the inhabitants throughout STP is done and finally the estimations in terms of the connections for both, companies and residential users such as the total BW required in each district.

## 3.1. FTTH in Africa

In Africa, the deployment of infrastructure based on FTTH technology to provide high speed internet connectivity through the optic fiber to the users is almost not-existent, although many international telecommunications companies realized of the potential and business opportunity in Africa is real, and some of them already have started a discreet deployment of infrastructure based on that technology. Just few countries are carrying out the deployment of networks infrastructures based on FTTH technology. This poor deployment can be justified by the fact that just two years ago when Africa started to be connected to the world through the optic fiber through WACS and ACE projects.

One of these countries is Tanzania, where the operator SimbaNET has successfully deployed GPON technology. The new GPON infrastructure increases bandwidth and allows greater communications speeds for internet connections in the city, as well as improving reliability and a variety of web-based communications applications such as telemedicine and videoconferencing [13]. Moreover, Huawei has already deployed networks high speed GPON in Ghana, which enables fiber to the home, and had also brought Ghana's bandwidth and speed to number one in west of Africa [12]. Vodafone Ghana also is deploying FTTC for increasing data rate to customers by using GPON as technology for backhauling street cabinet DSLAMs. Vodacom South Africa is starting a project for delivering FTTH services to business and high spending residential customers using GPON technology [11]. Ericsson has signed a contract with Nigerian Telecom Company “21st Century Technologies” in 2008 to build and supply systems to integrate a nationwide residential optic fiber broadband network. The contract includes the latest GPON FTTH technology and will enable advanced high speed broadband services [14].

As it was pointed in the figure 2.1, the average estimated bandwidth needed in the world up to 2030 in typical home is 8Gbps; of course that Africa will not demand that amount of bandwidth in fifteen years yet, but the increment of BW in Africa is inevitable as well as is inevitable in Sao Tome and Principe. And considering that most of the deployment realized in Africa up to now is based on GPON, is recommendable the use of the same technology in STP.

### 3.1.1. Benefit of FTTH based infrastructure in Africa

Africa is the world’s second largest and the second most populous continent, and with over a billion peoples in 61 territories, which correspond to 15% of the world people. It is this vastness and variety that makes communications and commuting in Africa become a challenge. But, without a robust infrastructure, the regional integration will not be reached. 90% of African traffic today is routed through Europe. Because of this, African states pay about $500 million every year to call to other African countries. A significant portion of the revenue from international calls is used to pay the European network operators and making it difficult for African`s citizens. An upgrading in modern telecommunications networks infrastructures in Africa would bring a lot of benefit:

- Direct link between one to another countries;
- Reduction in international call cost;
- Economic growth and competitively;
- Fast and secure connectivity;
- Less dependence from Europe;

Apart from intra-African cable networks, which are growing at moderate proportions, Africa is also a beneficiary of intercontinental initiatives such as the BRICS (Brazil, Russia, India, China and South Africa) cable project. The BRICS submarine cable of 34.000 km and 12.8Tbps capacity is an underwater optic fiber cable system that will link the cities in the BRICS economies with the USA [15], fig. 3.1.


**Fig.3.1.** BRICS cable project.

BRICS project is aimed at join BRICs with USA and ensures millions of people access to internet easier and cheaper. Furthermore, is an alternative in a world that is in the midst of major economic challenges. In the present, BRICS are interconnected via telecommunication center located in Europe and USA, which involves high costs for them [16]. It is an interesting project, because it will cover 62% of the world´s people and reduce the interdependence of Norte and West.

## 3.2. Distributions of people throughout STP

To carry out this project, the GPON technology is selected. The reason why this technology have been selected is due several factors, one of them is that the ITU has recommended the use of them in Africa, according FTTH African council. Furthermore, in some African´s countries like Ghana, Nigeria, Tanzania and South of Africa are already using that technology to deliver FTTH services to the users.

The Democratic Republic of Sao Tome and Principe is an archipelago formed by two islands subdivided in seven districts; one of them is the other island - Principe. Most of the people live in Agua Grande districts where the capital – Santo Tome is located with 38,9% of the people, and in the second more important one is Mé-zochi with 25,0% of the whole people [17]. The rest of the people are distributed throughout of others districts as it is indicated in the figure 3.2. Principe is also a district, but it is not included in this project because up to now no connections through optical fiber between the two islands.

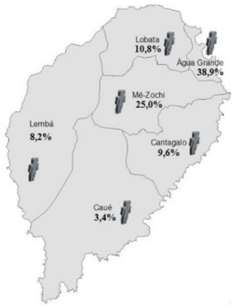



**Fig.3.2.** Distribution of people throughout Sao Tomé.

To perform better the services delivered, the end users will be differentiated taking into account some factors, like if they are business or residential users, and, in case of users, if they live in urban or rural area, also considering the company´s size: big, medium or small. So that, five types of subscribers are defined:

- Big company;
- Media company;
- Small company;
- Urban residential users;
- Rural residential users;

For the companies in Agua Grande and Mé-zochi it will be assigned 50Mbps for 50% of the companies, 100Mbps to 30% and 1Gbps for 20%. In area of Neves it will be assigned 1Gbps for 30% of the companies and 100Mbps for 70%. While for residential users in Agua Grande and Mé-zochi, it will be assigned 20Mbps to the urban and 10Mbps to rural ones, for the other districts it will be assign just 10Mbps for all the users.

### 3.2.1. Estimation of business connections

Data from 2012 of One-stop Shop for Businesses (Guiché Unico para Empresas - GUE), published that the total of companies in STP is over 1.000 [18] and other available information by National Institute of Statistique (Instituto

Nacional de estatística - INE) about business census are shown in the following table.

**Table 3.1:** Volume of business per district [19]

| District | Ag. Grande | Cantagalo | Caué | Mé-zochi | Lembá | Lobata | Total |
|---|---|---|---|---|---|---|---|
| **Total of Company** | 575 | 76 | 30 | 128 | 51 | 53 | 913 |
| **% of Company** | 62,91 | 8,32 | 3,28 | 14,00 | 5,58 | 5,91 | 100,00 |
| **Volume of Business (%)** | 88,30 | 1,10 | 0,80 | 5,00 | 4,20 | 0,60 | 100,00 |

Most of the company are located in the Agua Grande district, where 63% of companies are registered and which provide major volume of business, 88,3%. Mé-zochi is the second one with 14% of companies and Lembá which, although the amount of companies is just 51, they represent 4,2% of the total volume of business, which can be explained by the fact that some powerful companies are located there. It worth to consider that in 2013 there was some decrement concerning to a numbers of companies, as shown on figure 1.5; however, estimations point to an increment for next years. The following table shows the estimated bandwidth demanded by companies for each district.

**Table 3.2**. Bandwidth Company´s assignment

| District | Ag. Grande | | | Cantagalo | Caué | Mé-zochi | | | Lembá | | Lobata |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Total of companies** | 575 | | | 76 | 30 | 128 | | | 51 | | 53 |
| **Size** | Small | Med. | Big | | | Small | Med. | Big | Med. | Big | |
| **Destribution** | 50% | 30% | 20% | | | 50% | 30% | 20% | 70% | 30% | |
| **Nº of Conct.** | 287 | 173 | 115 | | | 64 | 38 | 26 | 36 | 15 | |
| **Assign BW (Mbps)** | 50 | 100 | 1000 | 100 | 50 | 50 | 100 | 1000 | 100 | 1000 | 100 |

The remaining districts are not differentiated because they do not represent enough volume of business because the companies located there are small ones.

### 3.2.2. Estimated connections for residential users

As it was shown in the figure 3.1, Agua Grande is the most populated district and the one which provide major volume of business (table 3.1) in STP, which correspond respectively to 69.709 peoples and 88,3% of business volume. If it is estimated that each family has five people, it will be obtained 13.942 families in Agua Grande. Assuming that 70% of them will adhere to the broadband services, it corresponds to 9.759 residential connections in that district. The following table summarizes the estimated domestic connections for all districts.

**Table 3.3:** Estimated residential connections per district

| District | Ag. Grande | Cantagalo | Caué | Mé-zochi | Lembá | Lobata |
|---|---|---|---|---|---|---|
| Total People | 69.709 | 17.203 | 6.093 | 44.800 | 14.694 | 19.354 |
| Volume of Business (%) | 88,3 | 1,1 | 0,8 | 5,0 | 4,2 | 0,6 |
| Nº of Family | 13.942 | 3.441 | 1.219 | 8.960 | 2.939 | 3.871 |
| Estimated Connections | 70% | 30% | 10% | 40% | 20% | 30% |
| Nº of Connections | 9.759 | 1.032 | 129 | 3.584 | 588 | 1.161 |

In the same way, the bandwidth demand of each user per district is not linear and depends of several factors for instance the number of peoples, poverty and the economy flowing. According to that the users differentiations is required mainly in the two more populated districts, which is, Agua Grande and Mé-zochi, as show in table 3.4.

**Table 3.4.** User´s Bandwidth assignment per area

| District | Ag. Grande | | Cantagalo | Caué | Mé-zochi | | Lembá | Lobata |
|---|---|---|---|---|---|---|---|---|
| Total of People | 69.709 | | 17.203 | 6.093 | 44.800 | | 14.694 | 19.354 |
| Class of users | Urban | Rural | | | Urban | Rural | | |
| Per cent of users | 40% | 30% | 30% | 10% | 10% | 30% | 20% | 30% |
| Nº of connect. | 5.577 | 4.182 | 1.032 | 129 | 896 | 2.688 | 588 | 1.161 |
| Assigned BW (Mbps) | 20 | 10 | 10 | 10 | 20 | 10 | 10 | 10 |

Considering the estimation above, the total capacity needed to cover both, companies and users, is presented in following tables, one by one per district, taking into account that the selected PON protocols is GPON.

**Table 3.5.** Total capacity needed in Agua Grande

| | Companies | | | Users | |
|---|---|---|---|---|---|
| Total subscribers | 115 | 173 | 287 | 5.577 | 4.182 |
| BW required | 1Gbps | 100Mbps | 50Mbps | 20Mbps | 10Mbps |
| Total BW / Class | 115Gbps | 17,3Gbps | 14,35Gbps | 111,54Gbps | 41,82Gbps |
| Total BW in AG | 300Gbps | | | | |

The total bandwidth demanded by Agua Grande subscribers is 300Gbps, of which 115Gbps come from the big companies, 17,2Gbps from medium companies and 14,35Gbps from the small ones. All residential users together demand 153,45Gbps which 111,54Gbps come from users of 20Mbps and 41,82Gbps from users of 10Mbps.

**Table 3.6.** Total capacity needed in Mé-zochi

| | Companies | | | Users | |
|---|---|---|---|---|---|
| **Total subscribers** | 26 | 38 | 64 | 896 | 2.688 |
| **BW required** | 1Gbps | 100Mbps | 50Mbps | 20Mbps | 10Mbps |
| **Total BW / Class** | 26Gbps | 3,8Gbps | 3,2Gbps | 17,92Gbps | 26,88Gbps |
| **Total BW in M-zchi** | **77,8Gbps** | | | | |

In Me-zochi district, only 26 companies demand 1Gbps which correspond to 26Gbps. The total capacity demanded by all the companies and residential users together is 77,8Gbps.

**Table 3.7.** Total capacity needed in Lembá

| | Companies | | Users |
|---|---|---|---|
| **Total subscribers** | 15 | 36 | 588 |
| **BW required** | 1Gbps | 100Mbps | 10Mbps |
| **Total BW / Class** | 15Gbps | 3,6Gbps | 5,8Gbps |
| **Total BW in Lembá** | **24,5Gbps** | | |

In this case, only 15 companies demand 1Gbps, the remaining 36 demands 100Mbps and residential users demand 10Mbps which make 24,5Gbps of total bandwidth demanded in Lembá.

**Table 3.8.** Total capacity needed in Cantagalo

| | Companies | Users |
|---|---|---|
| **Total subscribers** | 76 | 1.032 |
| **BW required** | 100Mbps | 10Mbps |
| **Total BW / Class** | 7,6Gbps | 10,32Gbps |
| **Total BW in Cantagalo** | **18Gbps** | |

In this district, no company demand 1Gbps or 50Mbps neither 20Mbps for residential users, just 100Mbps and 10Mbps, so that, the total capacity demanded is 18Gbps.

**Table 3.9.** Total capacity needed in Lobata

| | Companies | Users |
|---|---|---|
| **Total subscribers** | 53 | 1.161 |
| **BW required** | 100Mbps | 10Mbps |
| **Total BW / Class** | 5,3Gbps | 11,61Gbps |
| **Total BW in Lobata** | **17Gbps** | |

This district is similar to the last one and just demands 17Gbps as the total.

**Table 3.10**. Total capacity needed in Caué

| | Companies | Users |
|---|---|---|
| **Total subscribers** | 30 | 129 |
| **BW required** | 50Mbps | 10Mbps |
| **Total BW / Class** | 1,5Gbps | 1,29Gbps |
| **Total BW in Caué** | **2,8Gbps** | |

That is the district which demands less bandwidth such for companies as users. The total bandwidth demanded in them is 2,8Gbps. After this analysis it is concluded that the total bandwidth needed in Sao Tomé is 440,1Gbps for all subscribers' class.

# Chapter 4. FTTH network design

**Summary**
An important issue in any network design is their protection scheme, in which the designer decides which elements should be protected and which not, determining the overall network availability. Thereby, in this chapter it will be decided the protection schemes to be used, and the corresponding network availability is calculated. The places where the equipment will be fit and the route to follow by fiber in each district such as the equipment selection and optic fiber to be used in each link will be presented.

## 4.1. Protection schemes

The protection scheme selected is the redundant trunk, and as it was pointed in the table 2.2., the main reason of this choice is because this protection scheme provides a good efficiency for the network, low cost of deployment and their robustness in terms of reduced number of the subscribers which loses connection in case of failure of one parameter when compared with other schemes, for instance redundant tree or redundant tree and branches. The ideal protection scheme should be redundant tree and branches because they provide protection at all levels in the network, it mean, all equipment and fibers are protected (OLTs, splitter, trunk fiber and branches fiber), but to avoid extra cost of fiber, the trunk protection has been selected, once the fiber is expensive.

## 4.2. Study of Availability

Availability (A) is the system which offers the highest level of protection to a network by eliminating negative service impacts caused by cable cuts and equipment failures. The availability calculations for this project are related to the protection scheme defined in the topics above, if no protection is provided for the network, Unavailability (U) due to optical fiber cuts or equipment failures would be unacceptable. The objective of the availability is a no service affecting protection switch in response to equipment (splitters and OLTs) and cable cuts failures.

The study of availability for the present project will be carrying out considering the longer link within the PON recommendation (20 Km) which is the worst case condition, so, every link on the project will be inside that recommendation. It will be analyzed availability without any protections scheme, which in case of fiber cut, the link will be in downtime during the Mean Time to Repair (MTTR) of optical fiber which is 12 hours and considering the trunk protection, which in case of the principal fiber cut, the traffic is redirected to the redundant fiber in 50ms.

The following table provides the Unavailability of each component of the network and cable cut which is used to calculate the Availability of the whole network.

**Table 4.1.** Unavailability of each component of the network.

| Componets | Failure in Time (FIT) | Mean Time to Rapair (MTTR), h | $U_c$ | Unavailability = FIT x MTTR/10^9 h |
|---|---|---|---|---|
| **Cable Cut (trunk = 20Km)** | 2283 | 12 | $U_{trunk}$ | $2{,}74\ x\ 10^{-5}$ |
| **Cable Cut (branch)** | 1712 | 12 | $U_{branch}$ | $2{,}05\ x\ 10^{-5}$ |
| **Splitter Failure** | 114 | 12 | $U_{splitt}$ | $1{,}37\ x\ 10^{-6}$ |
| **OLT Transmitter Failure** | 3424 | 2 | $U_{OLT\text{-}Tx}$ | $6{,}85\ x\ 10^{-6}$ |
| **OLT Receiver Failure** | 1142 | 2 | $U_{OLT\text{-}Rx}$ | $2{,}28\ x\ 10^{-6}$ |
| **ONU Trannmitter Failure** | 1712 | 6 | $U_{ONU\text{-}Tx}$ | $1{,}03\ x\ 10^{-5}$ |
| **ONU Receiver Failure** | 1142 | 6 | $U_{ONU\text{-}Rx}$ | $6{,}85\ x\ 10^{-6}$ |

### 4.2.1. Availability without protection

To calculate the availability in the network without any kind of protections scheme is necessary to consider potential failure in each components which is part of the network, for instance, equipment (OLT and splitter) and fiber. Knowing the Unavailability of each of them from the table 4.1, the availability is obtained.

Unavailability of a communication channel is defined as the probability that the channel is out of service at any given time, and can be expressed as % down time of total. So, unavailability of the network is calculating through equation 4.1.

$$U_{Total} = U_{Trunk} + U_{OLT-Tx} + U_{OLT-Rx} + U_{Split} + U_{Branch} \qquad \textbf{(4.1)}$$

Where:
$U_{Total}$ : is the unavailability of the link;
$U_{Trunk}$: is the probability of downtime of fiber;
$U_{OLT-Tx}$: is the probability of downtime of OLT transmitter;
$U_{OLT-Rx}$: is the probability of downtime of OLT receiver;
$U_{Split}$: is the probability of downtime of splitter;
$U_{Branch}$: is the probability of downtime of fiber branch;

$$U_{Total} = (2{,}74\ x\ 10^{-5}) + (6{,}85\ x\ 10^{-6}) + (2{,}28\ x\ 10^{-6}) + (1{,}37\ x\ 10^{-6}) + (2{,}05\ x\ 10^{-5})$$

$$U_{Total} = 5{,}84\ x\ 10^{-5}\ hour/year$$

$$A = 1 - U_{Total} = 0{,}9999416 \qquad (4.2)$$

The network will be available 99,99416% of the time during a year without protection.

### 4.2.1. Availability with protection

The trunk protection, usually provided protection of optical fiber, OLTs and splitters. To calculate the total availability of the network, it is necessary to consider potential failures in each of them; equipment (OLTs and Splitters) and cable in such way to calculate their Unavailability. According to that, the probability of channel out is calculated as showing in equation 4.3.

$$U_{Total} = (U_{Trunk})^2 + U_{OLT-Tx} + U_{OLT-Rx} + U_{Split} \qquad \textbf{(4.3)}$$

Knowing all this parameter from the table, the total unavailability is:

$$U_{Total} = (2{,}74\ x\ 10^{-5})^2 + (6{,}85\ x\ 10^{-6}) + (2{,}28\ x\ 10^{-6}) + (1{,}37\ x\ 10^{-6})$$

$$U_{Total} = 1{,}05\ x\ 10^{-5}\ hour/year$$

and

$$A = 1 - U_{Total} = 0{,}9999895 \qquad \textbf{(4.4)}$$

Which mean that the network will be available 99,99895% of the time during a year with trunk protection.

From now, knowing the availability of the network with and without protection, the trunk-based protection is assumed, and as the consequence of them, it will be necessary to use two GPON card (OLTs), two fibers and a 2xN splitter in each link.

## 4.2. Network design

### 4.2.1. Companies and residential users

#### 4.2.1.1. Companies in Agua Grande

In Agua Grande´s district there are 575 companies which 20% (115) of them demand 1Gbps, 30% (173) demand 100Mbps and 50% (287) demand 50Mbps. The companies in that district are located mainly in three different zones, namely zone A, B, C respectively, as showed in the following figure.


**Fig. 4.1**: Locations by zone of main companies in AG.

The zone A is the one located in the center of the city, which corresponds the zone of high traffic with more bandwidth demand, the zone B is a new luxury neighborhood still under construction with some important infrastructures including national Central Hospital, and the zone C is the airport zone which register also an important traffic. The broadband demand in each zone is represented in the following table:

**Table 4.2.** Bandwidth requested by companies per zone in AG.

| **Zone** | **Requested bandwidth** | | |
|---|---|---|---|
| | 1Gbps | 100Mbps | 50Mbps |
| A | 62 | 83 | 121 |
| B | 39 | 69 | 115 |
| C | 14 | 21 | 51 |

Once the zones have been located, the next step is to define the locations of the equipment and how the connections will carry out. The CO will be located at the same place where ACE is located in San Gabriel, because all infrastructure of ACE is located there and provide enough space and security. From that point it will be established connections to a different identified zone, namely zone A, B and C, even with other district according each case, where companies and also the residential users are located. Knowing the CO locations, the networks will look like as showing in the following figure.

Zone A


**Fig. 4.2.** Network design for companies of 1Gbps in zone A.

As showed in table 4.2, in this zone, at least 64 companies demand 1Gbps and the main concentration of the companies are represented in the figure 4.2 and the connections between CO and the three different zones are showing on the table 4.3. To provide internet broadband services in this zone is required seven 2:10 splitters, considering the protections scheme defined. Each splitter will connect at least 10 companies with a total capacity of 10Gbps and the whole capacity is 64Gbps.

Zone B:

**Fig. 4.3.** Network design for companies of 1Gbps in zone B.

In this zone, four points are selected considering that only 39 companies demands 1Gbps. Therefore four 2:10 splitters which connect eight GPON cards is required to connect all those companies in this area considering that the total capacity demanded in this zone is 39Gbps.

Zone C:

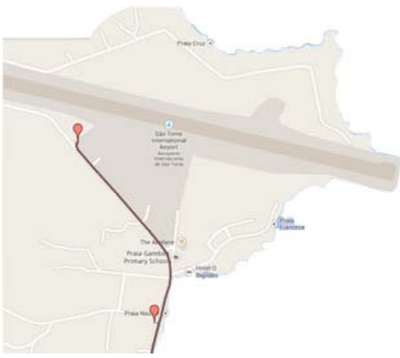


**Fig. 4.4.** Network design for companies of 1Gbps in zone C.

Only 14 companies in this zone demand 1Gbps which leads to a total capacity of 14Gbps. Just two 2:10 splitters connected to a four GPON card in each point is enough to connect all those companies. The following table show how the connections are done. Considering that the commercial 2x10 splitter does not exist, the 2x16 ones will be used.

The following table reflects how the connections will be established in each zone. All the connections between OLT and the splitters starts in a common place, ACE, which connect to the different points in each zone throughout the district and his respective recommended split ratio needed and finally the distance of the route to be traveled by each link.

**Table 4.3.** Connections per zone for companies in AG.

| Zone | Origen | Destination | Split ratio | Distance (Km) |
|---|---|---|---|---|
| **A** | ACE | TVS station | 2x16 | 1,03 |
| | | Parliament house | 2x16 | 1,11 |
| | | UN house | 2x16 | 1,90 |
| | | Popular Park | 2x16 | 2,24 |
| | | Center | 2x16 | 3,02 |
| | | Aduana | 2X16 | 2,78 |
| | | Ind. Plaza | 2X16 | 2,98 |
| **B** | ACE | Hospital | 2x16 | 5,43 |
| | | C. Milho 1 | 2x16 | 6,45 |
| | | C. Milho 2 | 2x16 | 6,45 |
| | | C. Milho 3 | 2x16 | 6,57 |
| **C** | ACE | Airport 1 | 2x16 | 7,46 |
| | | Airport 2 | 2x16 | 8,36 |

For the companies which demand 100Mbps and 50Mbps, the scenario is similar, which means that the principal zone of demand are similar to the ones which demand 1Gbps, but the difference is the equipment to be used in each case. For companies which demand 1Gbps is recommendable the use of a symmetrical 10Gbps GPON and an asymmetrical 1,25Gbps / 2,5Gbps for the companies which demand 100Mbps, 50Mbps and all residential users.

#### 4.2.1.2. Residential users in Agua Grande

In this district, 5.577 residential users demands 20Mbps and 4.182 10Mbps. The total capacity demanded by them is 153,36Gbps, therefore ten strategic points in the district is selected, but each possible point will request for more than one 2xN primary splitters depending on the point which the demand is lower or higher. With this configuration, the number of fiber that will arrive to each point is related with number of splitters in each point, always considering the protection. The following figure shows all those points.

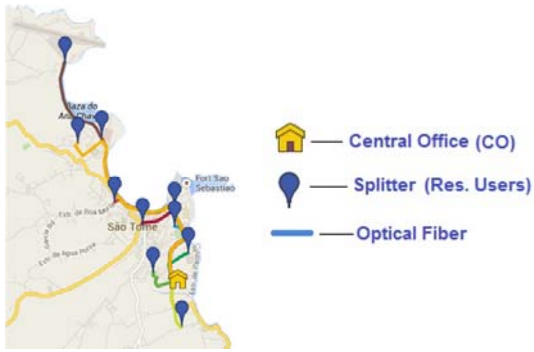



**Fig. 4.5.** Network design for residential users in AG.

Is premature to say exactly where will be located each residential users, the connections scheme have done considering the population density and their purchasing power. Like in the companies, all connections start in ACE and route to all those identified points throughout the district by digging streets. The GPON cards refer to the total number of OLTs each point requires and the distance between ACE an those points, table 4.4.

**Table 4.4.** Connections of residential users in AG.

| Origen | Destination | GPON cards | Distance (Km) |
|---|---|---|---|
| ACE | TVS Station | 12 | 1,03 |
| | Parliament House | 10 | 1,11 |
| | UN House | 12 | 1,90 |
| | Popular Park | 12 | 2,24 |
| | Center | 18 | 3,02 |
| | At. Gomes | 6 | 3,79 |
| | Hospital | 8 | 5,43 |
| | C. Milho | 36 | 6,45 |
| | Airport | 6 | 7,46 |
| | Pantufo | 4 | 1,32 |

The split ratio for residential users is 2x4 or 2x8 for primary splitter, and in the output of each one can be 1:8, 1:16, 1:32 or 1:64 depending of demand of each point. Considering this connections scheme, the total capacity demanded by 5.577 users of 20Mbps is 111,54Gbps and 41,82Gbps for 4.182 users which demand 10Mbps. At this point is not possible determine the exact split ratio needed, but the total OTLs needed is 124 being 90 to the users of 20Mbps and 34 for the ones of 10Mbps. All companies of 50/100Mbps and residential users together will require 148 GPON cards of 1,25/2,5Gbps.

#### 4.2.1.3. Companies in Mé-zochi

The companies in this district are located mainly in two different zones; A and B as showing in the figure bellow.


**Fig.4.6:** Locations by zone of main companies in Mé-zochi.

Zone A is located in the center of Mé-zochi´s city and zone B is located in the boundary of Agua Grande district, thereby, the companies in zone B could be connected to the CO located in ACE, but once that there is a CO in Mé-zochi city with less distance, it will be connect there. The percent of companies in each zone are shown in the table 4.5.

**Table 4.5.** Bandwidth requested by companies per zone in Mé-zochi.

| **Zone** | **Requested bandwidth** | | |
|---|---|---|---|
| | 1Gbps | 100Mbps | 50Mbps |
| A | 7 | 16 | 39 |
| B | 19 | 22 | 25 |

#### 4.2.1.4. Connections in zone A and B

All the connection for zone A will be assigned to an existent CO on the center of the same district, see figure 4.7, and all splitters needed to provides services to those companies will locate at the same place, considering that is a small area which all companies located within a zone where the maximum radius not exceed 2Km. As mentioned before, the companies in zone B, the connection go from CO located in Mé-zochi to the splitters in Bobo Forro. The following figure shows the connections in both zone, A and B.


**Fig. 4.7.** Connections structure for companies in zone A and B.

Once the number of companies is reduced in both zones, the connections in them are differentiated in two parts: on the one hand considering those companies which demand 1Gbps and secondly those which demand 100Mbps and 50Mbps. Those companies which demand 100Mbps and 50Mbps will share the same equipment and those which require 1Gbps will be assigned their own equipment in such way to optimize the bandwidth and reduce cost, for instance, if a symmetrical 10Gbps GPON card is used to provide services to at least 50 companies (which is not the case) which demand 100Mbps each one, the total bandwidth requested for all those companies is 5Gbps and the remaining 5Gpbs will be wasted, which is no sense. Considering the bandwidth required in table 4.5, the connections in Me-zochi district for companies will be:

**Table 4.6.** Connections by zone for companies in Mé-zochi.

| Zone | Origen | Destination | Distance (Km) |
|---|---|---|---|
| **A** | CO | CO | 0,00 |
| | | CO | 0,00 |
| | | CO | 0,00 |
| **B** | CO | Bobo Forro | 4,77 |
| | | Bobo Forro | 4,77 |
| | | Bobo Forro | 4,77 |
| | | Bobo Forro | 4,77 |

As mentioning before, in zone A the equipment, such as OLT and splitters are located in the CO, and distance between them is very short, for this connection, usually the pigtails of fiber is used to carry out connections between OLTs and splitters. In zone B four connections go from CO to Bobo Forro by a distance of 4.7km each one, therefore it is considered the trenching at roadside for possible pipeline fiber. Two of these connections from CO to Bobo Forro belongs the companies which demand 1Gbps and others two belongs the companies of 100Mbps and 50Mbps together.

#### 4.2.1.5. Residential users in Mé-zochi

In Mé-zochi district there are 896 users which demand 20Mbps and 2.688 ones which demand 10Mbps. The total capacity demanded for all them is 44,8Gbps. It was selected six potential points to fits splitters where concentration of population is substantially high as show in figure 4.8, and the connections between CO and any those points, naturally has different distances and the pipeline fiber is considered for the solution. Table 4.7 gives more details about those connections.

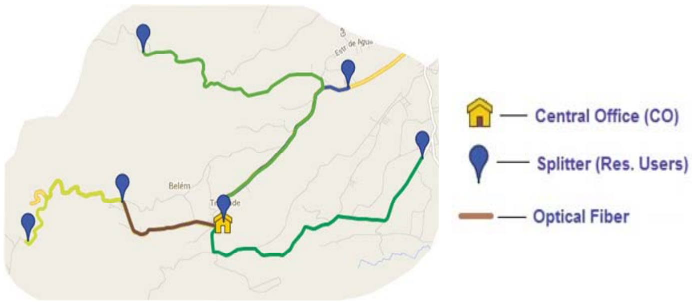



**Fig. 4.8.** Connection structures for residential users in Mé-zochi.

Take into account this connections, the group of splitter located in CO of Trindade, will require at least eight asymmetrical GPON cards of 1,25/2,5Gbps to provide services to 896 residence (urban users) which demand 20Mbps each one. Such as OLTs and splitter share the same place, it will be used also the pigtails of fiber to connect them. The remaining 2.688 rural users throughout the district, which demand 10Mbps each one, will require at least ten similar GPON cards to provide services to them. The proposed route is based on roadside ditches to travel the fibers. Together, all companies of 50/100Mbps and residential users will require at least 40 GPON cards of 1,25/2,5Gbps.

**Table 4.7**. Connections for residential users in Mé-zochi.

| Origen | Destination | Nº GPON Cards | Distance (Km) |
|---|---|---|---|
| CO Trindade | CO Trindade | 16 | 0,0 |
| | Batepa | 4 | 3,5 |
| | Pousada Boavista | 4 | 14,6 |
| | Caixão Grande | 6 | 8,3 |
| | Bobo Forro | 6 | 4,3 |
| | Madalena | 4 | 10,1 |

According to the protections scheme defined, all primary splitters must to be 2x4 or 2x8 and the secondary, if exist, can be 1x8, 1x16, 1x32 or 1x64, but always considering that the total amount of ONT hanging never overcome 128.

The remaining districts present basically the same geographical and infrastructural characteristics and the equipment to be used to provide services to the users are the same, therefore their design follow the similar procedure of the district studied above and the analyses are the same. So, it will be skipped the to reproduce the same for all of them, but the full connections including all district together considering either, companies and residential users is represented in the figure 4.9 and how the connections is done such as the route to be followed for each connections, the distance between CO and splitters clusters such as the equipment needed are shown on the table 4.8.


**Fig. 4.9.** Final connection structures for all districts in STP.

**Table 4.8.** Final connections for all subscribers in each district.

| District | Connetcions | Zone | Origen | Destination | Distance (Km) | GPON Card | |
|---|---|---|---|---|---|---|---|
| | | | | | | 10G/10G | 1,25/2,5G |
| Agua Grande | Companies | A | ACE | TVS Station | 1,03 | 26 | 26 |
| | | | | Parliament House | 1,11 | | |
| | | | | UN House | 1,90 | | |
| | | | | Popular Park | 2,24 | | |
| | | | | Center | 3,02 | | |
| | | | | Aduana | 2,78 | | |
| | | | | Ind. Plaza | 2,98 | | |
| | | B | ACE | Hospital | 5,43 | | |
| | | | | C. Milho 1 | 6,45 | | |
| | | | | C. Milho 2 | 6,45 | | |
| | | | | C. Milho 3 | 6,57 | | |
| | | C | ACE | Airport 1 | 7,46 | | |
| | | | | Airport 2 | 8,36 | | |
| | Residential Users | ACE | | TVS Station | 1,03 | | 124 |
| | | | | Parliament House | 1,11 | | |
| | | | | UN House | 1,90 | | |
| | | | | Popular Park | 2,24 | | |
| | | | | Center | 3,02 | | |
| | | | | At. Gomes | 3,79 | | |
| | | | | Hospital | 5,24 | | |
| | | | | C. Milho | 6,11 | | |
| | | | | Airport | 7,48 | | |
| | | | | Pantufo | 1,32 | | |
| Mé-zochi | Companies | A | CO | CO | 0,0 | 6 | 8 |
| | | | | CO | 0,0 | | |
| | | | | CO | 0,0 | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | B | CO | Bobo Forro | 4,7 | | |
| | | | | Bobo Forro | | | |
| | | | | Bobo Forro | 4,7 | | |
| | | | | Bobo Forro | 4,7 | | |
| | Residential uasers | CO Trindade | | CO Trindade | 0,0 | | 36 |
| | | | | Batepa | 3,0 | | |
| | | | | Pousada Boavista | 7,3 | | |
| | | | | Caixão Grande | 7,2 | | |
| | | | | Bobo Forro | 4,7 | | |
| | | | | Madalena | 9,6 | | |
| **Lembá** | Companies | CO Neves | | CO | 0,0 | 4 | |
| | | | | CO | 0,0 | | |
| | | | | CO | 0,0 | | 8 |
| | Residential Users | CO Neves | | CO | 0,0 | | |
| **Lobata** | Companies | ACE | | Guadalupe | 15,8 | | 14 |
| | Residential Users | ACE | | Guadalupe | 15,8 | | |
| **Cantagalo** | Companies | ACE | | Santana | 10,6 | | 16 |
| | Residential Users | ACE | | Santana | 11,9 | | |
| **Caué** | Companies | CO Angolares | | Angolares | 0,0 | | 4 |
| | Residential Users | CO Angolares | | Angolares | 0,0 | | |

Usually the populations of the remaining district live in the city, which is the small village, therefore all OLT and splitters are located substantially at the same place.

### 4.2.1. Equipment

According to the study done above, some equipment, namely OLTs, ONT and splitters have to be selected to perform a good project. Many of them had been analyzed and their main specifications are listed in the following table.

**Table 4.9.** Study of equipment to be used.

| Equipment | Manufactures | Model | Slots Cards | Up. bitrate | Dw. bitrate | Tx Wavelength | Rx wavele |
|---|---|---|---|---|---|---|---|
| OLT | Cisco | Cisco ME 4620 | 18 | 10Gbps | 10Gbps | 1490/1550 nm | 1310nr |
| | Huawei | SmartAX MA5600T | 8 | 1,25Gbps | 2,5Gbps | 1490 nm | 1310 n |
| | Ericsson | BLM 1500 17RU | 16 | 1,25Gbps | 2,5Gbps | 1490 nm | 1310 n |
| | MAiPU | PT4300-08 OLT | 8 | 1,25Gbps | 2,5Gbps | 1490/1550 nm | 1310 n |
| | Enablence | L-6208 GPON | 8 | 1,25Gbps | 2,5Gbps | 1490/1550 nm | 1310 n |
| | | | **Rj-11/Rj-45/CATV** | | | | |
| ONT | Ericsson | T063G SFU | 2/4 | 1,25Gbps | 2,5Gbps | 1310 nm | 1490 n |
| | Alcatel-Lucent | 7342 I-Series | 2/4 | 1,25Gbps | 2,5Gbps | 1310 nm | 1490 n |
| | Cisco | ME 4600 Series | 2/4/\|1 | 1,25Gbps | 2,5Gbps | 1310 nm | 1490/155 |
| | Huawei | HG8242 | 2/4/1 | 1,25Gbps | 2,5Gbps | 1310 nm | 1490/155 |
| | Enablence | G4021i | 2/4/1 | 1,25Gbps | 2,5Gbps | 1310 nm | 1490/155 |
| | | | **Input ports** | **Split rate** | **Opetaring Wavalength** | | |
| Splitter | Ericsson | RDJ 901 200 | 1 | 1x4 to 1x64 | 1260 - 1650 nm | | |
| | | | 2 | 2x4 to 2x64 | | | |
| | Raisecom | T-type 19" 1U rack | 1 | 1x2 to 1x64 | 1260 - 1650 nm | | |
| | | | 2 | 2X8 to 2x32 | | | |
| | Telesail | PLC Rack Mount/1U | 1 | 1x to 1x64 | 1260 - 1650 nm | | |
| | | | 2 | 2X8 to 2x32 | | | |

To carry out this network design in STP, is necessary to use two different types of OLT, one of them specifically intended to the companies which demand 1Gbps and another one to the companies which demands 100Mbps, 50Mbps and all residential users. This differentiation is just to optimize de bandwidth needed and reduce costs of the network. The “Cisco ME 4600 Series OLT”, a “PT4300-09 GPON OLT”, from MAiPU, the “Cisco ME 4600 Series ONTs” and Splitter “RDJ 901 200” from Ericsson are the selected ones, the main reason of those selection is their best adaptability to the characteristics of the design. The OLT from Cisco will provide services to all companies which demand 1Gbps, however, PT4300-08 from MAiPU is used to provide services to the companies which demand 100Mbps, 50Mbps and all residential users. The main characteristics of each of them are listed in followings tables.

#### 4.2.1.1. Selected OLTs

**Fig.4.10.** Cisco ME 4620 Optical Line Terminal.

**Table 4.10.** Main parameters of Cisco ME 4620 OLT.

| Slots Cards | Up. Bitrate | Dw. Bitrate | ONT / PON | Tx wavelength | Rx wavwlength |
|---|---|---|---|---|---|
| 18 | 10Gbps | 10Gbps | 128 | 1490/1550 nm | 1310 nm |


**Fig.4.11.** MyPower PT4300-08 OLT.

Because of the protections scheme used based in redundant trunk, half of the slots will be used as the primary fiber and rest of them as the redundant ones.

**Table 4.11**. Main parameters of MyPower PT4300-08 OLT.

| Slots Cards | Up Bitrate | Dw Bitrate | ONT / PON | Tx wavelength | Rx wavwlength |
|---|---|---|---|---|---|
| 8 | 1,25Gbps | 2,5Gbps | 128 | 1490/1550 nm | 1310 nm |

#### 4.2.1.2. Selected ONT

**Fig.4.12.** Cisco ME 4600 Series Optical Network Terminal.

**Table 4.12.** Main parameters of Cisco ME 4600 Series ONTs.

| Tx power | Rx Sensitivity | Tx wavelength | Rx wavelength |
|---|---|---|---|
| +18dBm | -28dBm | 1310 nm | 1490/1550 nm |

#### 4.2.1.3. Selected Splitter

The RDJ 901 200 Optic Splitter is selected and their main characteristics is showing in the table 4.13., the following picture shows RDJ 901 200 Optic Splitter.

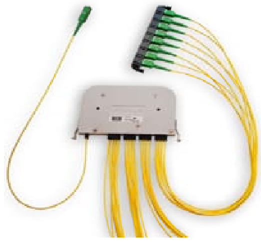


**Fig. 4.13.** RDJ 901 200 Optic Splitter.

**Table 4.13.** Main parameters of RDJ 901 200 Optic Splitter.

| Split ratio | Input Port | Insertion Loss (max) dB | Operating Wavelength | Max. Input power |
|---|---|---|---|---|
| 1x2 | 1 | 4 | 1260 - 1650 nm | 500 mW |
| 1x4 | | 7,6 | | |
| 1x8 | | 11 | | |
| 1x16 | | 14,5 | | |
| 1x24 | | 16,5 | | |
| 1x32 | | 18 | | |
| 1x64 | | 21,5 | | |
| 2x2 | 2 | 4,3 | | |
| 2x4 | | 7,9 | | |
| 2x8 | | 11,5 | | |
| 2x16 | | 15,1 | | |
| 2x32 | | 18,7 | | |
| 2x64 | | 22,3 | | |

Cisco ME 4620 OLT provides a symmetrical bandwidth of 10Gps with 18 functional GPON slots and PT4300-08 OLT provides an asymmetrical bandwidth of 1,25/2,5Gbps with 8 functional slots. Take into account that, this network will be protected using redundant trunk scheme, which leads that respectively nine and four of those slots will be used as a redundant for protections.

### 4.2.2. Fibers selections

To select the suitable cable for the project, several aspects of transmissions have to be considered, for instance the length of the optical cables in each link of the project, the economic factor, wavelength of transmissions, attenuation, connectors, split ratio and so on. Is important to note that all parameters using throughout of this project are carrying out take into account that the maximal link between an OLT and an ONT never exceed 20 Km. The following table summarizes the typical characteristics and performance of different categories of optical fiber cables G.650–G.659 from ITU-T recommendation.

**Table 4.14.** Main characteristics of a single mode optical fiber [22].

| Categories | Subcategories | Wavelength range | Chromatic dispers. | Attenuation coefficient |
|---|---|---|---|---|
| G.652 | G.652.A | 1310 nm - 1550 nm | 0,092 ps/nm$^2$ x Km | 0,5 dB/Km - 0,4 dB/Km |
| | G.652.B | 1310 nm - 1550 nm | 0,092 ps/nm$^2$ x Km | 0,4 dB/Km - 0,35 dB/Km |
| | G.652.C | 1310 nm - 1625 nm | 0,092 ps/nm$^2$ x Km | 0,4 dB/Km - 0,3 dB/Km |
| | G.652.D | 1310 nm - 1625 nm | 0,092 ps/nm$^2$ x Km | 0,4 dB/Km - 0,3 dB/Km |
| G.653 | G.653.A | 1460 nm - 1625 nm | 0,085 ps/nm$^2$ x Km | 0,35 dB/Km (Max 1550 nm) |
| | G.653.B | 1460 nm - 1625 nm | | 0,35 dB/Km (Max 1550 nm) |
| G.654 | G.654.A | 1530 nm - 1625 nm | 0,070 ps/nm$^2$ x Km (S1550max) | 0,22 dB/KM (Max 1550 nm) |
| | G.654.B | 1530 nm - 1625 nm | 0,070 ps/nm$^2$ x Km (S1550max) | 0,22 dB/KM (Max 1550 nm) |
| | G.654.C | 1530 nm - 1625 nm | 0,070 ps/nm$^2$ x Km (S1550max) | 0,22 dB/KM (Max 1550 nm) |
| | G.654.D | 1530 nm - 1625 nm | 0,070 ps/nm$^2$ x Km (S1550max) | 0,20 dB/KM (Max 1550 nm) |
| G.655 | G.655.C | 1460 nm - 1625 nm | 10 ps/nm x Km (1530 nm -1565 nm) $D_{max}$ | 0,35 dB/Km (1550nm) - 0,4 dB/Km (1625 nm) |
| | G.655.D | 1460 nm - 1625 nm | | 0,35 dB/Km (1550nm) - 0,4 dB/Km (1625 nm) |
| | G.655.E | 1460 nm - 1625 nm | | 0,35 dB/Km (1550nm) - 0,4 dB/Km (1625 nm) |
| G.656 | | 1460 nm - 1625 nm | | 0,4 dB/Km |
| G.657 | G.657.A | 1310 nm - 1550 nm | 0,092 ps/nm$^2$ x Km | 0,4 dB/KM - 0,3 dB/Km |
| | G.657.B | 1310 nm - 1550 nm | 0,11 ps/nm$^2$ x Km | 0,4 dB/KM - 0,3 dB/Km |

According the characteristics of the project, the suitable fiber considering ITU-T recommendation of optical fiber cables from G.650–G.659, is G.652. Although, G.657 is more adequate for network access uses, they present some limitations in terms of distance once they are useful for short reach distances, less than 1Km at the end of access networks, in particular inside buildings or near buildings [22]. In the other hand, the categories of fiber from G.653 to G.656, usually work in third windows for applications which require long distance transmission like transport networks or submarine cable systems.

**Table 4.15.** Parameters of the selected optic cable, G.652.D.

| Model | Manufacturer | Type | Attenuations (dB/Km) | | | Chromatic Dispers. ps/(nm x Km) | | Fiber Nº |
|---|---|---|---|---|---|---|---|---|
| | | | 1310 nm | 1383 nm | 1550 nm | 1285 nm - 1330 nm | at 1550 nm | |
| Up to 48 G652D/OM2 Fibre | PRYSMIAN | G.652D | ≤ 0,36 | ≤ 0,36 | ≤ 0,22 | ≤ 3,5 | ≤ 18 | 12 |

The selected G.652.D fibers are optimal for wavelengths in the third window in terms of attenuation, but not in terms of dispersion, in this case 18 ps/(km x nm). On the other hand, for wavelengths in the second transmission window, they are better in terms of dispersion, 3,5 ps/(km x nm) as showing in the table above.

### 4.2.3. Economic Budget

The financials data for this project have been taken from a market analysis of the current prices of equipment and fibers. Moreover, it is important to notice that this cost evaluation of the project is to provide an approximated estimation of the expenses, in order to complement the technical solution. The implementation of a proper business plan is out of the scope of this project. For these purposes, it would be fundamental to split the zones, and starts the network deployment in the zone where the principal companies and major concentrations of people are, for instance Agua Grande; a period of time of evaluation which foresee a self-financing to spread the deployment in others districts should be also taken into account; this way, the initial cost will be reduced considerably. The following table shows the cost of the equipment, fiber and the total budget for the whole project.

**Table 4.16.** Total cost of the project.

| Equipment | Model | Slots | Amount | Unitary Price ($) | Total Price ($) |
|---|---|---|---|---|---|
| OLT | Cisco ME 4600 Series | 18 + 2 | 4 | 25.000,00 | 100.000,00 |
| | PT4300-08 GPON Aggregation OLT | 8 + 2 | 31 | 3.800,00 | 117.800,00 |
| ONT | Cisco ME 4600 Series | 4 + 2 | 16.253 | 250,00 | 4.063.250,00 |
| Splitter | Ericsson RDJ 901 200 | 1x16 | 312 | 198,48 | 61.925,76 |
| | | 2x8 | 39 | 140,00 | 5.460,00 |
| | | 2x16 | 34 | 220,53 | 7.498,02 |
| | | 2x32 | 57 | 290,00 | 16.530,00 |
| | | 2x64 | 5 | 365,00 | 1.825,00 |
| Fiber | Up to 48 G652D/OM2 Fibre | | 824,89 Km | | 33.799.537,79 |
| Total cost | | | | | **38.173.826,57** |

The amount of fiber is related with the total kilometers of the cable needed to cover all demands according the estimation. The total of cable needed for the whole project is 825km, considering that each cable has 12 fibers and the calculation have done based on cable which the cost is 40.974,6$/km including public works of digging streets for fiber pull. Apart of that, a 0,3km average of fiber per connections had been added to connect from subscriber premise to splitter. The total connection estimated in STP is 16.253, considering that each cable has 12 fiber, the number of connection reduce to 1.354,4; multiply by 0,3Km it was obtained an additional 406,3Km of cable. For public works of digging streets for fiber pull, just the connections between OLTs and splitters have been considered. The connection between splitters and ONT in the user´s home has done by aerial cable which is quick and inexpensive, therefore, the total cost of the whole project is valued in **38.173.826,57M$**. If it be considered 0,6Km maximum of fiber per connections added to connect subscriber premise to splitter, the additional 812,65Km of cable will be needed and the total cost increase up to 54.823.855,28M$.

# Conclusions

It is undisputed that the future of telecommunications infrastructure in STP will pass over FTTH networks solutions. This is because, apart of the environmental friendly aspects, they offer considerable social and economic benefits and provides broadband services support for at least the next 50 years. Considering that today Africa and STP is connected to the world by submarine cable, the deployment of FTTH network is viable to ensures millions of people access to internet easier and cheaper taking into account that is the only solution that has been recognized as the ultimate solution for providing all required services to the end users.

Telecommunication infrastructures constitute a critical activity, key factors for economic development of any country, and considering the increment in international internet bandwidth through the ACE and WACS projects, a positive effect on prices is also expected to allow the increment of penetration in STP.

The whole design has followed all standard and recommendation proposed by the recommended entity and has met all the objectives for which it was proposed. For its deployment a business plan must be implemented based on a deep market analysis in order to reduce the initial expenses.

# Bibliography

[1]. http://www.cstome.net/en/tarifarios/internet-e-dados,*CST*, (Mars 05th, 2014)
[2]. “XDSL and DSLAM Access Technologies”
[3]. “ITU Measuring Information Society 2013”, *ITU*, 35-103 (2013)
[4]. Cheng, N. and Effenberger, F. “WDM PON: Systems and Technologies”, *Huawei*, 3, 1-27 (2010)
[5]. FTTH Council “Definition of Terms”, *FTTH Council*, 1-6 (2011)
[6]. FTTH Council “FTTH Advantages of Optical Access”, *FTTH Council,* 1-28 (2012)
[7]. Saheb Shaik, J. and N R Patil, “FTTH Deployment Options for Telecom Operators” *Sterlite Optical Technologies Ltd,* 1-9
[8]. DR. PEARSON, M. “WDM-PON: A VIABLE ALTERNATIVE FOR NEXT GENERATION FTTP”, *Enablence,* 1-7 (2010)
[9]. ITU, Gigabit-capable Passive Optical Networks (GPON):General characteristics, *ITU-TG.984.1*, 1-34 (2003)
[10]. “Introducción a las redes PON” http://www.telnet-ri.es/soluciones/acceso-gpon-y-redes-ftth/la-solucion-gpon-doctor-a-la-interoperabilidad-gpon/ (February 22th, 2014)
[11]. Carroll, M., “FTTx Access in North America, Europe, and Other Regions – Status and Perspectives”, *IEEE and ITU,* 35, 1-38 (2012)
[12]. “Huawei to launch its branded devices in Ghana this year” http://business.myjoyonline.com/pages/news/201205/86843.php (August 18th, 2012)
[13]. “SimbaNET deploys GPON in Tanzanian capital” http://www.africatelecomit.com/simbanet-deploys-gpon-in-tanzanian-capital, *Africa Telecon&IT,* (August 28, 2013)
[14]. “Ericsson to build residential fiber-optic network for 21st Century Technologies in Nigeria”, 21st century technologies Limeted, http://www.21ctl.com/ericsson_build_fibre_net.php
[15]. “Bond Africa via fibre networking” http://www.africatelecomit.com/bond-africa-via-fibre-networking, *Africa Telecon&IT,* (October 06, 2013)
[16]. “El sistema de Internet de los BRICS podría poner fin a una Red dominada por EE.UU.”, http://actualidad.rt.com/actualidad/view/106517-brics-internet-eeuu-cable-espionaje, *Trading 212 Pro* (September 22, 2013)
[17]. “IV Recenseamento Geral da População e Habitação de 2012”, *INE,* IV Ed, 21-27 (2012)
[18]. “Guiché unico de empresas”, http://gue-stp.net/spip.php?rubrique1, *RDSTP,* (August 03, 2012)
[19]. “Iº Recenseamento Empresareal”, *INE, Iº Ed*, 11-15 (2003)
[21]. “How Fiber-to-the-home Broadband Works” http://computer.howstuffworks.com/fiber-to-the-home2.htm (February 23th, 2014)
[22]. “Recommendation ITU-T Optical fiber cables G.650–G.659” SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS, *ITU-T*, (2010)