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Apêndice 1

A tabela 13 detalha a configuração de equipamentos utilizada para a composição de uma rede GPON com 32 usuários e para a composição de 64 redes GPON com 32 usuários em cada uma. Ambas as configurações foram utilizadas na seção 3.6.

Tabela 13 - Configuração de equipamentos OLT e ONT utilizada na seção 3.6.

	1 rede 32 usuários Quantidade	64 redes 32 usuários por rede Quantidade
OLT (Optical Line Terminal)		
Sub-rack da unidade OLT	1	1
Fonte de alimentação para a unidade OLT	2	2
Módulo de ventilação para a unidade OLT	1	1
Unidade de supervisão e controle da OLT	1	1
Switch Ethernet para a unidade OLT com 2 uplinks 10 GbE		2
Módulo óptico 10 GbE para a placa Switch Ethernet		4
Placa com 8 portas GPON com uplink 1 GbE	1	8
Módulo óptico 1 GbE para Placa com 8 portas GPON	2	
Módulo óptico de interface GPON para a Placa com 8 portas GPON	1	64
ONT (Optical Network Termination)		
ONT com 4 portas Fast Ethernet + 2 portas POTS (telefonia)	32	2048
Sistema de Gerência		
Hardware (servidor)	1	2
Softwares de gerenciamento	1	1
Passivos - Adicional para suporte ao cenário 1		
Filtro WDM	1	64
Passivos - Adicional para suporte ao cenário 2		
MUX/DEMUX 08 canais DWDM banda C com filtro WDM	2	128

As tabelas 14, 15 e 16 a seguir detalham a configuração de equipamentos utilizada para a composição dos sistemas DWDM com e sem ROADM utilizados na seção 4.3.

Tabela 14 - Configuração de equipamentos correspondentes aos cenários 1, 2 e 3 utilizada na seção 4.3.

	Cenário 1		Cenário 2		Cenário 3	
	400 Gbps		400 Gbps com ROADM		800 Gbps	
	Quantidade /Nó	Quantidade/ Total	Quantidade/ Nó	Quantidade /Total	Quantidade /Nó	Quantidade /Total
Equipamentos	-	-	-	-	-	-
Acessórios e Miscelâneos	-	-	-	-	-	-
Bastidor com Alimentação Redundante	2	10	3	15	4	20
Sub-bastidor de Transponder e Amplificador	9	45	9	45	17	85
Sub-bastidor de Transponder 40 G / 100 G / ROADM WSS		0	2	10		0
Unidades de Gerenciamento	-	-	-	-	-	-
Módulo de Supervisão - Sub-bastidor de Transponder e Amplificador	9	45	9	45	17	85
Módulo de Supervisão - Sub-bastidor de Transponder 40 G / 100 G / ROADM WSS	0	0	2	10	0	0
Canal Óptico de Supervisão	1	5	1	5	1	5
Unidades de Multiplexação/Demultiplexação	-	-	-	-	-	-
Mux/Demux DWDM 40 Canais 100 GHz com Mux/Demux de Canal Óptico de Supervisão	2	10	2	10		0
Mux/Demux DWDM 80 Canais 100 GHz com Mux/Demux de Canal Óptico de Supervisão		0		0	2	10
Amplificação	-	-	-	-	-	-
EDFA Booster 21 dBm	2	10	2	10	2	10
EDFA Booster 24 dBm		0		0		0
EDFA Pré Amplificador	2	10	2	10	2	10
EDFA Linha		0		0		0
Raman		0		0		0
Transponders	-	-	-	-	-	-
Transponders 10 Gbps - OTU-2	80	400	80	400	160	800
Muxponder 4x10 Gbps - OTU-3 DPSK		0		0		0
Muxponder 10x10 Gbps - OTU-4		0		0		0
ROADM	-	-	-	-	-	-
Módulo ROADM WSS Grau 1		0	2	10		0
Unidade Analisadora de Canal		0	1	5		0
Sistema de Gerência	-	-	-	-	-	-
Software de Gerenciamento		1		1		1
Hardware de Gerenciamento	-	1	-	1	-	1

Tabela 15 - Configuração de equipamentos correspondentes aos cenários 4, 5 e 6 utilizada na seção 4.3.

	Cenário 4		Cenário 5		Cenário 6	
	800 Gbps com ROADM		1600 Gbps		1600 Gbps com ROADM	
	Quantidade /Nó	Quantidade /Total	Quantidade /Nó	Quantidade /Total	Quantidade/ Nó	Quantidade /Total
Equipamentos	-	-	-	-	-	-
Acessórios e Miscelâneos	-	-	-	-	-	-
Bastidor com Alimentação Redundante	5	25	6	30	6	30
Sub-bastidor de Transponder e Amplificador	17	85	1	5	1	5
Sub-bastidor de Transponder 40 G / 100 G / ROADM WSS	2	10	12	60	12	60
Unidades de Gerenciamento	-	-	-	-	-	-
Módulo de Supervisão - Sub-bastidor de Transponder e Amplificador	17	85	1	5	1	5
Módulo de Supervisão - Sub-bastidor de Transponder 40 G / 100 G / ROADM WSS	2	10	12	60	12	60
Canal Óptico de Supervisão	1	5	1	5	1	5
Unidades de Multiplexação/Demultiplexação	-	-	-	-	-	-
Mux/Demux DWDM 40 Canais 100 GHz com Mux/Demux de Canal Óptico de Supervisão		0	2	10	2	10
Mux/Demux DWDM 80 Canais 100 GHz com Mux/Demux de Canal Óptico de Supervisão	2	10		0		0
Amplificação	-	-	-	-	-	-
EDFA Booster 21 dBm	2	10	2	10	2	10
EDFA Booster 24 dBm		0		0		0
EDFA Pré Amplificador	2	10	2	10	2	10
EDFA Linha		0		0		0
Raman		0		0		0
Transponders	-	-	-	-	-	-
Transponders 10 Gbps - OTU-2	160	800		0		0
Muxponder 4x10 Gbps - OTU-3 DPSK		0	80	400	80	400
Muxponder 10x10 Gbps - OTU-4		0		0		0
ROADM	-	-	-	-	-	-
Módulo ROADM WSS Grau 1	2	10		0	2	10
Unidade Analisadora de Canal	1	5		0	1	5
Sistema de Gerência	-	-	-	-	-	-
Software de Gerenciamento		1		1		1
Hardware de Gerenciamento	-	1	-	1	-	1

Tabela 16 - Configuração de equipamentos correspondentes aos cenários 7 e 8 utilizada na seção 4.3.

	Cenário 7		Cenário 8	
	4000 Gbps		4000 Gbps com ROADM	
	Quantidade/Nó	Quantidade/Total	Quantidade/Nó	Quantidade/Total
Equipamentos	-	-	-	-
Acessórios e Miscelâneos	-	-	-	-
Bastidor com Alimentação Redundante	8	40	8	40
Sub-bastidor de Transponder e Amplificador	1	5	1	5
Sub-bastidor de Transponder 40 G / 100 G / ROADM WSS	18	90	18	90
Unidades de Gerenciamento	-	-	-	-
Módulo de Supervisão - Sub-bastidor de Transponder e Amplificador	1	5	1	5
Módulo de Supervisão - Sub-bastidor de Transponder 40 G / 100 G / ROADM WSS	18	90	18	90
Canal Óptico de Supervisão	1	5	1	5
Unidades de Multiplexação/Demultiplexação	-	-	-	-
Mux/Demux DWDM 40 Canais 100 GHz com Mux/Demux de Canal Óptico de Supervisão	2	10	2	10
Mux/Demux DWDM 80 Canais 100 GHz com Mux/Demux de Canal Óptico de Supervisão		0		0
Amplificação	-	-	-	-
EDFA Booster 21 dBm	2	10	2	10
EDFA Booster 24 dBm		0		0
EDFA Pré Amplificador	2	10	2	10
EDFA Linha		0		0
Raman		0		0
Transponders	-	-	-	-
Transponders 10 Gbps - OTU-2		0		0
Muxponder 4x10 Gbps - OTU-3 DPSK		0		0
Muxponder 10x10 Gbps - OTU-4	80	400	80	400
ROADM	-	-	-	-
Módulo ROADM WSS Grau 1		0	2	10
Unidade Analisadora de Canal		0	1	5
Sistema de Gerência	-	-	-	-
Software de Gerenciamento		1		1
Hardware de Gerenciamento	-	1	-	1

Apêndice 2

Durante a elaboração da presente dissertação foi preparado um *paper* sobre arquiteturas de redes ópticas de acesso de próxima geração GPON intitulado "*Evolution of GPON Architectures Towards Next-Generation GPON Investment Analysis*". O documento foi aceito no *3rd ngnlab.eu International NGN Workshop* ocorrido entre os dias 02 e 03 de novembro de 2011 na cidade de Delft na Holanda.

Na sequencia são mostradas respectivamente a programação da conferência, mostrando a inserção da apresentação do material na conferência, e a íntegra do *paper*.

TNO innovation for life

3rd ngnlab.eu International NGN Workshop

Wednesday 02 and Thursday 03 November 2011

Programme

http://tno.nl/ngnworkshop2011

Wednesday November 2nd, 2011

09:00-09:50: Registration
09:50-10:00: Introduction by host Oskar van Deventer
10:00-12:00: Tutorials

Time	Presenter	Title
10:00	Eugen Mikoczy, ST	NGN-based IPTV (tutorial)
11:00	M. Oskar van Deventer, TNO, Netherlands	Content Delivery Networks and their interconnection (tutorial)

12:00-13:00: Lunch
13:00-13:15: Welcome by Prof. Erik Fledderus, Innovation Director "Future Internet Use"
13:15-16:00: Presentations

Time	Presenter	Title
13:15	Ivan Kotuliak, Slovak Technical University of Bratislava, Slovakia, Founder of NGN Workshop	NGN Workshops: exchanging practical experiences
13:30	Pieter Veenstra, KPN, Netherlands	National IP Interconnection and IMS Peering solutions
14:00	Julius Müller, Technical University Berlin, Germany	Packet Core Network Evolution in regard to Future Internet Research Trends - Service Control Mechanisms in NGN and Beyond

14:30-15:00: Break, social networking

Time	Presenter	Title
15:00	Stephan Massner, Leipzig University of Applied Sciences, Germany	Service Level Agreements focussed on network interconnections
15:30	Andrej Binder, Slovak Technical University of Bratislava, Slovakia	The dark side of IP: multi-homing, network identity and mobility
16:00	Rogier Noldus, Ericsson, Netherlands	VoLTE roaming, An overview of practical considerations for deploying Voice over LTE in heterogeneous networks

16:30-17:30: Posters and demos

Time	Presenter	Title
	Rudolf Strijkers, Marc Makkes, TNO, Netherlands	Interactive networks, network virtualization and cloud computing
	Ray van Brandenburg, TNO, Netherlands	FP7 Fascinate: video super-zoom

19:00-22:00: Diner

Thursday November 3rd, 2011

09:00-12:00: Presentations

Time	Presenter	Title
9:00	Sebastian Schumann, Slovak Telecom, Slovakia	Next-generation services: The operator's dream - The OTT's reality?!
9:30	Daniel Hartmann, Ostfalia University of Applied Sciences, Germany	SIP-based Mobility in a future NGN-based Core Network for TETRA-PMR-Systems
10:00	Tomas Kovacik, Slovak Technical University of Bratislava, Slovakia	Multimedia services transfer among IMS domains

10:30-12:00 Panel session: The Future of NGN
12:00 Closing

Handouts from participants, who were unable to travel to Delft.

Time	Presenter	Title
-	Henrique Graciosa, Pontifícia Universidade Católica do Rio de Janeiro, Brazil	Evolution of GPON Architectures
-	Ranganai Chaparadza, Frainhofer Fokus, Berlin, Germany	ETSI-AFI: Autonomic network engineering for the self-managing Future Internet

Evolution of GPON Architectures Towards Next-Generation GPON Investment Analysis

Henrique B. Graciosa and Marbey M. Mosso

CETUC/PUC-Rio
Centro de Estudos em Telecomunicações
Pontifícia Universidade Católica do Rio de Janeiro
Rio de Janeiro, Brazil
marbey@cetuc.puc-rio.br

***Abstract*—Optical Access Technologies are increasingly being deployed worldwide. Aiming to follow these technologies evolution path towards higher bandwidths, this paper presents an economical and technical analysis of Gigabit Capable Passive Optical networks (GPON) and their evolution in Brazilian telecom infrastructure.**

***Keywords*—Gigabit Capable Passive Optical Networks; Investment Analysis; Optical Distribution Networks; Passive Optical Networks.**

I. Introduction

Service providers currently offer a variety of services to end users - residential or business ones. These services can be very basic, such as internet and telephony services, or more sophisticated, including simultaneous High Definition Television (HDTV) channels with video on demand, web access directly on television, online games and others, leveraged by Internet Protocol Television (IPTV) technology.

The access to basic internet and telephony services is currently well served by traditional access technologies, such as Wimax and DSL (Digital Subscriber Line), which offers a few megabits per second bandwidth, enough to provide a reasonable quality of service. However, due to the introduction of internet with higher bandwidth, HDTV and new services, access networks need to deploy new technologies in order to achieve a higher bandwidth.

Projections at present overcome 35 Mbps per user, considering higher internet speed and 5 HDTV simultaneous channels. A Cisco projection foresees a peak above 250 Mbps of bandwidth consumption for residential users after 2015. Video signals will consume most part of the networks bandwidth, since communication will be based on interactive video, with HD video format, intensive IPTV traffic and high application of video-call and conference.

Among all already available access network technologies, the one that best fits this expected intensive bandwidth consumption is based on PON (Passive Optical Network).

Investment analysis is generally focused in short time performance and based on legacy infrastructure. In this paper, an evolutionary investment evaluation is carried out aiming a superior bandwidth, capable of sustaining next generation services after 2015.

Section II introduces PON architectures, comparing EPON (Ethernet Passive Optical Networks) and GPON (Gigabit Capable Passive Optical Network) and detailing their topologies. Section III describes the evolution steps since the traditional GPON up to XG-PON1 and WDM (Wavelength Division Multiplexing) PON. Section IV presents the upgradeable scenarios involving all these systems. Section V presents a detailed investment analysis associated with PON topology evolution, highlighting next generation service application. Finally, section VI presents the main comments and conclusions of this paper, followed by references for this paper.

II. PON Description

PON networks are point to multipoint optical distribution networks that does not make use of electronic elements in the outside plant, but rather are formed by passive splitters and couplers to distribute bandwidth among multiple users. This network segment is named Optical Distribution Network (ODN). Its range depends on the type of technology used, but generally has between 10 and 20 km and can distribute traffic for up to 128 users with the same infrastructure, also depending on the technology used.

Besides the external passive infrastructure, PON networks are also formed by optical line terminals (OLT - Optical Line Termination), located in the service provider site, and optical network terminals ONT () or ONU (Optical Network Unit), placed in the customer premises or near to that.

The Fig. 1 below shows a generic PON architecture:

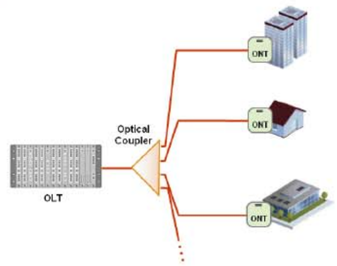

Fig. 1. Generic Passive Optical Network (PON) architecture

A. *EPON versus GPON*

Among all considered PON Technologies, GPON (Gigabit Capable Passive Optical Network) and EPON (Ethernet Passive Optical Networks) are the most used worldwide. GPON was standardized in 2003 by the ITU-T G-984 and EPON was standardized in 2004 by the IEEE 802.3ah. Both technologies are ready to withstand CATV overlay signal on 1550 nm, protection architectures, and they have roughly the same costs.

However, GPON can bear 1250 and 2500 Mbps on downstream and 155, 622, 1250 and 2500 Mbps on upstream, while EPON support only 1250 Mbps on both ways. Considering also that GPON protocol efficiency is around 92% and EPON is around 72%, it can be inferred that, with the combination of higher delivered bandwidth and a more efficient protocol, GPON net bandwidth delivered is twice the size of the EPON one.

GPON is also ready to withstand TDM (Time-Division Multiplexing) traffic in native format, allowing telecom operators to keep the legacy TDM on their network while EPON is not ready for that.

Moreover, EPON withstands only ODN classes A and B, while GPON withstands also class C. In practice, this implies that, for the same distance, GPON can attend more than twice the users attended by EPON. It reduces costs since more users can share the same optical distribution network.

Also taking into consideration that GPON is the technology adopted by Brazilian and Latin American telecom operators, this paper will focus on GPON architectures and on their evolution rather than on EPON.

B. *GPON Architecture Description*

On GPON architecture, as described on the generic PON architecture, there is equipment on the service provider site (named OLT) and equipments on the user premises (named ONT).

The maximum transmission rate on the downstream direction OLT-ONT is 2500 Mbps and the maximum transmission rate on the upstream direction ONT-OLT is also 2500 Mbps, as mentioned earlier. For the downstream transmission, the OLT broadcasts optical signal to all ONUs in continuous mode while for the upstream each ONU only transmits information when it is allocated a time slot and all the ONUs share the upstream channel in the time division multiplexing mode. The maximum number of allowed users per port GPON of the OLT is 128.

Considering scenarios with 32, 64 and 128 users per OLT port, there is the following approximate delivered capacity bandwidth, considering a protocol efficiency of 92%:

-32 users: 72 Mbps
-64 users: 36 Mbps
-128 users: 18 Mbps

Considering the previously mentioned forecast of bandwidth consumption, it is possible to conclude that the architecture with 128 users per GPON does not meet the expectation of 35 Mbps. With 64 users it is possible to reach around 35 Mpbs without oversubscription, which is enough for application needs in the short and medium terms.

The architecture is also prepared to support CATV overlay video signal, using additional wavelength at 1550 nm, optical amplifier and WDM multiplexer.

III. GPON Evolution

There are two stages of development associated to the GPON evolution. The first, called NG-PON1, is compatible with current deployments of GPON and observes the decision of using the wavelength or enhancement bands defined in [5]. For this first scenario there are two options available:

1) Use of 10 Gbps. In this case, there are two alternatives regarding the upstream transmission rate: a 2.5 Gbps option, called the XG-PON1 (X referring to 10 in Roman numeral), and another with 10 Gbps, called XG-PON2. In both alternatives, 10 Gbps is used on downstream, what makes the first option asymmetrical and the second one, symmetrical;

2) Use of WDM in the same fiber infrastructure using the wavelength plan also defined according to [5]. In this case, the architecture is point to point to reach each user with dedicated wavelength, with protocol transparency and improved security.

NG-PON1 also includes options to reach distances beyond 20 km.

On the other hand, the second stage, called NG-PON2, will not necessarily be compatible with the infrastructure already installed for the current GPON and its evolution NG-PON1, since solutions will present greater capacity per wavelength and higher number of wavelengths. Its standard is expected to be ready in 2015.

The Fig. 2 presents the previously mentioned evolution scenarios:

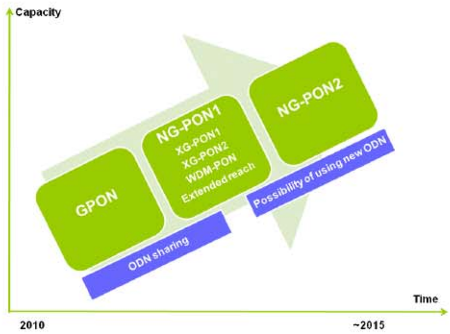

Fig. 2. Evolution of GPON network

IV. Upgradeable Scenarios

A natural evolution scenario of a basic GPON network is the use of XG-PON1, but coexisting with the GPON formerly in operation. This will be the focus of the following investment analysis. In this situation, it is possible to serve new users directly with XG-PON1, using the same ODN infrastructure already existent. Likewise, a subscriber served with GPON can be attended with XG-PON1 in the future simply replacing its ONT with a higher capacity model compatible with the XG-PON1.

Below there is a diagram showing the GPON and XG-PON1 coexistence, using a distinct wavelength plan for the XG-PON1, as defined in [6].

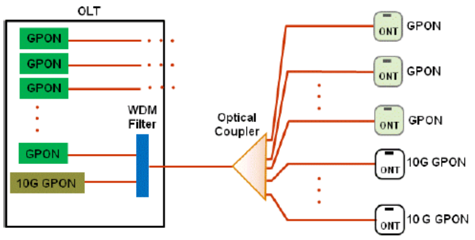

Fig. 3. XG-PON1 coexisting with a basic GPON topology

This architecture uses a WDM filter located in the service provider site close to the OLT to allow GPON and XG-PON1 wavelengths multiplexing and demultiplexing. The GPON ONTs should be equipped with a filter WFB (Wavelength Blocking Filter) to block XG-PON1 wavelengths. The XG-PON1 ONTs can be used to attend new subscribers or replace current GPON ONTs.

The network design should respect the total power budget available, with particular emphasis on power losses introduced by optical filters and wavelength blocking Filters both mandatory for multiplexing and demultiplexing. Those components have to be introduced in the optical infrastructure in the initial deployment of the network, even if the network does not use XG-PON1 at first. This avoids traffic disruption in the future for its insertion.

The main advantage of this architecture, with both technologies coexisting, is not to have to transfer all subscribers simultaneously for XG-PON1, since it is possible to use basic GPON network initially.

V. Investment Analysis

The resource allocation for the deployment, maintenance and operation of a GPON network can be divided basically in two items:

1) CAPEX (Capital Expenditure): investment to build and upgrade the network;
2) OPEX (Operational Expenditures): costs to maintain the network working.

CAPEX can be subdivided into four other items:

1) OLT: value of equipment installed on the service provider site;
2) ONT: value of equipment installed on the user premises;
3) Miscellaneous materials: fiber optic cable, optical distributors, optical splitters, cabinets and other passive elements;
4) Civil works and installation for network deployment.

OPEX can be subdivided into the following sub items:

1) License for network operation, in the case of telephony, for example;
2) Administrative costs (office rent, car...);
3) Staff costs (salaries, training...);
4) Rights of use costs (for land use or third party posts, in the case of aerial network);
5) Costs related to the sites (rent, electricity, security...);
6) Connection to network backhaul;
7) Marketing;
8) Network operation and maintenance.

For the study related to the basic scenario with GPON, it is considered a network formed by 1024 subscribers in the first year, with 32 subscribers per GPON network, a total of 32 networks in order to be able to offer a guaranteed 72 Mbps bandwidth without oversubscription to each subscriber, with telephony, data and HD television. The analysis will be made for a 5 years period.

Considering a careful research based on prices practiced by Brazilian service providers and GPON vendors also in Brazil, it is adopted generally the following cost and investment assumptions regarding the network and its CAPEX and OPEX, with all prices considered in Brazilian Reais (R$):

-OLT installed with its management system (R$): 300,045.03;
-ONT installed: (R$) 757,760.00;
-Spare part units (proportional to the equipment prices): 15%;
-Average length of the fiber optical cable per GPON network (km): 12;
-Average price of installed ODN per km, including fiber cable, all passive elements, such as couplers, cabinets and optical distributors (R$): 12,500.00;
-Monthly operational cost proportional to the revenue: 5%;
-Monthly cost (maintenance and rights of use) of the ODN per km of fiber cable (R$): 250.00;
-Monthly subscription for each ONT user (R$): 450.00;
-Months with revenue on year 1 (4 months for network installation and deployment): 8;
-Annual reduction of user subscription after year 2: 10%;
-ONT installation service per ONT (R$): 150.00;
-Minimum rate of attractiveness: 12%;
-Cost for the use of network infrastructure, in addition to the CAPEX (metro-ethernet, optical backbone, energy, space) – could be adopted as a OPEX: 15%;
-Financing conditions as a percentage of the fundable CAPEX (only active elements): 100%;
-Financing condition – grace period (years): 1;
-Financing condition – period (years): 4;
-Financing condition – annual cost: 12%.

From the above items it is possible to infer that investment in fiber network is the largest one compared to investments in OLT and ONT – observing that price differences of OLT and ONTs may occur depending on the vendor considered.

Considering the architecture has 32 GPON networks, the following distribution of CAPEX is obtained:

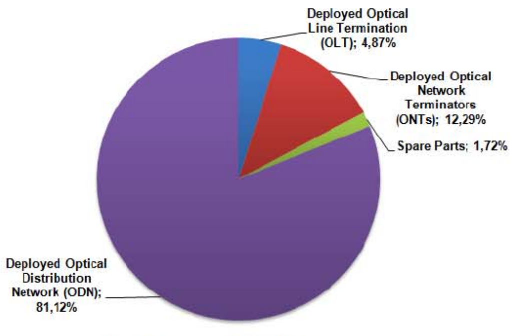

Fig. 4. Relative CAPEX distribution

It is also possible to verify that the size (length) of each network – and therefore the GPON network density, as well as the price of installed network per kilometer – has a strong impact on CAPEX and, as analyzed, a significant impact on financial results.

Computing all parameters previously presented, the following cash flow performance chart (discounted and accumulated discounted) can be obtained, with a net present value of approximately (R$) 1,125,000.00 and investment return before 4 years:

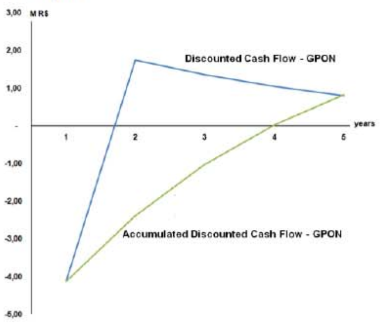

Fig. 5. Discounted cash flow and accumulated cash flow for a basic GPON network.

Starting from the scenario described before, XG-PON1 subscribers will be added over the same network already deployed, in a topology of GPON and XG-PON1 coexistence. This analysis will consider 20 users of this type of service after the second year, with the following assumptions:

-XG-PON1 OLT installed – 20 subscribers (R$): 42,444.25;
-XG-PON1 ONT installed – 20 subscribers (R$): 239,000.00;
-Monthly subscription for each ONT XG-PON1 user (R$): 3,000.00.

With this structure – merging GPON and XG-PON1 – it is obtained a net present value of approximately (R$) 1,950,000.00 and a return before 3,5 years as presented on the chart below and in comparison to the basic GPON architecture:

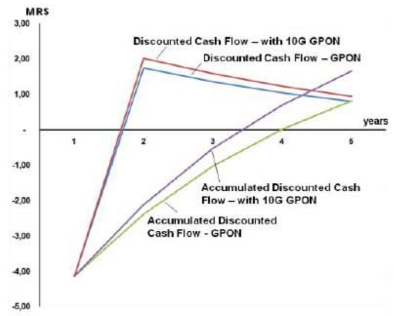

Fig. 6. Discounted cash flow and accumulated cash flow for a basic GPON network, comparing with the same architecture coexisting with XG-PON1.

With 20 users in two separate GPON networks, 10 on each network, it is possible to offer more than 950 Mbps of bandwidth to each of them. It could be an application, for example, for a corporate client or a service delivered to a condominium or building. In this case, the cost of network structured cabling inside the building or office should also be considered – they were not included in this analysis. In the case of the guaranteed 72 Mbps delivered to the initial GPON users, it could also be a corporate client or even a premium residential subscriber.

As previously mentioned, optical distribution network (density and price) strongly influences CAPEX and also the network investment return. Starting from the GPON basic scenario, it is done a sensitivity analysis of the project net present value, considering each network GPON distance variation from 6 to 14 km, for 3 values of km of installed optical distribution network – (R$) 11,000.00, (R$) 12,500.00 and (R$) 14,000.00. The following figure is obtained:

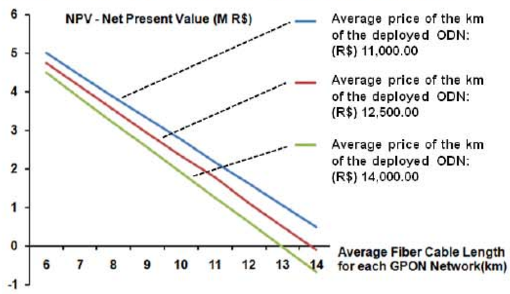

Fig. 7. Net present value variation as a function of average length of fiber cable and average fiber cable price per km, including all passive elements.

From the figure above, it is possible to observe the significant net present value variation as the length of the GPON network improves, which shows the importance of attending subscribers in more concentrated areas. From the same figure, and also showing the impact of the fiber cable extension, it is possible to infer that protected architectures, where more fiber cable will be used, will only be viable in very restricted lengths situations. Considering a network with 7 km and a protection with 6 km, it would result in a 13 km total network, implying in a net present value of approximately zero, with (R$) 14,000.00 as a average price per km of deployed optical distribution network.

VI. Conclusion

GPON has emerged as an alternative to cope with the increase of bandwidth consumption on the access networks and it is being widely deployed. Standardized by ITU-T G.984, GPON evolution towards next-generation architectures, able to deliver even higher bandwidth to end users, is already being considered. It is possible to verify that, in controlled CAPEX and OPEX conditions, an economical feasible GPON architecture can be done. It is also proved that the same network can be designed to withstand XG-PON1, enabling the coexistence of GPON and some XG-PON1 users, with an even better result concerning investment return. In this situation, since more users are sharing the same infrastructure with higher bandwidth, a reduction of cost per bit can be verified. To the best of our knowledge, an investment analysis considering next generation passive network evolution topologies as reported in this work is an innovative contribution.

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