Impact on the Aggregation Capacity of Inline Data Bit Rates Increase in Optical Access Networks

Moufida FEKNOUS, Bertrand LE GUYADER,
Orange Labs,
Lannion 22300, France
Moufida.feknous@orange.com

Annie GRAVEY
Telecom Bretagne
Technopole Brest-Iroise, CS 83818,
29238 Brest, France
Annie.gravey@telecom-bretagne.eu

***Abstract*— Evolution of data bit rates in the optical access networks raises the need to reconsider metro and access architectures in order to limit potential bottlenecks. Moreover, any new architecture has to be motivated by taking into account both energy and infrastructure costs. Different traffic scenario should be considered when assessing metro and access networks aggregation capacity. The present paper presents alternative architectures based either on hyper centralization or on centralization of Central Offices (COs) equipments; these architectures are compared and discussed in terms of aggregation features (QoS), power savings and cost optimization.**

Keywords—aggregation capacity; power savings; QoS; cost optimization

I. INCREASE OF BANDWIDTH DEMANDS IN ACCESS AND AGGREGATION NETWORKS

The development of video services such as 4K, High Definition (HD) Internet Protocol Television (IPTV) based on 16Mbit/s data bit rates, services individualization, home equipments multiplication, virtualization of storage areas in the network and Internet video development [1, 2] are major elements leading to a significant increase in terms of bandwidth demands.

The introduction of Fiber To The Home (FTTH) technologies allows to fulfill the demands created by the range of the previously mentioned services. Gigabit-capable Passive Optical Network (G-PON [3]) present a first answer to these bandwidth demands. In the meantime, later generations of optical access technologies such as 10 Gigabit-capable Passive Optical Network (XG-PON1/2 [4]) and Next Generation Passive Optical Network (NG-PON2 [5]) are being discussed in Full Service Access Network (FSAN) and International Telecommunication Union (ITU).

The deployment of optical access technologies makes it possible to modify the access local loop which links the Optical Line Termination (OLT) (located at the Central Office, or CO) with Optical Network Units (ONUs) located at customers' premises. The distance between an ONU and its OLT can be as large as 60km no impact on delivered bandwidth, which is significantly larger than the current distance between customers and CO. This allows considering an increase in the number of customers accessing the network at a given CO, or in other terms, increasing customers' concentration.

OLTs nowadays present high customers' aggregation capacity (16000 customers per OLT is common with currently available equipment). This may lead to bottlenecks when the capacity of the output interface is lower than the sum of all input links' capacities. Let ρ denote the ratio between these capacities; a small ρ value could lead to QoS degradations such as packet losses, excessive delay, and jitter degradation.

This article discusses likely evolutions of metro and access networks architectures, and uses ρ to estimate the probability of bottlenecks occurrence. Section II describes access networks architecture migration, from DSL access to optical access and focuses on optical access equipment OLT, their evolution and the number of customers can be aggregated in this equipment. The results of dimensioning presented in this section based on dimensioning bit rate currently used in a DSL access network. Section III studies how the current dimensioning method will evolve depending of traffic assumptions and customers' activity scenarios. Section IV enumerates driving issues to take into account in the network architectures evolution and proposes potential architectures. Section V is a multi-criteria (aggregation and fix/mobile convergence features, power consumption, cost optimization, protection/security mechanisms) comparison of these architectures in order to give a first quantitative evaluation. Some preliminary conclusions are given in Section VI.

II. FROM DSL TO OPTICAL ACCESS NETWORKS

A. *Current Access/Aggregation Architectures*

Fig.1 represents a network architecture that is commonly deployed in the metro and access network segments. Access network is composed of Digital Subscriber Line Access Multiplexers (DSLAMs) or OLTs and the metro network is composed of secondary and primary loops (Gigabit Ethernet rings) deployed on a IP/MPLS architecture.

For a DSL access network, the link capacity between access and metro networks (the "aggregation" link) typically reaches 2 Gbit/s. A primary Node Edge (NE) aggregates at most 64000 customers while a DSLAM connects an average of 900 Triple Play customers. This corresponds to an average of 70 DSLAM per primary NE (i.e. a total link capacity of 140Gbit/s).

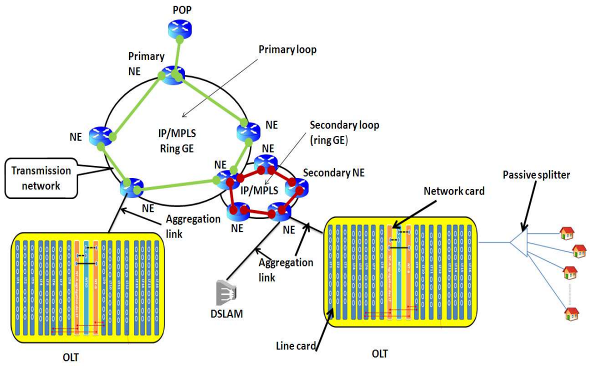

Fig. 1. Current network architecture *(metro/access).*

B. First impact of optical access technologies introduction

Optical infrastructure deployed in the access network is based on optical splitters, which perform physical aggregation of bursts emitted by ONUs (up to 64 ONUs). G-PON (respectively XG-PON1) technology allows to logically aggregating up to 128 ONUs (respectively 1024).

OLT equipments proposed by the Industry consist of a set of at most 16 line cards equipped with N G-PON (or XGPON1) interfaces with either one or two network cards. The line cards perform an Ethernet aggregation of total flow from the GPON (or XGPON1) interfaces and the network cards aggregate flows coming from these line cards as shown in Fig.1. OLTs are based on network cards offering uplink capacities of up to 80Gbit/s and can aggregate up to 16000 customers.

Traffic flows are subsequently aggregated (IP aggregation) first by secondary NEs and finally by primary NEs. Large capacity COs can also be directly linked to primary NEs.

- *Potential congestion within OLT*

This sub-section describes the potential congestion points within an OLT. The congestion ratio for an OLT is derived from the capacity of links in line cards (10Gbit/s or 40Gbit/s) and network cards (up to 80Gbit/s), from the number of GPON or XGPON1 interfaces (up to 16 interfaces) and depends on the deployed technology (GPON or XGPON1).

Fig.2 justifies that the congestion ratio in line cards generally is always larger than 1 (potential congestion only appears in one case with ρ=0.5), which means that the multiplexing of OLTs on line cards cannot lead to congestion. On the other hand, Fig.3 depicts that contention is possible within network cards as ρ can indeed be significantly smaller than 1.

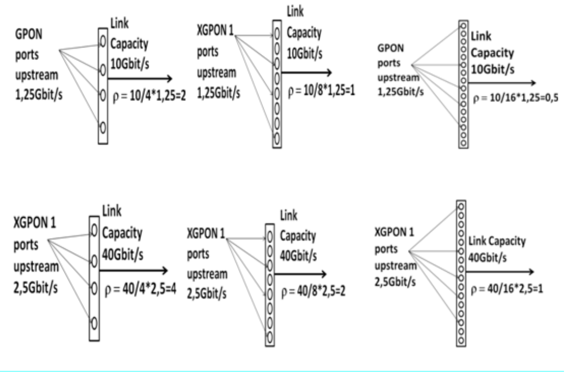

Fig. 2. Congestion in line card .

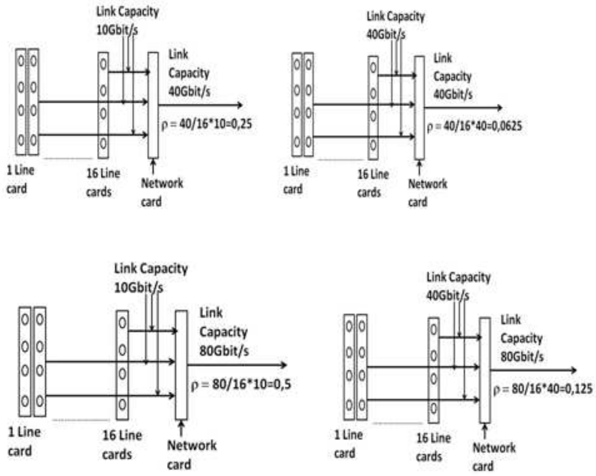

Fig. 3. Congestion in network card.

- *Capacity of the aggregation links*

In the current DSL based access networks (see Fig.1), the deployed capacity between NE and DSLAM is 2Gbit/s and aggregates the traffic for 900 customers. This corresponds approximately to allocating 2Mbit/s per user.

If the same rate is allocated per user for optical access, the aggregation link should have a larger capacity since the number of users served by a given OLT is significantly larger.

Fig.4 illustrates the relationship between the number of customers per CO and the capacity requested for multiplexing their traffics.

In the case of 16000 customers, for example, the requested capacity is 36Gbit/s, which can be provided by 4 10Gbit/s links. The 64000 customers linked to the primary ring by a given NE can then be aggregated on only 4 OLTs. Whereas 140 Gbit/s links were used to link the 70 DSLAMs to the NE, only 16 10Gbit/s links are requested to link the 4 OLTs to the NE. This is one of the first impacts of optical access technologies properties.

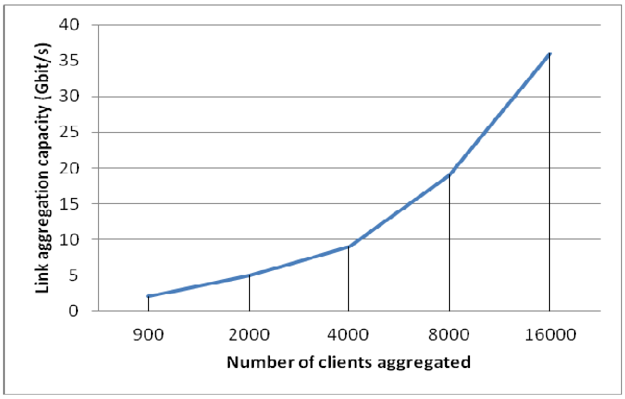

Fig. 4. Link capacity between OLT and NE (link aggregtaion) depending on the number of customers aggregated.

III. EVOLUTION SCENARIOS

A. *Traffic hypotheses and activity scenarios*

This section describes how the dimensioning bit rate will evolve depending of traffic hypotheses and customers' activity scenarios.

Traffic hypothesis are as follows: the multicast service is IPTV, which only generates multicast traffic in the downlink. The unicast service is the superposition of video distribution, VoIP and Internet access. It generates traffic both upstream and downstream.

The first set of considered traffic characteristics for downstream multicast and unicast service characteristics are the following:

- IPTV: 85 TV channels, with 25% of HD channels and 75% of SD channels (this considers MPEG4 coding with FEC). Bit rate per SD channel is 2.8Mbit/s and 16Mbit/s per HD channel. It is supposed that a customer accesses at most 1 flow at a time. The average bit rate for IPTV is thus 6Mbit/s resulting from weighting the bit rates of SD and HD channels with their respective access probabilities.
- Unicast video: 1 SD flow coded at 2.8Mbit/s,
- Unicast VoIP + Fast zapping: 0.7Mbit/s,
- Internet data: 0.5Mbit/s.

The corresponding upstream service characteristics are the following:

- Upstream video per user: 2.8Mbit/s,
- Unicast VoIP+ Fast zapping: 0.7Mbit/s,
- Internet data: 0.5Mbit/s.

Per customer, the first set of traffic hypothesis (hypothesis A) corresponds to a mean downstream rate equal to 10Mbit/s when the customer uses both unicast and multicast services and a mean upstream traffic rate equal to 4Mbit/s.

A second set of traffic hypothesis (hypothesis B) considers that customers access higher bit rate services:

- IPTV: 85 TV channels, with 90% proportion of HD channels and 10% proportion of SD ones (MPEG4+FEC). Bit rate per SD channel is 2.8Mbit/s and 16Mbit/s per HD channel. The average bit rate for a single IPTV flow is thus 14.75Mbit/s resulting from weighting the bit rates of SD and HD channels with their respective access probabilities. It is now supposed that a customer accesses at most 3 flows at a time.

- Unicast video: 1 HD flow at 16Mbit/s,
- Unicast VoIP + Fast zapping: 0.7Mbits/s,
- Unicast visio conference: 5Mbit/s,
- Internet data: 34.05Mbit/s.

The corresponding upstream service characteristics are the following:

- Unicast video per user: 4.2 Mbit/s,
- Unicast visio conference: 5Mbit/s,
- Unicast VoIP + Fast Zapping: 0.7Mbit/s,
- Internet data: 10.1Mbit/s.

Per customer, the second set of traffic hypothesis corresponds to a mean downstream rate equal to 100Mbit/s when the customer uses both unicast and multicast services and a mean upstream traffic rate equal to 20Mbit/s.

We propose 2 scenarios differing by customers' "activity" rate. The "activity rate" a_r, expressed in Erlangs ($a_r \in [0;1]$) is the proportion of time during which the customer uses a given service

- Scenario 1 is based on multicast service with $a_r = 1$ and unicast service with $a_r = 0.2$,
- Scenario 2 on multicast and unicast services with $a_r = 1$

B. *Evolution of the aggregation capacity*

A dimensioning tool is used to derive the capacity of aggregation links corresponding to a given set of customers concentrated in an OLT. The tool is based on two traffic models, which take into account traffic fluctuations at two time scales:

- Model 1 (packet level): This model assumes that the traffic is stationary and the packets arrive according to a Poisson process.
- Model 2 (flow level): This model follows a Gaussian approximation for the distribution of the aggregate flows of each service.

The traffic corresponding to each service is characterized by the its bit rate and a related activity rate. The bit rate of each service is assumed to be constant. The activity rate of a service is defined as the ratio between the number of flows for this service during the busy hour and the potential number of customers. The tool also uses parameters specific to multicast traffic (IPTV) such as the number of TV channels, users' distribution according to different sets of channels, bit rate and audience of each channel. Service engineering rules may also be considered: for example, the channels with a large audience are transmitted permanently while other channels are transmitted only when requested by at least one user.

In the case of an OLT aggregating 16,000 customers, Fig.5 and Fig.6 show that the requested downlink and uplink capacities are almost identical with traffic hypothesis A. This capacity reaches 21Gbit/s in scenario 1 and 66Gbit/s in scenario 2. The NE that aggregates 64000 customers should thus support 84Gbit/s (resp. 264Gbit/s) in scenario 1 (resp. in scenario 2) with 4OLTs, each OLT aggregating 16000 customers.

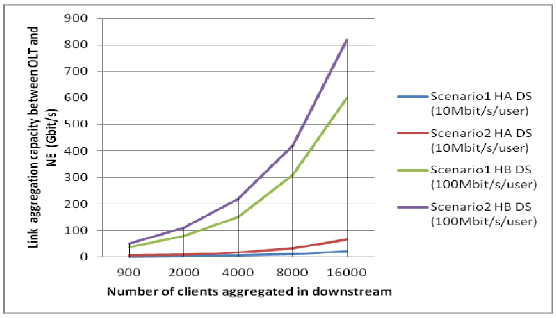

Fig. 5. Downstream link aggregation capacity according to the number of customers aggregated in the same OLT equipement

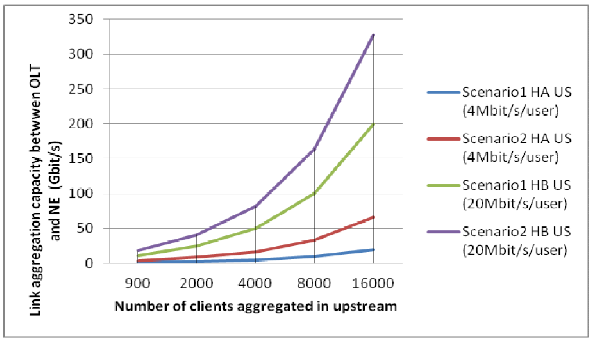

Fig. 6. Upstream link aggregation capacity according to the number of customers aggregated in the same OLT equipement

Under traffic hypothesis B, and in scenario 1 (resp. in scenario 2), the downlink aggregation capacity is close to 600Gbit/s (resp. to 820Gbit/s) and the uplink capacity is 200Gbit/s (resp. 328Gbit/s) (as shown in Fig.5 and 6 in the case of 16000 customers aggregated in the same equipment OLT).

Under traffic hypothesis A and scenario 1, the requested aggregation capacity is similar to the current link aggregation capacity (140Gbit/s) described in section II.B. However, supporting scenario 2 implies to upgrade links aggregation and metro networks (routers switching and inter router links capacities evolution). Traffic hypothesis B and scénario2 represents a significant evolution: the metro network has to support 3.28Tbit/s (4 OLTs each supporting 820 Gbit/s) of downstream traffic (shown in Fig.5) and 1.31Tbit/s (4 OLTs each supporting 320 Gbit/s) of upstream traffic (shown in Fig.6) for a single primary NE. This significant increase is due to the increase of unicast traffic. Hypothesis A and scenario 2 together require an aggregation capacity of about 260 Gbit/s (as shown in Fig.5 and 6, with 4 OLTs each requiring 66 Gbit/s). As the links between NEs (inner metro links) in metro are currently of capacity 40Gbit/s (4 wavelengths at 10Gbit/s), the congestion ratio between a typical aggregation link between OLT and NE and metro links would then be in the order of 0.15 (ρ=40/260). In order to avoid the metro network to become a bottleneck the metro links' capacity should be upgraded which can be done by adding a few 10Gbit/s wavelengths to each metro link.

The congestion ratio is even lower for hypothesis B scenario 2: ρ=40/3280 $\approx$ 0.01 in downlink and $\rho \approx$ 0.03 in the uplink. As currently installed routers support at most interface of 500Gbit/s, a new generation of routers for metro network is necessary. These routers would support a high capacity of switching and interface (some Tbit/s), very powerful CPU.

IV. Issues driving network architectures evolution

In the first part of this section, main issues to take into consideration in the networks architecture evolution are listed. The architecture described in the section II is naturally considered as the reference architecture. According to operators' requirements, architectures are described in the second part of the section

A. *Reference architecture limitations and evolution*

- According to traffic hypotheses, traffic volumes can drastically increase as it is illustrated in the section III. Also, in order to support bandwidth demands up to some Tbit/s in the access / metro network, it is necessary to engage an evolution of the reference architecture. First, it can consist in replacing metro network NE routers by a new generation of routers supporting switching and interfaces capacity of several Tbit/s. Moreover, this will impact on the metro network links capacity (100 wavelengths of 10Gbit / s for example). This evolution directly impacts core network, and especially Concentration Node (CN) router which is the core network gateway aggregating traffic coming from all primary NEs. Metro network evolution thus leads to increase the number of CN routers, to upgrade both interfaces bit rate and CNs' switching capacity, and lastly to increase the capacity of the links between NEs and CNs.
- Central Offices number is is a structuring factor in the optical networks evolution. Due to the copper local loop history, CO number remains very high. Nowadays, performances of FTTH technologies give the opportunity to revise the local loop and to drastically decrease CO number (as described in the section II.B where it is underlined that 70 DSLAMs can be replace by 4 OLTs).
- Equipment power consumption is also a driving factor in the networks evolution. To face to the increase of demanded bandwidth in the networks, it will be generally necessary, in the case of the reference architecture, to introduce additional new generation equipment, to re-

design ring networks. This can naturally lead to a power consumption increase.

- In the reference architecture, security and protection mechanisms can be introduced at different levels of the network:
  - CN nodes duplication in order to secure the connections of primary NEs,
  - Central primary NEs duplication to secure either the connection with a DSLAM/OLT or a connection with secondary loops.
  - OLT network card duplication to secure OLT characterized by a high number of aggregated customers.

According to the security/protection mechanism, level, it can impact the invests as it is synonym of additional equipment in the network (routers, network cards…). Moreover, it generally needs links duplication (between OLT and the NE, between secondary and primary routers, between the NE and the CN). Protection mechanisms involve exploitation and administration functions which can induce OPEX increase.

B. Metro networks equipment evolution

With respect to network evolution, the current trends result in:

- The deployment of an infrastructure compliant with Wavelength Division Multiplexing (WDM) or Dense Wavelength Division Multiplexing (DWDM) technologies able to transport several Tbit/s
- The evolution of switching and interface capacities to support several Tbit/s of traffic;
- The support of new features as it could be necessary to support both Ethernet and IP aggregations in a single equipment, to support fixed/mobile networks convergence (e.g. BBU hostelling), to consider multiple technologies coexistence (SDH, G-PON, XG-PON1…);
- The CPU data processing increase [6];
- The power consumption limitation, e.g. equipment presenting a high capacity optical backplane (46Tbit/s) [6] allowing OLT/NE "organic". It is required to have equipments embedding standby functions, dozing and sleeping modes.
- In the point of view of an operator and customer, centralization and convergence functions are considered to simplify network implementation because of: The possible convergence of identification and authentication mechanisms for services access. Indeed, today, a customer has several identities and authentications certificates to access to a service depending on the access type (fixed, mobile, Wifi…). The convergence aims at simplifying the processes thanks to a single service identifier and authentication certificate.
- The reduction of the electronic aggregations points number (such as routers and Ethernet switches which will result in power savings;
- The CO number reduction,
- The facility to implement a security and protection mechanism of the network.

C. Potential architectures

Next generation metro and access architectures have to take into account QoS constraints, defined in the Service Level Agreements (SLAs). They should support data bit rates summarized in the section III. Moreover, they will have to facilitate fixed/mobile convergence, and to implement protection / security mechanisms. Network architectures evolution should yield power savings by reducing OPeration EXpenditures (OPEX) and CAPital EXpenditures (CAPEX). For example, reducing the number of COs and so the number of equipment is a way to decrease power consumption and OPEX. The reference architecture described section II is compared to 2 alternative architectures. The first one is a highly centralized architecture based on a "Service Cloud" and relying on an optical aggregation network described in [7, 10]. The second one is a centralized architecture, named Next Generation Point of Presence (NGPoP) [8].

Whatever the architecture (hyper centralized or centralized), distances between aggregation central entity either located in the metro or backbone network and ONUs increase. Also, optical budgets can be greater than 32dB (maximum optical budget proposed by G-PON C+ class) and several solutions exist in order to compensate the extra insertion losses. Thanks to a reduction of the splitting ratio, it is possible to limit PON insertion losses but this approach requires more invests in optical fiber deployments. This is a passive solution and active ones, like Reach Extenders, OLT subtending (small capacity OLT subtended by masters OLT) and solution based on photonics aggregation can be involved. According to the active technology, it is possible to reach a distance up to 60km in the case of RE and 100km for the two other solutions. A last technology could be a photonic aggregation architecture as described in [9].

D. Highly centralized architectures description

Fig.7 [10] represents an architecture based on a "Service Cloud" and relying on an Optical Aggregation Network. The service Cloud is a central entity installed in the backbone network and which consists of a very powerful Cloud router associated to server applications. Routers and servers are integrated into the Cloud Router and applications servers in the service Cloud. This single entity ("Service Cloud") has a very high capacity and supports traffic volumes as calculated in Section III (i.e. a super router with switching capacity of 1 Tbit/s is requested in the hypothesis B, scenario 2 outlined in section III).

The aggregation policy corresponds to a seamless connection between the super router (IP aggregation) and final users via a single optical hop (aggregation layer 1 and 2) that combines WDM performed via Arrayed Waveguide Gratings

(AWGs) (making several hundreds of wavelengths available) and Time Division Multiplexing (TDM) based on Plumb Lanthanum Zirconate Titanium (PLZT) optical switches [7]. The reduction of hops in the network should improve QoS and network performance by decreasing latency and jitter [10]. In this highly centralized architecture, distances between CO equipment and ONUs can be 100km or more. Advanced Dynamic Bandwidth Allocation (DBA) algorithms have to be defined in order to take into account propagation delays up to 500µs.

In the case of a WDM infrastructure, some limitations can appear according to the wavelength allocation plans involved in different optical access technologies (GE-PON, G-PON, XG-PON1, Point-to-point link for Mobile backhauling and Base Band Unit (BBU) hostelling, Synchronous Digital Hierarchy (SDH) interface…) [11]. In a TDM configuration, one time slot is allocated to a technology type and in this approach, the number of technologies is limited to the number of possible time slots in the cycle and time slots allocation algorithms are needed in order to manage coexistence of these different nature technologies.

The centralized architecture presents the difficulty to manage heterogeneous customer profiles (residential, mobile, business) with different QoS profiles on a single platform. Moreover, relying on a Service Cloud requires a very high processing capacity CPU.

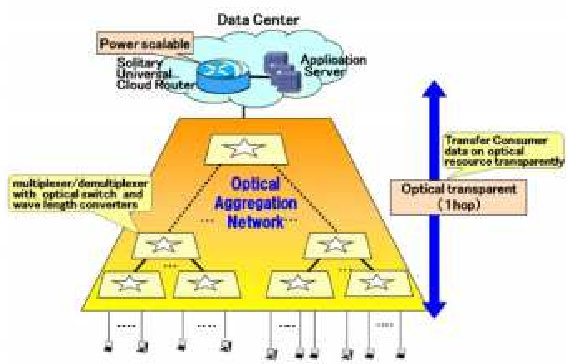

Fig. 7. Architecture based on Service Cloud and optical aggregation [13].

E. *Centralized architectures description*

The NGPoP architecture shown in Fig.8 has two objectives: on the one hand, it proposes to converge fixed and mobile traffic access, contents server on a single CO equipment, and on the other hand, it offers a combined Ethernet and IP aggregation equipment that can control distant ONUs (up to 40km).The "NGPoP" is a central entity located at NEs and presents a high aggregation capacity. While centralizing the control functions in the NGPoP, it may still be necessary to offer access to distant customers. This can be done thanks to subtended line cards (or subtending OLT), or solution based on photonic aggregation supporting a distance up to 100km. But Reach Extenders can be used to achieve a distance of 60km.

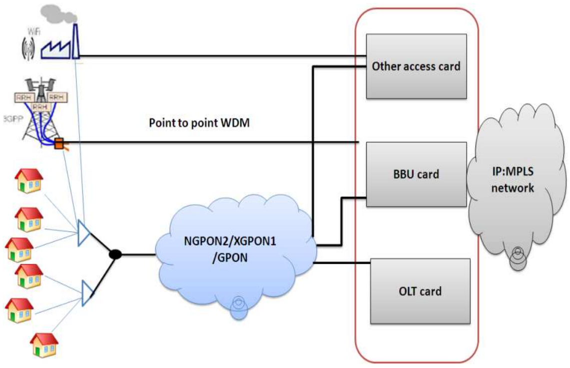

Fig. 8. NGPoP architecture[10].

F. *Reach Extension solutions*

- Small capacity OLT subtending

Small capacity OLT (<1000 customers) can be used in hyper centralized and centralized architectures in order to extend the optical fiber reach between new CO and final customers. In this case, such OLTs are in subtending of CO equipment. Introducing any active equipment on the field will induce an additional delay in the information processing (34µs for a small OLT and 17µs for G-PON, XG-PON1 line cards subtending).

- Photonic aggregation solution

Illustrated by Fig.9, photonic aggregation is based on AWGs and Optical Subscriber Units (OSUs). An OSU is a small capacity OLT (typically 64 customers per OSU), which uses a dedicated wavelength to aggregate the traffic corresponding to its set of customers. The photonic aggregation relies on traffic control performed by a Dynamic Wavelength Bandwidth Allocation (DWBA) mechanism used to optimize the bandwidth allocation according to filling ratio of an OSU wavelength.

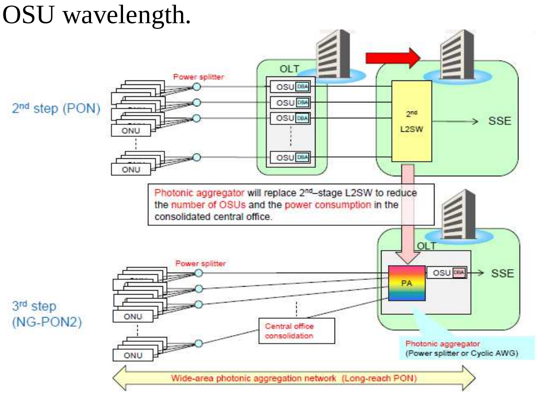

Fig. 9. OSU and DWBA based architecture[9].

In this scenario, once an ONU is installed, any congestion situation can be avoided thanks to an additional OSU and the ONU switching towards another wavelength and another OSU. This implies colorless ONUs.

V. MULTI CRITERIA COMPARISON OF FUTURE ARCHITECTURES

A. *Comparing the energy efficiency of the proposed architectures*

Hyper centralized architectures based on Service Cloud and optical aggregation can really reduce power consumption in the networks. Indeed, global power savings up to 90% [10] have been assessed even if these architectures imply routers of high switching capacity (several Tbit/s).

In the case of NGPoP architecture, according to the CO equipment and ONU distance, first results demonstrated it is possible to have power savings of 40% (resp. 20%) for a distance of 100km (resp. 20km).

Photonic aggregation can manage ONUs connection with dedicated OSUs. Also, an underused OSU can be put in standby mode and gives the opportunity to reduce power consumption [9]. Moreover, OSUs based on smaller capacities avoid using high power energy.The OLT subtending introduces sleeping and dozing mechanism to reduce energy consumption.

B. Comparing the cost optimization of the proposed architectures

In highly centralized architectures, the trend is to reduce the CO number and to limit aggregation hops and equipments in the CO. In service Cloud architecture, this reduction can reach 95%.

In the case of NGPoP architecture, preliminary estimations give that for a 60km (resp. 100km) distance between CO equipment and ONUs results in a CO reduction of 90% (resp. 80%).

Qualitatively, the architecture based on Service Cloud and Optical aggregation needs reach extension solutions as described in the section IV.F. Also on one hand CO number is reduced but on the other hand, it is necessary to plan street cabinets equipped with power supplies for active equipment. First studies demonstrate an interest in CAPEX reduction but these results have to be consolidated.

OLT subtending needs to install street cabinets equipped with power supplies. ,

Photonic aggregation architecture contributes to reduce the number of equipments in the street cabinets and finally optimize the CAPEX.

C. Architectures comparison in terms of security and protection

Because of the high number of aggregated customers and various integrated technologies, Cloud router architectures require a reliable security/protection mechanism. These mechanisms are less complex than ones implemented in the reference architecture as the aggregation stages number remains limited (cloud router should be duplicated and some optical links with final users).

NGPoP architecture requires same type of security/protection mechanisms than ones previously mentioned. Some aggregation stages are deleted also security mechanisms are less complex than ones defined in the refrence architecture (possible duplication of NGPoP elements, CN, CN/NGPoP links and NGPoP/final users links).

In the case of the architecture based on photonic aggregation, once an OSU is installed, any congestion can be avoided thanks to the introduction of an additional OSU. Some ONUs connected to the saturated OSU are switched to the new OSU. This approach means it is necessary to use colorless ONUs. In this architecture, PON protection mechanism is present by default. Architectures based on mini OLT or G-PON line card subtending does not automatically need a protection mechanism as it depends on the number of aggregated customers remain which is generally quite low (<1000), the customers type (mainly residential, but it could be possible to have coexistence of residential, mobile and business customers) and the optical protection scheme cost.

D. Architectures comparison in terms of fixed/mobile network convergence

The fourth generation of mobile networks (LTE) is an evolution for wireless networks by its total compatibility with IP networks. We do not distinguish any difference between the fixed and mobile networks as the applications are treated by IP protocol. This new generation of IP mobile network encourages a convergence of fixed and mobile networks.

Currently, fixed access (mobile) networks present 20%(resp.22%) of total invests. A convergence of the networks will surely allow to reduce these invests, Cloud router architecture and NGPoP are potential candidates for fixed and mobile networks convergence.

E. Preliminary evaluation of t potential architectures

Table I (resp. Table II) gives a qualitative evaluation of future architectures (resp. Solution to extend optical range) architectures based on several comparison criteria (Security/protection mechanisms complexity, QoS impacts, Operational constraints, costs optimization based on the CO number reduction, power savings).

TABLE I. QUALITATIVE EVALUATION OF FUTURE ARCHITECTURES.

Architecture Label	NGPOP	Service Cloud
Security /protection mechanism complexity	+	++
QoS impacts	U	U
costs optimization based on the CO number reduction	+	++
Operational constraints	-	--
Power saving	+	+

TABLE II. QUALITATIVE EVALUATION OF SOLUTIONS TO EXTEND OPTICAL RANGE.

Solution to extend optical range	Subtending OLT	Photonic aggregation
Security /protection mechanism complexity	-	++
QoS impacts	U	U
Costs optimization based on the CO number reduction	+	+
Operational constraints	++	--
Power saving	-	+

U: Under study (current simulation to evaluate the performance of architectures in terms of QoS)
++: very good
+: good
-: bad
--: very bad

Cloud Service architecture based on photonic aggregation shows an advantage according to the chosen criteria with respect to NGPoP. Anyway, operational constraints need to be taken into account to clearly identify global deployment topics associated to this architecture.

VI. CONCLUSION AND PERSPECTIVES

Optical access technologies encourage customers' concentration in the same OLT equipment (up to 16000). This naturally impacts on the possible CO reduction, which can reach 90% (resp. 95%) in the case of NGPoP deployment (resp. Service Cloud and optical aggregation architecture). Moreover, these architectures promise a potential power savings of 40% for NGPoP and 90% for Cloud Router architecture. This CO reduction has to take into account services QoS performances and SLA levels and should thus incorporate traffic flow performances.

Innovative architectures such as Service Cloud and NGPoP can reduce the investment infrastructure costs with sharing a large part of infrastructure for fixed and mobile Networks.

Another potential advantage of these innovative architectures is their efficiency regarding security enforcement. Indeed, whereas the current architectures require a hierarchical implementation, a more centralized approach can be deployed in the innovative architectures.

Likely evolutions of the applications required by the customers and associated service profiles imply that the capacity of aggregation links can reach for example 260Gbit/s, so an evolution of metro network and links aggregation capacity is needed.

Multi-criteria comparisons of these architectures need to involve specific models to better quantify QoS performances for the studied architectures. Furthermore, it requires developing dedicated models in the case of a convergent architecture like NGPoP. Costs and power savings analysis will have to be developed in order to really quantify, according to the different choices, the real CAPEX and OPEX gain of the considered architectures.

ACKNOWLEDGMENT

This work was partially funded by the FP7 European project COMBO (COnvergence of Fixed and Mobile BrOadband access/aggregation networks).

REFERENCES

[1] Cisco Visual Networking Index :Forcast and Metodology, 2011-2016, May 2012. http://www.cisco.com

[2] V. Flood, "Bandwidth a barrier for (Dis) connected TV in South Korea", February 2012. http://www.videoadnews.com/2012/02/13/bandwidth-a-barrier-for-disconnected-tv

[3] Recommandation ITU-T G.984, Gigabit capable Passive Optical Networks GPON , 2008.

[4] Recommandation ITU-T G.987, 10 Gigabit capable Passive Optical Networks XGPON, 2010.

[5] Recommandation ITU-T G.989, Next Genration Optical Acess Networks NGPON2, December 2012.

[6] A.Benner, "Optical Interconnect Opportunities in Supercomputers and High End Computing", OFC 2012Tutorial, March 2012.

[7] Y.Shimada, T.Sato, K.Ashizawa, T.Tokuhashi, D.Ishii, S.Okamoto, E.Oki, N.Yamanaka, "Study Of Scalable Dynamic Bandwidth Allocation In Optical aggregation Networks", Keio University, Chofu Electro-communications University, Japan [Technical reports IEICE PN October 2011].

[8] Technical annex of COMBO project, January 2012.

[9] NTT's perspective for NGPON2, NTT Access Service Systems Laboratories, April 2012.

[10] H.Takeshita, Daisuke Ishii, S.Okamoto, E.Oki, N.Yamanaka, "Highly Energy Efficient Layer-3 Network Architecture Based on Service Cloud and Optical Aggregation Network", IECE Trans. Commun.,Vol.E94-B, NO.4 April 2011.

[11] T.Sato, K.Ashizawa, K.Tkuhashi, D.Ishii, S.Okamoto, E.Oki, N.Yamanaka, "A Study of Slot Switching-based All-optical Service Aggregation Network", Keio University, Kanagawa, Japan, iPOP 2011.