Revisiting Access and Aggregation Network Architecture

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Abstract. Optical technologies allow the end-user to take advantage of a very high bitrate access. This in turn modifies traffic patterns to be supported by access and aggregation (metro) networks. The present paper first proposes tentative traffic scenarios to assess future capacity requirements for these networks. It is shown that the current aggregation architecture based on primary and secondary aggregation rings should be reconsidered to limit potential bottlenecks and to take account of both infrastructure costs and potential energy savings. The paper then presents alternative architectures to revise and move the boundaries existing today between access and aggregation networks. A first alternative architecture is fully centralized and performs traffic aggregation in a central location. The second alternative architecture proposes to locate the first aggregation points (called “Next Generation Points of Presence”) on the primary aggregation ring and to centralize control functions.

Keywords: Aggregation Network, Bottlenecks, Next Generation PoP.

1 Introduction

The development of video services such as 4K, High Definition (HD+) Internet Protocol Television (IPTV) and of personal services, together with the multiplication of terminals and virtualization of in-network-storage [1-2] leads to a significant increase of bandwidth demands.

The introduction of Fiber To The Home (FTTH) technologies allows fulfilling these demands in the access network segment. Gigabit-capable Passive Optical Network (G-PON [3]) presents a first answer. Future 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 currently being discussed both in Full Service Access Network (FSAN) and International Telecommunication Union (ITU).

The deployment of optical access technologies enables revising the current access local loop linking the Optical Line Termination (OLT) (located at the Central Office, or CO) to the Optical Network Units (ONUs) located at customers' premises. With no impact on delivered bandwidth, the distance between an ONU and its OLT can indeed be made as large as 60km which is significantly larger than the current distance between customers and CO in legacy DSL access networks. This allows reducing the number of COs while increasing the number of customers per OLT or in other terms, increasing customers' concentration in CO [6].

OLTs nowadays present high customers' aggregation capacity (16000 customers per OLT is common with currently available equipment). This could lead to traffic bottlenecks when the ratio ρ of the capacity of output interface to the sum of all input links' capacities is small. Such bottlenecks could in turn lead to QoS degradations such as packet losses, excessive delay, and jitter degradation.

This article discusses likely evolutions of aggregation and access networks' architectures, and uses ρ to quantify the probability of bottlenecks occurrence.

Section 2 introduces a practical dimensioning method for aggregation networks while Section 3 describes access network architecture migration, from DSL access to optical access. Section 4 studies how the current dimensioning method will evolve depending on traffic evolution assumptions. Section 5 proposes two alternative architectures, which take advantage of potential technical advances. Section 6 describes a qualitative multi-criteria (energy efficiency, cost optimization, protection and fixed/mobile convergence features) comparison of theses architectures. Some preliminary conclusions are given in Section 7.

2 Dimensioning aggregation networks

As traffic is bursty, users are allowed to send traffic at high peak rate, although the mean offered traffic per user is quite modest. Operators have always taken advantage of this when dimensioning their network, a famous example being the phone network being dimensioned thanks to the Erlang formula. This principle has been applied to the dimensioning of residential broadband networks. A practical tool is used in [7] to derive the capacity of "aggregation links". The "aggregation link" is the first link that (de)multiplexes the traffic from (respectively to) a large number of residential users, with identical traffic profiles, that access the aggregation network by a given DSLAM or OLT.

The approach in [7] considers an "equivalent bandwidth" per subscriber, where the downstream equivalent bandwidth is typically larger than the upstream equivalent bandwidth for a residential user. Computing an equivalent bandwidth per subscriber facilitates dimensioning aggregation links.

Equivalent bandwidth is computed thanks to two traffic models, which take account of traffic fluctuations at two time scales. Model 1 (packet level) assumes that traffic is stationary and that packets arrive according to a Poisson process. Model 2 (flow level) follows a Gaussian approximation for the distribution of the aggregate flows of each service. The traffic corresponding to each unicast or multicast service is characterized by its bit rate and a related activity rate. The bit rate of each service is assumed to be constant while the activity rate a_r, defined as the ratio between the number of flows for this service during the peak hour and the potential number of customers, may vary. The tool also relies on 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. The interested reader is referred to [7] for details.

3 From DSL to optical access networks

This Section first describes the current network architecture used in France, by Orange, in its network dedicated to residential customers. It then focuses on optical access equipment, their potential evolution and derives their aggregation capacity. Dimensioning results presented here are based on the dimensioning policy currently used in the legacy DSL access network.

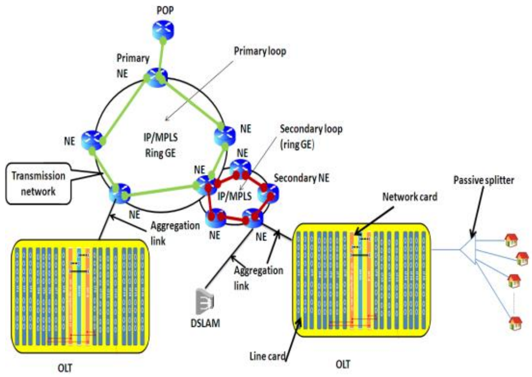

Fig. 1: Reference Network Architecture (Aggregation/Access)

Fig.1 represents a network architecture that is commonly deployed in the aggregation and access network segments. The access network is composed of access links (either copper or fiber based) and Digital Subscriber Line Access Multiplexers (DSLAMs) or OLTs. The aggregation network is composed of secondary and primary loops (Gigabit Ethernet rings) deployed on MPLS architectures.

3.1 Dimensioning aggregation links

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.

The current traffic profile for a residential DSL access in the Orange network yields an equivalent bandwidth close to 2 Mbit/s. A DSLAM's aggregation link can be carried by two links of capacity 1 Gbit/s, which yields, for a primary NE, a total number of 140 (1 Gbit/s) aggregation links.

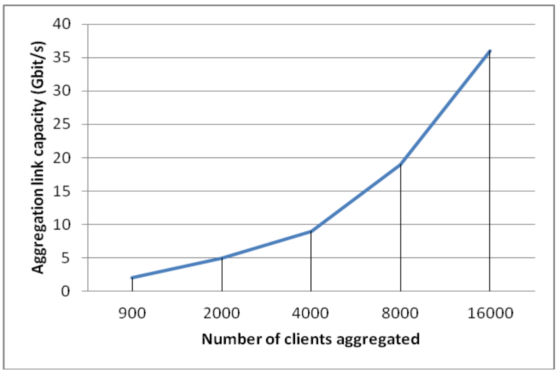

Fig. 2 : Aggregation link capacity versus number of customers under current traffic hypothesis.

Considering a 2 Mbit/s equivalent bandwidth per subscriber for an optical access architecture would yield a higher capacity for the aggregation link since the number of users served by a given OLT is significantly larger than the one served by a DSLAM. Fig. 2 illustrates the relationship between the number of customers per OLT and the aggregation link's capacity per OLT assuming an equivalent bandwidth equal to 2 Mbit/s. For 16000 customers per OLT, Fig.4 shows that the requested aggregation link capacity would be 36 Gbit/s per OLT, which can be provided by four 10Gbit/s links. Only 4 OLTs would then be required to aggregate the 64000 customers linked to the primary ring by a given NE, with only sixteen links (10 Gbit/s) between the OLTs to the NE. This is to be compared with the 140 (1 Gbit/s) used in the typical DSL case..

3.2 Assessing potential bottlenecks

The G-PON (respectively XG-PON1) technology allows aggregating up to 128 ONUs (respectively 1024). Upstream traffics from these ONUs are passively aggregated by a splitter, and access the OLT thanks to an upstream PON port.

A typical OLT equipment currently consists in a set of 4, 8 or 16 line cards equipped with several G-PON (or XG-PON1) ports with either one or two network cards. A line card perform an Ethernet aggregation of the total flows from the G-PON (or XG-PON1) upstream ports, while a network card aggregates the flows coming out of these line. OLTs are based on network cards offering uplink capacities of up to 80 Gbit/s and can aggregate up to 16000 customers.

The traffic flows coming out of network cards are subsequently aggregated first by secondary NEs and finally by primary NEs. Large capacity COs can also be directly linked to primary NEs.

The potential congestion points depend on the deployed technology (G-PON or XG-PON1). Potential congestion is assessed thanks to congestion ratio ρ. For an OLT, ρ is derived from the capacity of links in line cards (10 Gbit/s or 40 Gbit/s) and network cards (up to 80 Gbit/s), and from the number of G-PON or XG-PON1 ports

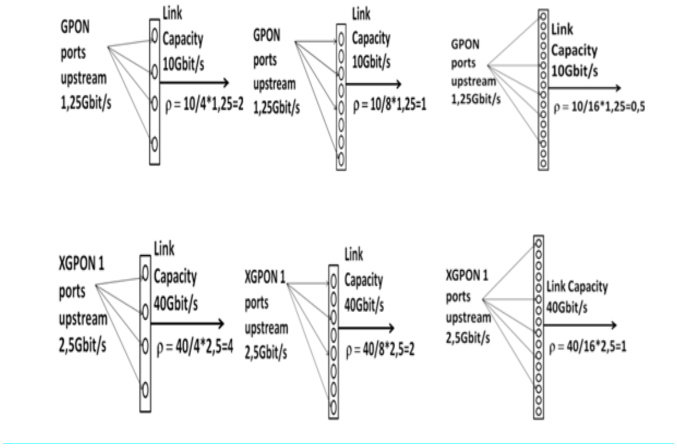

Fig. 3: Congestion Ratio for different types of line cards

Fig. 3 shows that the congestion ratio in line cards generally is almost 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 should not lead to congestion. On the other hand, Fig. 4 depicts that contention is possible within network cards as ρ can indeed be significantly smaller than 1.

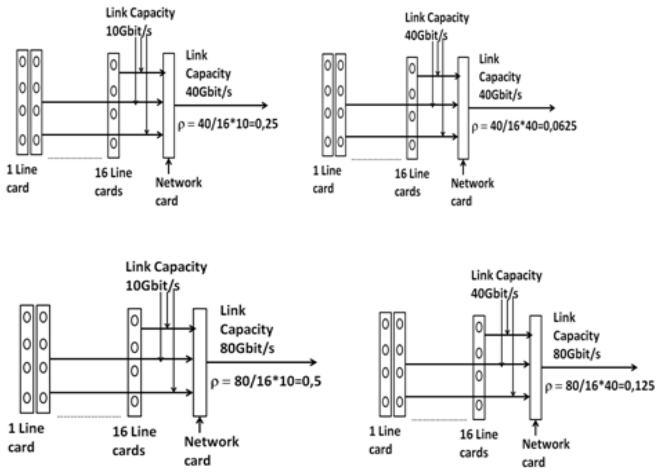

Fig. 4: Congestion Ratio for different configurations of network cards

4 Traffic evolution scenarios

This section describes how the equivalent bandwidth could evolve in the future. Scenarios are derived from traffic measures taken in 2012 on the Orange Network and on some hypotheses regarding customers' activity scenarios during peak hours [8] [9].

Table 1. Traffic characteristics for downstream and upstream multicast / unicast services.

		HBA hypothesis	VHBA hypothesis
Downstream	IPTV	85 TV channels, with 25% of HD+ channels and 75% of SD channels. Bit rate per SD channel is 2.8 Mbit/s and 16 Mbit/s per HD+ channel. A customer accesses at most 1 flow at a time. The average bit rate per IPTV flow is thus 6 Mbit/s	85 TV channels, with 90% of HD+ channels and 10% of SD channels. Bit rate per SD channel is 2.8 Mbit/s and 16 Mbit/s per HD+ channel. The average bit rate per IPTV flow is thus 14.75 Mbit/s. A customer accesses at most 3 flows at a time.
	Unicast video	1 SD flow coded at 2.8 Mbit/s	1 HD+ flow at 16 Mbit/s
	Internet data	0.5 Mbit/s	34.05 Mbit/s
	Unicast visio conference	N/A	5 Mbit/s
	Unicast VoIP and IPTV control	0.7 Mbit/s	0.7 Mbit/s
Upstream	Video per user	2.8 Mbit/s	4.2 Mbit/s
	Unicast VoIP and IPTV control	0.7 Mbit/s	0.7 Mbit/s
	Internet data	0.5 Mbit/s	10.1 Mbit/s
	Unicast video conference	N/A	5 Mbit/s

4.1 Traffic hypotheses and activity scenarios

Traffic hypothesis are as follows: the multicast service is IPTV, which generates multicast traffic in the downlink. The unicast service is the superposition of video distribution, VoIP and Internet access. It generates traffic in both uplink and downlink. We shall consider a High Bitrate Access (HBA) and a Very High Bitrate Access (VHBA). HBA (hypothesis A) corresponds to a downstream rate equal to 10Mbit/s and an upstream traffic rate equal to 4 Mbit/s. VHBA (hypothesis B) corresponds to a downstream rate equal to 100Mbit/s and an upstream traffic rate equal to 20 Mbit/s. Table 1 depicts traffic characteristics for downstream and upstream, multicast and unicast services, for both HBA and VHBA.

We propose 2 scenarios differing by customers' activity rate a_r (as defined in Section 2). Scenario 1 (resp. Scenario 2) is based on multicast service with $a_r = 1$ and unicast service with $a_r = 0.2$ (resp. $a_r = 1$).

4.2 Impact of traffic characteristics on aggregation capacity

We now apply the model described in Section 2 to derive the capacity of aggregation links under the various traffic evolution scenarios.

In the case of an OLT aggregating 16000 customers, **Fig. 5** and **Fig. 6** show that the requested downlink and uplink aggregation link capacities per OLT reach 21 Gbit/s (resp. 66 Gbit/s) in scenario 1 (resp. scenario 2) under HBA hypothesis. The NE that aggregates 64000 customers should thus support 84 Gbit/s (resp. 264 Gbit/s) in scenario 1 (resp. in scenario 2) with 4 OLTs, each OLT aggregating 16000 customers.

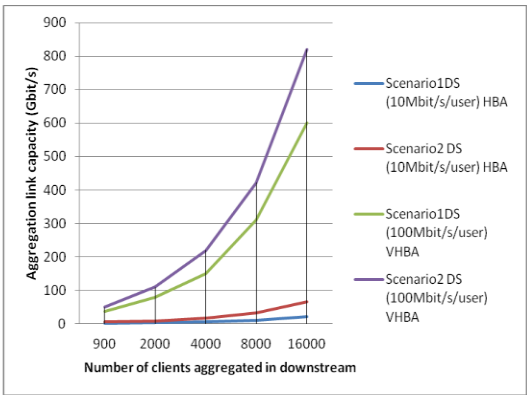

Fig. 5: Downstream Aggregation Link Capacity versus number of aggregated customers for 2 scenarios and 2 types of traffics.

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

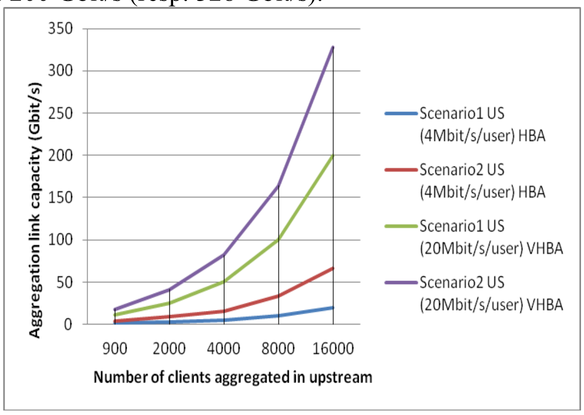

Fig. 6: Upstream aggregation link capacity versus number of aggregated customers for 2 scenarios and 2 traffic types.

For HBA and scenario 1, the total requested aggregation capacity per primary NE is similar to the current aggregation link capacity (140Gbit/s) obtained in Section 3.

However, supporting scenario 2 (with an overall higher activity rate of customers) implies to significantly upgrade aggregation link and aggregation networks. HBA with scenario 2 requires an aggregation capacity of about 260Gbit/s (as shown in **Fig. 5** and **Fig. 6**). For VHBA with scenario 2, the aggregation network has to support 3.28 Tbit/s (4 OLTs each supporting 820 Gbit/s) of downstream traffic (shown in **Fig. 5**) and 1.31 Tbit/s (4 OLTs each supporting 320 Gbit/s) of upstream traffic (shown in **Fig. 6**) for a single primary NE. This increase is mainly due to the increase of unicast traffic.

As the capacity of the links between NEs (inner metro links) is equal to 40 Gbit/s (4 wavelengths operating at 10Gbit/s), the congestion ratio between a typical OLT-NE aggregation link and metro links would then be in the order of 0.15 (ρ=40/260) for the HBA, scenario 2 case. In order to avoid the metro network becoming a bottleneck, the metro links' capacity should thus be upgraded, which can be done by adding a few 10 Gbit/s wavelengths to each metro link.

The congestion ratio would be even worse for VHBA with scenario 2: ρ=40/3280≈ 0.01 in downlink and $\rho \approx 0.03$ in the uplink. However, as current routers support at most 500Gbit/s interfaces, these values would imply operating a new generation of routers for metro network. These routers should support a high capacity of switching and interface (some Tbit/s), and present very powerful CPU.

4.3 Impact of traffic evolution on the core network gateway

The huge increase in traffic volumes identified above first implies replacing metro network NE routers by equipment with a switching capacity of several Tbit/s. Metro links' capacity should be increased similarly (considering e.g. a hundred 10 Gbit/s wavelengths). This directly impacts the core (backbone) network, and especially its gateway at the Concentration Node (CN) that aggregates traffic coming from all primary NEs. Interface bit rate and CNs' switching capacity should be increased, together with the capacity of the links between NEs and CNs.

5 Alternative architectures

With the current access and metro architectures, Section 4 has shown that traffic increase could imply both OPeration EXpenditures (OPEX) and CAPital EXpenditures (CAPEX) increase; moreover, supporting the high bit rates computed in Section 4 could also yield a sharp energy consumption increase.

We present here two classes of alternative access/metro architectures that are expected to (1) support data bit rates summarized by section 4 with a good QoS, (2) facilitate fixed/mobile convergence, (3) encompass efficient protection mechanisms and (4) present significant CAPEX and OPEX savings by reducing the operator's footprint and limiting energy consumption.

The first alternative is fully centralized, based on a "Service Cloud" and relies on a passive optical aggregation network [11] [13] [14]. There is a single CO (the CN). The second alternative is intermediate between the reference architecture and the fully centralized one, relying on a limited set of COs (located at primary NEs).

In both cases, the distances between subscribers' ONUs and CO are larger than those achieved in the reference architecture. Optical budgets can thus exceed 32 dB (maximum optical budget proposed by G-PON C+ class). A passive solution consists in limiting PON insertion losses by limiting the splitting ratio, at the cost of increasing fiber deployments. Active solutions rely on using Reach Extenders (RE), on "subtending" OLTs (small capacity OLT subtended by masters OLT) or deploying photonic aggregation architecture (e.g. [10]). The maximum distance between ONU and CO is 60 km for G-PON and 100 km for the other solutions.

5.1 Fully centralized architecture

Fig. 7 represents an architecture based on a "Service Cloud" and relies on an Optical Aggregation Network [13]. The Service Cloud is part of the backbone and consists in a very powerful Cloud Router associated to application servers. The "Service Cloud" has a very high capacity and supports the high traffic volumes computed in Section 4.

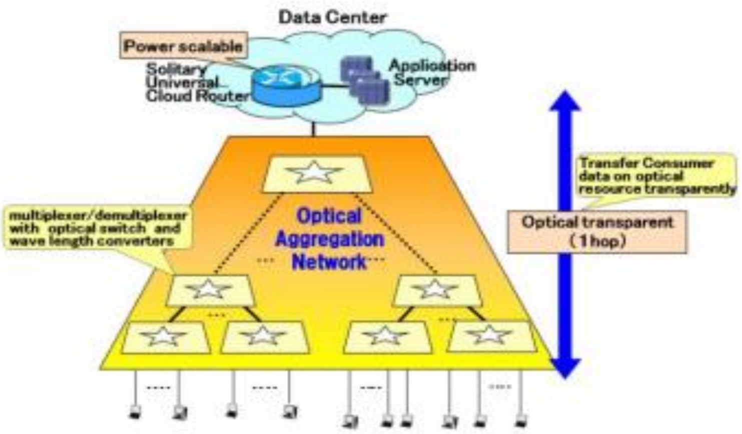

Fig. 7: Architecture based on a Service Cloud and on optical aggregation [13].

There is a seamless connection between the Cloud Router that performs IP aggregation and the final user via a single optical hop (aggregating layer 1 and 2) that combines WDM performed via Arrayed Waveguide Gratings (AWGs) and Time Division Multiplexing (TDM) based on optical switches [11]. Decreasing the number of hops should improve QoS and network performances by decreasing latency and jitter [13]. In this fully centralized architecture, the distance between CO equipment and ONUs is 100 km or more. Advanced Dynamic Bandwidth Allocation (DBA) algorithms have to be defined to take into account propagation delays up to 500 µs.

In a TDM configuration, one time slot is allocated to a technology type (GE-PON, G-PON, XG-PON1, Point-to-point link for Mobile backhauling and BBU hostelling, Synchronous Digital Hierarchy (SDH) interface…) 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 technologies. This fully centralized architecture allows managing a large number of heterogeneous customer profiles (residential, mobile, business) with different QoS profiles on a single platform.

5.2 Intermediate architecture

The intermediate architecture relies on the concept of Next Generation Points of Presence (NGPoP) [12]. A NGPoP is a central entity located at an NE and presents a high aggregation capacity and also centralizes control functions.

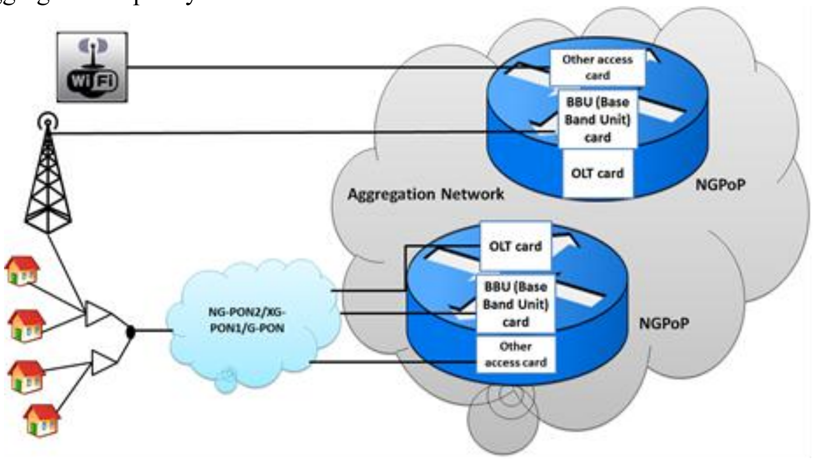

Fig. 8: Intermediate architecture based on NGPoP [12].

A typical intermediate architecture is shown in **Fig. 8**. Such an architecture has two objectives: on the one hand, it proposes to converge fixed/mobile access control and content distribution on the NGPoP; on the other hand, it offers a combined Ethernet and IP aggregation equipment that can control distant ONUs (up to 40km).

6 Multi-criteria comparison of legacy and alternative architectures

The present Section presents a preliminary, mostly qualitative multi-criteria comparison between reference, fully centralized and NGPOP based architectures.

6.1 Energy efficiency

As the fully centralized architecture does not require intermediate COs while relying on optical aggregation and a Service Cloud, it can really reduce power consumption. Compared to the reference architecture, energy savings of 90% [13] can be expected even with Tbit/s routers. In the case of NGPoP architecture, depending on the distance between ONU and CO, studies carried out in Orange labs indicate that it is possible to have energy savings of 40% (resp. 20%) for a distance of 100 km (resp. 20 km).

6.2 OPEX optimization

A fully centralized architecture allows reducing the number of COs by 95% [13]. For intermediate architecture, internal studies indicate that the CO reduction depends on the maximum distance between CO and user: for a 60km (resp. 100km) distance the CO reduction is 80% (resp. 90%). RE solutions such as described in Section 5 rely on power-supplied street cabinets. The gain in reducing the footprint in terms of CO number is thus partially counterbalanced by the cost of street cabinet equipment, although preliminary studies show that there is still some gain in terms of CAPEX.

6.3 Protection

The current architecture is protected only in the aggregation and core networks. The legacy access network is currently not protected due to the small number of customers connected per DSLAM/OLT. The aggregation network is first protected thanks to ring-based topologies. Moreover, several equipments (CN nodes, primary NE, network cards for large OLTs) are duplicated. The core network relies on nodes and inter-router link duplication, while in the nominal situation both parities are used in order to perform load sharing.

The intermediate architecture may require duplication of NGPoP elements, CN, CN/NGPoP links and NGPoP/final users links. As larger numbers of customers are connected to a single OLT, it is necessary to partially protect the access network by e.g. duplicating network cards. Moreover, if mesh networks replace rings, the native protection provided by rings is lost. In order to protect the fully centralized architecture, it is necessary to duplicate the Cloud Router and some optical links in the passive aggregation network. As both architectures reduce the number of aggregation stages present in the reference architecture, less duplication is required, which reduces complexity. But both architectures will require longer reach, therefore an additional cost [6].

6.4 Fixed/mobile convergence features

LTE networks are full IP: both voice and data services are carried over IP, relying only on packet switching (contrarily to 3G mobile networks that still rely on circuit switching for voice). However, mobile backhaul is currently tunneled through the wireline aggregation network, which both precludes function mutualization with the fixed network and limits multiplexing gain. As fixed (respectively mobile) access networks present 20% (respectively 22%) of total CAPEX, there is a strong incentive in converging fixed and mobile backhaul infrastructures. Both alternative architectures present strong cases regarding this type of convergence as they centralize control functions. Further analysis is needed in order to assess their respective capabilities.

6.5 Preliminary evaluation of the potential architectures

Table 2 recaps the above qualitative comparisons between reference, fully centralized and intermediate architectures. The preliminary analysis provided below shows that a fully centralized Cloud Service architecture presents some advantage according to the chosen criteria with respect to NGPoP, and that both alternative architectures are better, on all criteria, than the legacy reference architecture. However, technical feasibility, scalability and operational constraints need to be taken into account to better identify pros and cons associated to these alternative architectures.

Table 2. Qualitative evaluation of reference and future architectures.

Architecture Label	Reference Architecture	NGPoP	Service Cloud
Power saving	-	+	++
Costs optimization due to CO number reduction	-	+	++
Protection mechanisms complexity	-	+	++
Fixed/ mobile convergence	-	++	++

++: very good, +: good, -: bad, --: very bad

7 Conclusion

We have proposed several traffic evolution scenarios and derived from those scenarios capacity requirements to be supported by future access and aggregation networks. In particular, we have shown that likely traffic evolutions imply that the capacity of aggregation links could reach 260 Gbit/s, which is a strong incentive for revisiting the legacy aggregation architecture initially designed to support DSL access.

Building on these requirements, we have compared two alternative architectures: a fully centralized architecture and an intermediate, NGPOP based architecture. Both rely on optical technologies, which modify both access and aggregation segments by moving the boundary between these segments towards backbone gateways. The driving feature for these alternative architectures is provided by optical access technologies, which allow a high customers' concentration in the same OLT. This concentration naturally impacts on the possible CO reduction, which can reach 90% (resp. 95%) in the case of NGPoP deployment (resp. fully centralized architecture). CO reduction may however impact on multiplexing gain and thus on network performance and delivered QoS. Further study is thus required to confirm the preliminary results given in the present paper.

Selecting alternative aggregation architectures also promises a potentially important energy saving: 40% for intermediate and 90% for centralized architectures. Innovative architectures such as proposed here reduce investment infrastructure costs by supporting fixed/mobile convergence (sharing a large part of infrastructure costs and several control functions). Another potential advantage of these innovative architectures is their efficiency regarding protection. Indeed, whereas the current architectures require a hierarchical implementation, a more centralized approach can be deployed in the alternative architectures.

All the above conclusions are still tentative since quantitative multi-criteria comparisons of these architectures with the reference architecture should involve specific models to better quantify QoS performances for the studied architectures. Costs and power savings analysis will have to be enhanced in order to quantify, according to the different choices, the real CAPEX and OPEX gain of the considered architectures. Ongoing studies address all the above points.

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

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