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Multi-Criteria Comparison Between Legacy and Next Generation Point of Presence Broadband Network Architectures

Moufida Feknous[1, 2], Bertrand Le Guyader[1], Pal Varga[3], Annie Gravey[2], Stéphane Gosselin[1], Jose Alfonso Torrijos Gijon [4]

[1] Orange Labs, Lannion, France
feknous.moufida@gmail.com
bertrand.leguyader@orange.com
stephane.gosselin@orange.com

[2] Telecom Bretagne,
Technopole Brest-Iroise, CS 83818 Brest, 29238, France
moufida.feknous@telecom-bretagne.eu
annie.gravey@telecom-bretagne.eu

[3] Budapest University of Technology and Economics
Magyar tudosok krt. 2, Budapest, 1117, Hungry
pvarga@tmit.bme.hu

[4] Telefõonica I+D, Distrito Telefonica Building South 3
3rd floor Ronda de la Communicacion, s/n - 28050 Madrid
jose.torrijosgijon@telefonica.com

Abstract

Development of new applications and the introduction of innovative technologies can lead to revise network architectures in order to build sustainable broadband infrastructures. The present paper describes the main drivers and enabling technologies leading to change the current fixed and mobile network architectures. The limitations of the aggregation network are briefly shown by a description of the legacy network architecture. The advantages of optical access technologies are also depicted. In order to avoid certain bottlenecks in the aggregation segment, an advanced solution called Next Generation Point of Presence (NG-PoP) is presented. The main idea of NG-PoP architecture is to move the existing boundaries between access and aggregation networks. Finally, the NG-PoP architecture is analyzed and compared to the legacy network one according to several criteria such as Quality of Service (QoS), cost criteria, power savings and Fixed Mobile Convergence (FMC) features.

Keywords: *NG-PoP, QoS, cost, power savings, FMC.*

1. Introduction

These last years, network traffic drastically exploded because of the development of new applications and new use cases [1, 2]. Firstly, this behaviour is fostered by the introduction of optical technologies in fixed access networks, for example using Gigabit-capable Passive Optical Network (G-PON) [3]. Secondly, new services are proposed thanks to more and more evolved and powerful end-user devices. The massive deployment of optical fiber in the access segment can have a significant impact on aggregation capacity. Optical technologies give the opportunity to modify the local optical loop architecture as the distance between Central Office (CO) equipment and end-users can reach a few tens km (up to 60 km in the limit of available optical budget [3]). In addition, it is possible to concentrate a large number of customers in the same CO [4]. Moreover, this can lead to reduce the number of COs and to redefine current fixed network architectures by optimizing the CAPital EXpenditures (CAPEX) / OPerational EXpenditures (OPEX). Furthermore, it is the opportunity to study these new architectures with a focus on a convergence of fixed and mobile networks thanks to the introduction of Base Band Unit (BBU) hostelling technology in the new generation of Long Term Evolution (LTE) networks. The mobile network architecture is highly centralized and does not appear suitable to efficiently absorb the data bit rate increase. In order to avoid bottleneck-issues due to a centralized traffic in core mobile elements, such as Packet Data Network (PDN) Gateway (PGW) and Serving Gateway (SGW), it could be conceivable to distribute SGW and PGW functions and to locate them in a CO closer to the end-users, thus reducing the end-to-end latency and allowing savings of transport resources within the mobile core network, i.e. the Evolved Packet Core (EPC). The wide deployment of the previously mentioned technologies allow great advances. This paper is focusing on the improvements obtained by introducing a new setup called Next Generation Point of Presence architecture, which includes revising the boundaries between the access and aggregation network segments. In a previous work [5], some modifications of today's architecture (legacy architecture) was proposed. The discussion there included a qualitative comparison of the legacy architecture with highly centralized and medium centralized architectures. The rest of this paper is organized as follows. Sections 2 and 3 detail the key elements – drivers and technological enablers – motivating the evolution of the legacy network architecture. Later, section 4 describes the legacy and Next Generation Point-of-Presence architectures. Next, section 5 gives a detailed quantitative multi-criteria comparison of these architectures based on QoS performances, investments and power consumption optimization. Finally, some conclusions are given in section 6.

2. The main drivers leading to revise today's broadband network architecture

The present section shows the motivations to revise and move the boundaries existing today between access and aggregation networks. First, a general overview of current drivers for motivating the architecture evolution are summarized. Next, an insight is given on a detailed analysis of real traffic data coming from two major European operators, with an emphasis on use cases driving fixed and mobile networks convergence.

2.1 Drivers for traffic growth and architectural change

A massive growth of fixed and mobile traffic has been observed for several years – and this trend will continue in the following years [1, 2]. Generally, the traffic growth is due to three factors: (i) availability of new, interesting and/or useful services, (ii) advanced capabilities of end-user devices, and (iii) the growing user demand of utilizing these. The limited set of managed services like IPTV enables the use of well controlled rules for network dimensioning – but this is not the case for general, "best effort" Internet traffic. Due to the ever-increasing success of newly deployed services and applications, the best-effort Internet traffic represents a significant growth in the recent years [1]. A close attention given to customer's usage is mandatory to make accurate forecasts in order to avoid future network bottlenecks. To underline this, in the next sub-section we present an overview of real Internet traffic captured on fixed (xDSL, FTTH) and mobile networks of Orange France and Telefõnica operators.

2.2 Analysis of real Internet traffic data provided by two major European operators

An analysis of real traffic data provided by two major European operators in 2013 [6] shows that whatever the operator and the access network type (FTTH, xDSL), Peer to Peer (P2P) and video streaming are the application types that mainly constitute the traffic [6].

In downstream direction, video streaming is the main application generating most of the traffic and also contributes with the same proportion (between 30% and 40%) to the total volume generated by fixed (xDSL, FTTH) and mobile customers. Mobile customers use the Wi-Fi interface embedded in their mobile device more and more. This behaviour impacts the traffic data profiles of fixed networks. The Compound Annual Growth Rate (CAGR) of downstream average traffic volume generated by Orange mobile customers using Wi-Fi access was +56% in the 2011-2013 period. In the same time, the number of customers using their mobile devices in fixed access networks increased by 38%.

Cisco VNI studies [7] showed that in 2012, 33% of total mobile data traffic was offloaded onto the fixed network through Wi-Fi or femtocell. Video streaming is commonly used at the same time over fixed and mobile networks - and became one convergent application. In other words, it could be handled, routed by using some kind of common policies. The offloading and a convergent usage mode conduct to provide a solution such as a convergent fixed and mobile network architecture. FMC allows to manage traffic more efficiently and to offer more capacity to the users through a common access and aggregation network segment [8].

3. Technologies enabling and evolution of broadband network architecture

In this section, technological enablers like optical access technologies, the concept of BBU hostelling and fixed mobile convergence features are described. More and more, network functions aim at being reorganized in the network and a particular focus is on Software Defined Networking (SDN) and Network Function Virtualization (NFV). In order to optimize content distribution in the network, a particular attention will be given to caching in Content Delivery Networks (CDN).

3.1 Optical Access Technologies

The introduction of FTTH technology allows to satisfy the strong increase of the traffic expected over the coming years in fixed access networks. Gigabit capable Passive Optical Network (G-PON [3]) is a first answer to this problem. Future generations of optical access technologies such as 10 Gigabit-capable Passive Optical Network (XG-PON1 [9]) and Next Generation Passive Network (NG-PON2 [10]) have been proposed, as well. This latter is currently under discussion at the Full Service Access Network (FSAN) Group [5] and International Telecommunication Union (ITU). Deploying optical access technologies makes possible to modify the access loop. Optical access systems link the Optical Line Termination (OLT) (located at the central office, or CO) to Optical Network Units (ONUs) located at customers' premises. The distance between an ONU and its OLT can be as large as few tens km depending on PON flavor and implementation, with no practical impact on delivered bandwidth. This optical reach is significantly larger than the current distance between customers and CO in legacy DSL access networks (typically 5 km). This allows reducing the number of COs while increasing the number of customers per OLT, or, in other terms, increasing customers' concentration in CO [5]. In order to further decrease the operational cost, this CO consolidation might be combined with BBU hostelling [11] described by Figure 1 which represents the mobile fronthaul architecture. This concept consists in separating the equipment in charge of the antenna traffic aggregation (BBU) from the Remote Radio Head (RRH) located near to the antenna and connected by an optical fiber to the digital processing unit in the BBU. The practical distance between the BBU and the RRH can reach up to 40 km. The BBUs of different base stations can be pooled and collocated in the same CO with an OLT. This concept called BBU resource pooling concept or C-RAN (Cloud Radio Access Network) are depicted by Fig 1. This technology allows to share the BBU resources between multiple RRHs and also to simplify the backhaul network by reducing the number of X2 interfaces [11, 12] as well as the bandwidth of the S1 interfaces [13]. This type of technology represents an interesting solution for LTE and LTE-A (Long Term Evolution-Advanced) with respect to delay, jitter, protection (e.g. BBU located in a CO), flexibility and scalability [14]. So the co-location of fixed and mobile equipment in the same CO (refer to Figure 2) yields a basic structural convergence of fixed and mobile network architectures by sharing the equipment shelves in the CO [8].

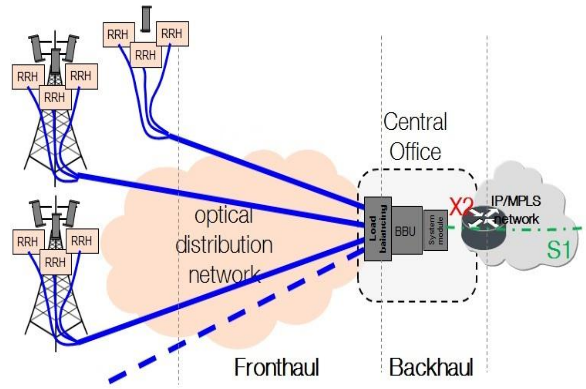

Fig. 1 BBU hostelling resources pooling concept [9]

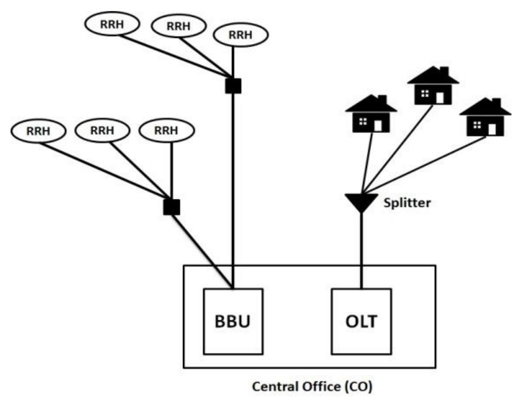

Fig. 2 Example of structural fixed and mobile convergence

3.2 Fixed Mobile Convergence features

Up to now, fixed and mobile networks have been conceived and evolved independently from each other. A first change came with LTE network architecture, which was designed to fully rely on IP-based traffic, both on the control, and the user plane. This means that both voice and data services are carried over IP and are based on packet switching (contrary to 3G mobile networks that still rely on circuit switching for voice), which may initiate the change towards FMC network architectures. The common routing and transport protocols are also enablers of the FMC network architecture. However, mobile backhaul is currently tunnelled through the wireline aggregation network, which both precludes polling of functionalities with the fixed network and a limitation of multiplexing gains [5]. The only convergence existing today is thus mainly at the service level with all IP services and IP Multimedia System (IMS) [15].

3.3 Software Defined Networking and Network Function Virtualization

Current networks are structured and implemented in a distributed way. In each network node, there is a network device which makes forwarding decisions locally based on its configuration and information collected in its neighborhood through some protocols as Open Shortest Path First (OSPF) or instead, Border Gateway Protocol (BGP). This network concept may change with the advent of SDN. This new concept consists in the separation of the control and data plane, centralizing the control plane and making it programmable via control applications. The SDN controller is the software logical centralised entity running on servers and is responsible of forwarding states to realize the network operators' goals. SDN controller has a global view of the physical network (e.g. forwarding devices, links) [16]. The FMC architecture using SDN can allow the simplification of the protocol architecture by reducing a number of protocols used (e.g. Point to Point protocol (PPP) in fixed networks and GPRS Tunnelling Protocol (GTP) in mobile networks). The second way which allows to change the historical architecture is the introduction of Network Function Virtualization (NFV). It permits to implement network functions as software running on standard hardware located in network nodes and data centers [17]. The NFV approach can decrease the need for installing new physical equipment. SDN represents an advantage for future network architectures, by using a single control protocol for multiple simple network devices. Also, NFV brings the required flexibility to encompass the various functions in an effective way into such nodes. This concept targets structural convergence on infrastructure and system level. It can ultimately lead to IP edge functional convergence with the definition of a generic IP edge functional entity used by any type of networks [8].

3.4 Software Defined Networking and Network Function Virtualization

Content Delivery Network (CDN) is an overlay network that supports special (better performance) routing and content delivery. This technology allows to deliver the contents from its providers to a set of users. Caching in CDN consists of implementing a set of servers in different segments of the network (customers premises, access, aggregation and core networks) to replicate content and facilitate its delivery to end users (refer to Fig. 3) [16].

CDNs can be used to avoid bottlenecks in a peering link, and to reduce traffic in different segments of the network. Deploying a CDN cache in the network may allow to maintain the QoS and Quality of Experience (QoE) in the era of continuously growing bandwidth demand of the end-user [17, 18, 19]. CISCO study [7] shows that in 2017 the traffic generated through CDN will represent half of the global Internet traffic (about 51%). The analysis of real Internet traffic data results shows a strong similarity of usage between fixed and mobile customers. Video streaming services generate most of the traffic and contribute with the same proportion (between 30% and 40%) to the total volume generated by fixed and mobile customers. This characteristic could drive to use of a convergent fixed and mobile CDN cache [18] in future FMC architectures, as proposed in Figure 3.

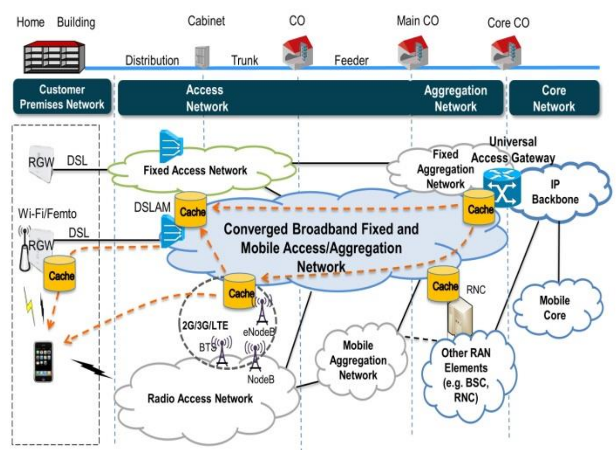

Fig. 3 Architecture overview of FMC unified Content Delivery [18]

4. From legacy to NG-PoP broadband network architecture

The present section starts with the high-level description of today's fixed and mobile network architectures (legacy architecture). Traffic growth (hypotheses towards 2020) and the increasing number of customers per CO are going to introduce certain limitations (which are also discussed below) in current fixed network architecture. Finally a possible evolution towards NG-PoP architecture is presented.

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4.1 Fixed network architecture

Figure 4 depicts current fixed access and aggregation network architectures deployed by Orange and dedicated to residential customers. With the fixed access network, the Triple Play services delivered to final users are carried over either copper or fiber access technologies. Digital Subscriber Line Access Multiplexer (DSLAM) and OLT are the main elements which constitute this segment. The access segment performs some functions such as connectivity of several subscribers to the network and the transport of traffic between customers' premises and the aggregation network [8, 20]. The aggregation segment is composed of secondary and primary loops (currently: Gigabit Ethernet rings) deployed on an Ethernet/ Multi-Protocol Label Switching (MPLS) architecture [5]. The aggregation network allows to aggregate the traffic of several access network domains and the layer 2 forwarding is done mostly using Ethernet. So, this segment is a gateway for fixed access services. Other functions are performed in this segment like QoS management and traffic policies [20].

The link capacity between access and aggregation networks (the "aggregation" link) typically reaches 2 Gbit/s. A primary Edge Node (EN) aggregates at the most 64000 customers while a DSLAM connects an average of 900 Triple Play customers. This corresponds to an average of 70 DSLAM per primary EN (equivalent to 4 OLTs per EN, each OLT aggregating up to 16000 customers) [5]. The core network has in general a mesh topology and is based on IP/MPLS and Optical Transport Network (OTN) technologies. The core segment performs some functions like user voice calls management, user data traffic routing to the Internet, TV content distribution, user management, policy and charging, lawful interception, network monitoring and management [20]

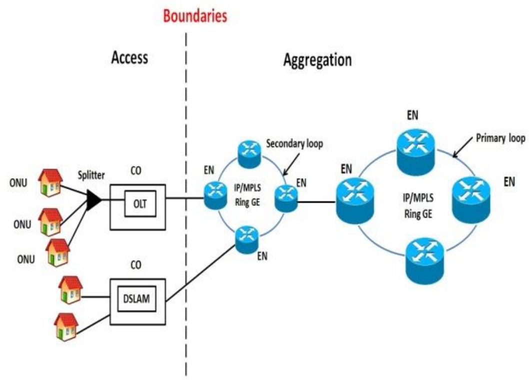

Fig. 4 Today's fixed network architecture [5]

4.2 Mobile network architecture

Figure 5 describes the end to end mobile network architecture. Radio Base Station (RBS) represents the main element of mobile access network. Each generation of mobile network provides different radio access stations, like Base Transceiver Station (BTS) for 2G, NodeB and evolved NodeB (eNodeB) for 3G and LTE respectively. The mobile access network performs various functions including presence handling of the User Equipment (UE) and transport of the UE communications [20]. Base Station Controller (BSC) in 2G and Radio Network Controller (RNC) in 3G constitute the main elements of the aggregation network. In LTE, this functionality is part of the access network in eNodeBs, which means that the LTE architecture is more flat and simple than in previous generations (2G and 3G) [20]. The main function performed by the mobile aggregation network is the aggregation and transport for the mobile traffic of a large number of subscribers. The mobile traffic is typically tunnelled through the aggregation network that was built up for the fixed broadband access [20]. The aggregation could be achieved via several levels and with various protocols like Ethernet, MPLS and IP. The main elements of the mobile core network are Mobile Management Entity (MME), Serving Gateway (SGW) and Packet-Data Network Gateway (PGW) for 4G. MME entity is used for handling the control plane, whereas SGW / PGW for data plane. Voice call switching, data access gateway, user management, policy and charging, network monitoring and management [8] [20] are the main functions performed by the mobile core network. In order to connect to other networks, all access and aggregation networks (fixed, mobile and Wi-Fi) are generally connected to a common IP/MPLS backbone network.

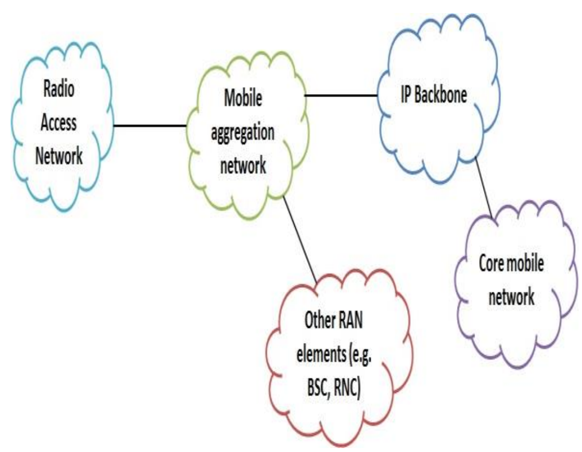

Fig. 5 Today's mobile network architecture [20]

4.3 Impact of bit rate increase on aggregation capacity in optical access network

CISCO VNI study shows that traffic increases more dramatically in metro segment (aggregation) than in other network segments. In 2012, the global aggregation traffic was 1.8 times higher than core network traffic – and will continue to grow towards 2017 [1]. Bell Labs study also shows that towards 2017 metro traffic will grow twice as fast as traffic going into the core network [21]. Also, in the next years, several reports show that the mobile data traffic will grow faster than fixed data traffic. Also in 2013 was forecasted that mobile data traffic will continue to double each year [1]. Despite this increase in mobile network, fixed data traffic is 10 times higher than mobile data traffic [22]. It is a driver for change – and this is why we include a study here about the impact of fixed traffic evolution on aggregation capacity. In order to dimension the aggregation network, we used a tool based on Erlang formula applied for residential broadband networks [23].

Two traffic hypotheses are proposed. Hypothesis 1 (H1) represents a downstream rate per customer equals to 10 Mbit/s and upstream rate equals to 4 Mbit/s. Hypothesis 2 (H2) represents a downstream rate equals to 100 Mbit/s and upstream rate equals to 20 Mbit/s. With H1, traffic characteristics for downstream multicast and unicast services are the following:

- IPTV: 85 TV channels, with 25% of "HD+ (High Definition (HD) and higher)" channels and 75% of Standard Definition (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.

- Unicast video: 1 SD flow coded at 2.8 Mbit/s, • Unicast VoIP and IPTV control: 0.7 Mbit/s, • Internet data: 0.5 Mbit/s.

The corresponding upstream service characteristics are the following:

- Upstream video per user: 2.8 Mbit/s,
- Unicast VoIP and IPTV control: 0.7 Mbit/s,
- Internet data: 0.5 Mbit/s.

With H2, traffic characteristics for downstream multicast and unicast services are the following:

- IPTV: 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 HD+ flow at 16 Mbit/s,
- Unicast VoIP and IPTV control: 0.7 Mbits/s,
- Unicast visio conference: 5 Mbit/s,
- Internet data: 34.05 Mbit/s.

The corresponding upstream service characteristics are the following:

- Unicast video per user: 4.2 Mbit/s,
- Unicast video conference: 5 Mbit/s,
- Unicast VoIP and IPTV control: 0.7 Mbit/s,
- Internet data: 10.1 Mbit/s.

Each traffic hypothesis contains two traffic scenarios which depend on activity rate parameter, ar, which represents the ratio between the number of flows of service used and the potential number of customers. Scenario 1 corresponds to ar=1 for multicast services and ar=0.2 for unicast services. Scenario 2 corresponds to ar=1 for both unicast and multicast services. For more background details of the scenarios and the experiment please refer to [5]. Figures 6 and 7 show the capacity of aggregation link corresponding to traffic evolution scenarios and according to the number of customers concentrated in the same OLT.

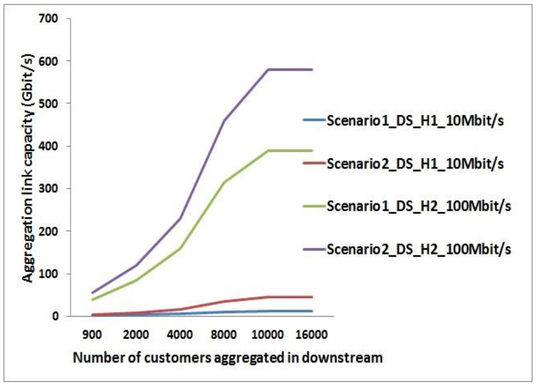

Fig. 6 Downstream aggregation link (EN→OLT) capacity versus number of customers per OLT for H1 and H2 with different value of ar

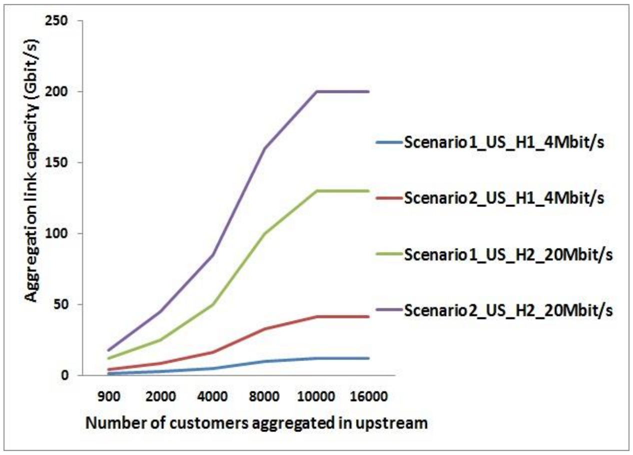

Fig. 7 Upstream aggregation link (EN→OLT) capacity versus number of customers per OLT for H1 and H2 with different value of ar

For H1 and in the case of 16000 customers aggregated in the same OLT, the required uplink capacity of aggregation link between OLT and EN is 12 Gbit/s (resp.41 Gbit/s) in scenario 1 (resp.scenario 2). The network Edge Node (EN) aggregates up to 64000 customers must support an uplink capacity of 48 Gbit/s (resp.164 Gbit/s) in scenario 1 (resp. scenario 2). In downstream direction and in the case of H1, the EN requires the aggregation capacity of 52 Gbit/s and 180 Gbit/s in scenario 1 and 2 respectively. Currently primary EN aggregates 70 DSLAM and the capacity of each aggregation link shall be equal to 2 Gbit/s. So, for H1, the aggregation capacity required by EN is close to the current aggregation link capacity"140 Gbit/s". For H2 and upstream direction, the EN must support an aggregation capacity of 520 Gbit/s and 800 Gbit/s in scenario 1 and scenario 2 respectively; whereas in downstream direction, each OLT supports 390 Gbit/s and 580 Gbit/s in scenario 1 and 2 respectively, as shown in figures 6 and 7. In this case, the EN which aggregates 4 OLTs should support the aggregation capacity of 1.56 Tbit/s and 2.32 Tbit/s in scenario 1 and 2 respectively. In the current study [5], the link between ENs (inner metro link) represents a capacity of 40 Gbit/s (4 wavelengths, each wavelength has a capacity of 10 Gbit/s). In order to quantify the congestion in aggregation network, we use ρ parameter, which represents the ratio between the capacity of output link or interface and the sum of input traffic. The congestion appears if ρ is less than 1. In the case of H2 and scenario 1, the congestion ratio between aggregation (the link between OLT and EN) and metro links is ρ=0.07 (40/520) in uplink and ρ=0.02 (40/1520) in downlink.

The congestion ratio is worse in scenario 2, ρ=0.05 in uplink and ρ=0.01 in downlink. With respect to such hypotheses scenarios, and to avoid any congestion in the aggregation network, it would be necessary to replace the current routers deployed in aggregation network (current router supporting a switching capacity of 500Gbit/s) by new generations that support a higher switching and interface capacity (some Tbit/s). Capacity of metro links also should be increased (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 ENs. Interface bit rate and CNs' switching capacity should be increased, together with the capacity of the links between ENs and CNs. Still, as mentioned earlier, this rule-of-the-thumb congestion metric does not take the distribution of access bandwidth requests in time and volume – into account. Nevertheless, as the endpoints are always-on (with 3G and LTE), and continuous high-bandwidth requests are common (e.g. people using video services to listening background music), link utilization is getting higher and higher. So in order to respond to a huge increase in traffic volumes discussed above, and to avoid congestions in various network segments, we need to propose a sustainable architecture allowing scalability, reducing the number of equipment, cost and allowing power savings.

4.4 Next Generation Point of Presence architecture

In this section we present an alternative architecture for access/aggregation network. The idea is to move the existing boundaries between access and aggregation networks – and to propose another distribution of some functionalities. This architecture includes a central function located in the Network EN. The aim of this new architecture is to integrate different physical access, networking and service functions into a single location called NG-PoP. The NG-PoPs are more centralized in the network than Central Offices, and are typically located at the level of ENs. The NG-PoP entity can host the functions of mobile network as SGW and PGW. The concept of NG-PoP aims at improving functional and structural fixed/mobile convergence.

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The functional convergence consists in emerging fixed and mobile functions and optimizing the location of these functions (e.g. distribution of PGW function allows to reduce the load in core mobile network, distribution of Content Delivery Network improves the QoS, collaborations between different access technologies and unified control plane offer a better use of network resources). Structural convergence means to put fixed and mobile equipment in the same entity and to share the infrastructures between fixed/mobile networks (e.g. BBU hostels and OLT hosted in the same CO and sharing the same equipment and fiber in the case of NG-PON2) as shown in Figure 8.

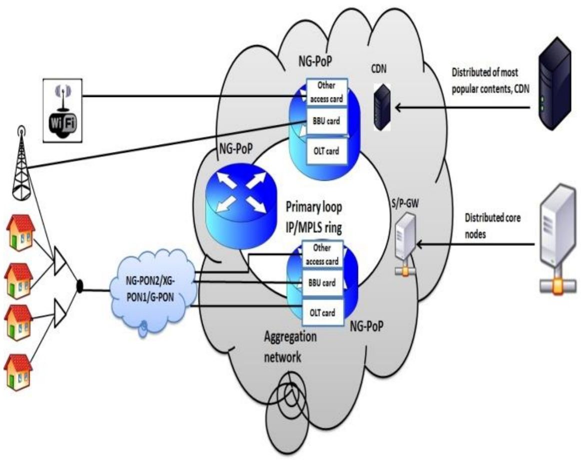

Fig. 8 Next Generation Point of Presence Architecture [15]

5. Multi-criteria comparison between legacy and NG-PoP architecture

This section compares legacy and NG-PoP based network architectures in terms of QoS, OPEX, CAPEX and FMC.

5.1 Quality of Service

In this sub-section the simulation and experimental results are presented in order to show the quantitative comparison between legacy and NG-PoP architecture. The QoS represents one of the key parameters which assesses the performances of new architectures (e.g. NG-PoP). End-to-end QoS depends on several parameters (latency, jitter, and bandwidth) [24] and different segments of the end-to-end network architecture (access, aggregation and core networks) [25]. Our comparative study is only based on latency. This parameter represents the time between transmitting packet from a source and the reception by its destination. The latency parameter depends on propagation time (according to transmission media), the processing time and packet size [25]. The comparison between legacy and NG-PoP consists in analysing qualitatively a downstream direction of traffic (from network to end-users), whereas, in upstream direction, we choose OPNET simulator to evaluate the access and aggregation segments. Many reasons led us to simulate only the upstream direction of the traffic, among them: the results performed in [6] show that the ratio between downstream and upstream users' traffic volume is more symmetrical (ratio of 1.9) compared to ADSL (ratio of 5.7). Also some FTTH customers are becoming P2P server (3% of FTTH customers generate 80% of the total traffic) because of increased performances and capacities of the upstream channel in FTTH access networks. In order to quantify the legacy and NG-PoP architectures, we simulate the main multiplexing upstream function of the access networks which is the Dynamic Bandwidth Allocation (DBA), also these results are confirmed by experimental test. This function represents the first multiplexing level in upstream access network. Additionally, we take into account the increasing delay (propagation) related to increasing range between ONUs and OLT. In aggregation segment, we simulate the propagation delay (range) and processing delay (according to the number of equipment crossed in this segment). The simulation in aggregation segment does not take into account the waiting delay in queues or the waiting delay introduced by the congestion. In downstream direction, we choose to evaluate qualitatively the traffic load in different segment of legacy and NG-PoP architectures through the traffic evolution and the applications generating most of the traffic. Additionally, this analysis is tied to QoS parameters. The reduction of traffic load in different segments of the network contributes to improve the QoS (e.g. reduce or eliminate the waiting delay in queues, reduce packet loss ratio or avoid bottlenecks).

5.1.1 Simulation results of DBA

The upstream channel of Passive Optical Network is based on DBA. The DBA is managed by the OLT and guarantees different levels of QoS per flow thanks to Traffic CONTainer (T-CONT) as defined by ITU-T.G.984.3 [3]. A T-CONT, identified by an Alloc-ID allows different G-PON Encapsulation Method (GEM) flows of an ONU to be aggregated in the same class of service. The properties of this T-CONT are defined by a Committed Information Rate (CIR), Assured Information Rate (AIR) and Excessive Information Rate (EIR) specified in the customer Service Level Agreement (SLA).

CIR: represents the fixed bandwidth allocated to T-CONT1. T-CONT1 service is based on unsolicited periodic permits granting fixed payload allocations. This T-CONT is supported by the applications with Constant Bit Rate (CBR) such as the applications with strict demands for throughput, delay, jitter and PLR [27]. This static T-CONT is not serviced by DBA. The bandwidth allocated to this T-CONT cannot therefore be increased neither used by another T-CONT if bandwidth is not used [26]. AIR: represents the bandwidth allocated to T-CONT2 and 3. These TCONTs are characterized by Variable Bit Rate (VBR) traffic [27]. The bandwidth allocated to these T-CONTs can be increased and used by another T-CONT if bandwidth is not used [27]. EIR: represents the maximum bandwidth authorized by the OLT. This bandwidth is generally allocated to T-CONT3 and 4. ITU-T.G984.3 defined 5 TCONTs types associated to different classes of service. The OPNET model contains only the MAC modules implemented in the OLT and the ONU. These modules comply with [3]. The model involved 13 ONUs, representing a PON filling ratio of 20% (in the case of a 1×64 splitting ratio) and the traffic load was 90% of the upstream G-PON bandwidth (e.g. 1.105 Gbit/s). A traffic of 85 Mbit/s was generated on each ONU. Table 1 summarizes the different T-CONTs types and properties used in the simulations.

Table 1: T-CONTs types and properties associated to the ONUs

	T-CONT
ONU1	Type1, CIR=AIR=EIR=200Mbit/s
ONU2	Type2, CIR=0, AIR=EIR=200Mbit/s
ONU3	Type3CIR=0,AIR=100Mbit/s, EIR=200Mbit/s
ONU4-ONU12	Type4, CIR=AIR=0, EIR=200Mbit/s

Figure 9 shows the simulation results (delay) of the ONUs for different TCONTs. These simulations also illustrate the delay evolution according to the distance (from 0 km to 60 km). These simulations results are subsequently used later in order to compare legacy and NG-PoP network architectures. The results show that the delay increases by 100 µs corresponding to the additional propagation delay induced by 20 km of optical fiber (5 µs/km).

The difference in delays between T-CONTs is mainly due to T-CONTs features and different packet size used for each T-CONT. For example: T-CONT1 uses CBR traffic and a fixed bandwidth is allocated every DBA cycle, while T-CONT2 and 3 are based on VBR traffic. Also, services supporting these T-CONTs are less stringent to delay, throughput, jitter and PLR compared to T-CONT1 based services. T-CONT4 supports Best Effort traffic and there is no specific requirement on delay, throughput, and jitter for services based T-CONT4.

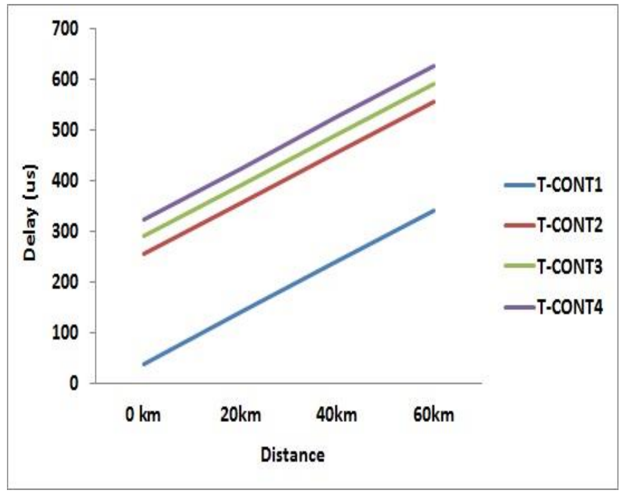

Fig. 9 Delay according to different T-CONTs and different distances

5.1.2 Experimental results

The experimental results are used to verify the simulation results. Figure 10 shows the experimental test setup used to evaluate DBA performances. TCONT parameters described in Table 1 are involved in the experimental configuration. The main difference is the number of ONUs: only 10 ONUs have been used and a load of 100 Mbit/s instead of 85 Mbit/s was generated. The OLT was a G-PON OLT supporting a maximum distance of 60 km between the ONUs and the OLT. Figure 11 shows the experimental results (delay) of the ONUs for different T-CONTs. These results show that the delay increases by 100µs corresponding to the additional propagation delay induced by 20 km of optical fiber. The experimental results are almost identical with simulation results.

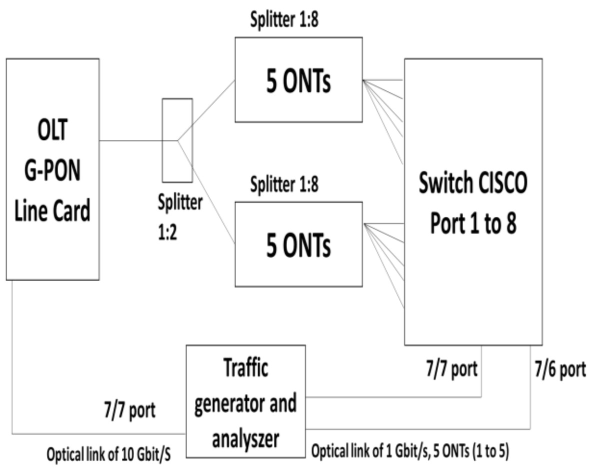

Fig. 10 DBA experimental setup

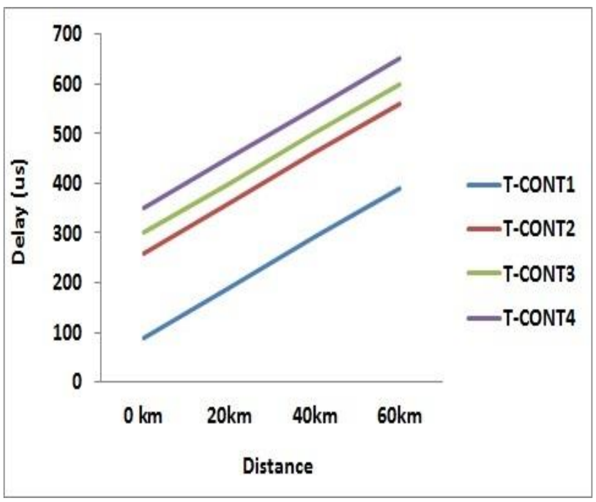

Fig. 11 Delay of DBA for different T-CONTs and for different distances

5.1.3 Performance evaluation related to delay parameter

The present sub-section compares legacy and NG-PoP architectures in terms of delay, using the simulation results of DBA presented previously. Figure 12 shows the methodology to calculate delay by using OPNET simulator.

The simulations show that the suppression of aggregation point reduces the total delay with 13% compared to the legacy network architecture. We can imagine the important reduction of the delay (more than 30%) if we take into account the waiting delay in the queues or the waiting delay introduced by the congestion in aggregation network. The reference [28] shows that increasing the number of aggregation points (hops) leads to an increase of the RTT (Round Trip Time) and delay jitter.

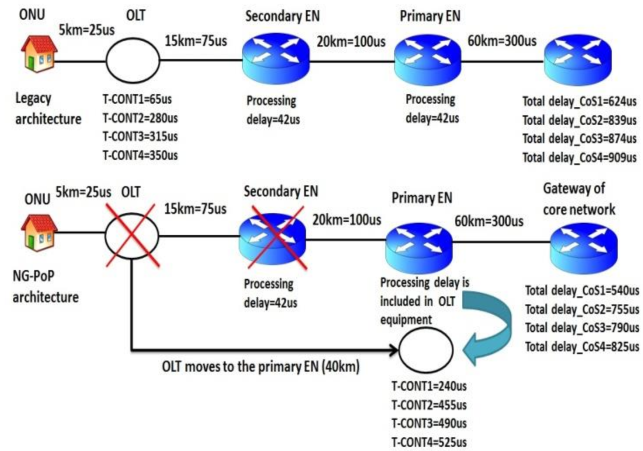

Fig. 12 Delay of legacy and NG-PoP network architecture

5.1.4 Performance evaluation related to traffic evolution in downstream direction

In sub-section 4.3, we showed the congestion can appear in current fixed aggregation network based on dimensioning rules and traffic evolution hypothesis. So, in the present sub-section we will show how the future network architecture allows to reduce the traffic load in different segments of the network compared to the current network architecture by using real traffic data [6] and its evolution towards 2020 [6]. The congestion that can appear in the network results either in excess delay or packet loss ratio. Reduce the load traffic in different segments of the network improves the QoS. Based on the main applications generating most of the traffic presented in [29, 6] and their evolutions these last years, we can imagine their evolutions towards 2020.

In fixed network, Figure 13 shows that the streaming video continues to grow over the coming years and represents more than 50% of total traffic in downstream direction. Figure 14 shows the evolution of Internet applications used in mobile networks towards 2020. Streaming video also represents a strong increase and will reach about 60% of total downstream traffic in coming years. The evolution of Internet traffic can represent a significant impact on current fixed and mobile network architectures. Tables 2 and 3 summarize the expected impact of the applications generating most of the traffic towards 2020 on current fixed and mobile network architectures.

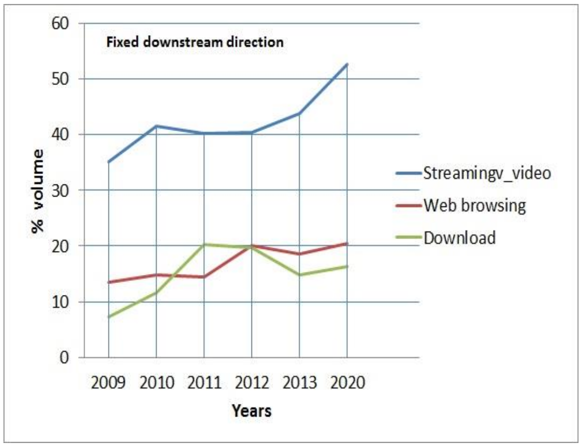

Fig. 13 Fixed downstream traffic evolutions

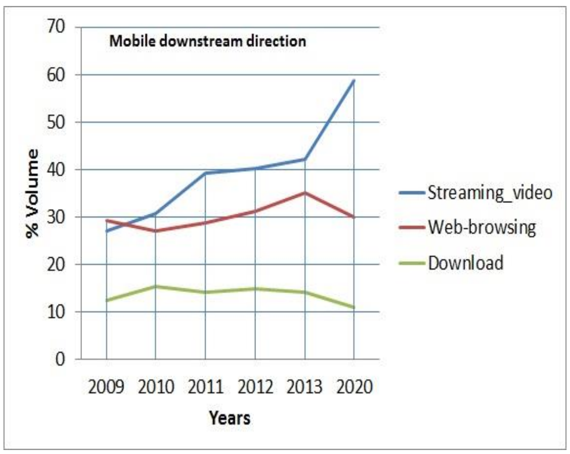

Fig. 14 Mobile downstream traffic evolutions

We deduce from the two tables that the strong use of streaming video can lead to a congestion in mobile core network and fixed aggregation networks, because a large proportion of total traffic such as streaming video will be terminated in the metro fixed network (aggregation network) [21]. In the case of mobile network, the total data traffic is centralized in core network [1].

Table 2: Impact of traffic evolution on fixed network architecture

Downlink fixed network	***Access load***	***Aggregation load***	***Core load***
P2P	very low	very low	very low
Web browsing	medium	medium	medium
Streaming video	high	very high	high

So the distribution of PDN GWs in the network and adopting distributed caching technologies for CDN allow to reduce the load in different segments of fixed and mobile networks. Also another important point which leads us to consider an evolution of the current network architecture is the similarities existing between fixed and mobile networks [6]:

- Streaming video represents the main downstream application either used in fixed or mobile networks whatever the operator (Orange or Telefõnica),

- Mobile customers tend to use their Wi-Fi interface embedded on their mobile device and thus use more and more the fixed network with their mobile devices.

Table 3: Impact of traffic evolution on mobile network architecture

Downlink mobile network	***Access load***	***Aggregation load***	***Core load***
P2P	very low	very low	very low
Web browsing	high	high	high
Streaming video	high	high	very high

Table 4 shows that the loads of streaming video in different segments of NG-PoP architecture are completely different in aggregation and core networks compared to legacy fixed and mobile network architectures. The load of streaming video must be medium in the converged aggregation and core networks. The introduction of distributed CDN caches close to the customers reduces the traffic in the aggregation segment. The traffic is also reduced in core network related the distribution of PGW/SGW functions.

Table 4: Qualitative load in different segments of NG-PoP architecture

Total traffic load	***NG-PoP load***	***Core network***
NG-PoP architecture	medium	medium

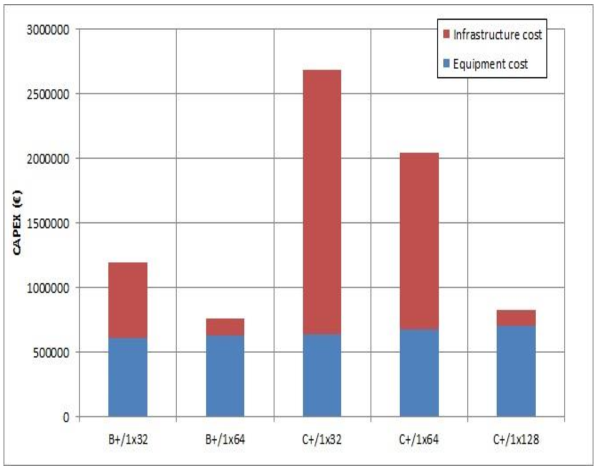

Fig. 15 Infrastructure and equipment costs

5.2 Optical architectures CAPEX and OPEX

The architectures described in this section are either based on B+ or C+ class optics defined in G-PON standard characterizing a maximum optical budget up to 28 dB and 32 dB respectively. The Central Office (CO) consolidation will depend on the chosen optical splitting ratio (1 × 32, 1 × 64 or 1 × 128) and the maximum optical distance between the OLT and one ONU is limited at best to 40 km depending on optical budget class and splitting ratio. Also, in order to quantify the equipment and optical infrastructure investments for each architecture, simulations are done for a small local area corresponding to a maximum number of homes varying between 46100 and 50700 (which is function of the Central Offices topology and so, the number of homes connected to).

The equipment costs depicted by Figure 15 take into account the OLT rack and shelf type (4, 8 or 16 possible line cards), the network card and the 8 G-PON ports line card. The infrastructure costs are function of the optical fibre cable capacity (up to 720 optical fibres per cable) to install between the main optical CO and a secondary CO or cabinet where the first optical splitter stage is located. The OPEX only take into account power consumption of the equipment. Figure 15 gives the investments according to the architecture type and Figure 16 depicts the costs represented by the power consumption tied to each architecture.

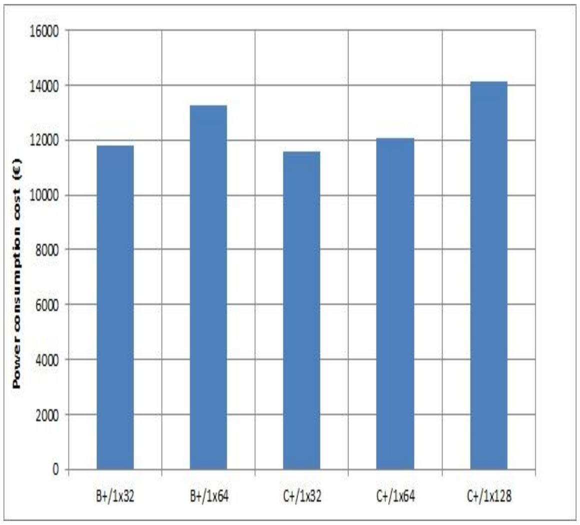

Fig. 16 Power consumption costs of each architecture

These simulations show that whatever the optical infrastructure type (B+ or C+), the investments drastically increase when the optical splitting ratio decreases (from 1 × 64 to 1 × 32). In general, changing the optical splitting ratio allows the operator to address longer distances between the CO and the ONUs, but it is also necessary to deploy new optical cables between the main CO and a secondary one, which impact the infrastructure investments. In the case of a PON architecture based on C+ class and 1×32 optical splitting ratio, the investments are about 2.7 Me, which is largely greater than the needed investments in the case of B+ class and 1×64 optical splitting ratio. In this C+/1 × 32 case, the consolidation is optimum, it is necessary to only have 3 Central Offices (OLT) to address 47900 homes while 18 OLTs are needed to cover the same geographical area in the option of a B+ and 1×64 optical splitting ratio architecture.

C+ class optics and 1×128 architecture is somewhere similar to B+ class and 1×64 architecture. Indeed, the additional optical budget is provisioned for a new 50% optical splitter and the number of CO needed to cover the considered geographical area is also equal to 18 (same than for B+ class, 1×64 architecture). The power consumption costs is minimum in the case of C+ class and 1×32 optical splitting ratio but the difference is only about 3 k€ with respect to the maximum power consumption costs represented by C+ class and 1×128 optical splitting ratio architecture. Central Office consolidation (in this case represented by C+ class and 1×32 optical splitting ratio architecture) is the most expensive due to the infrastructure investments, which are very important as they represent 76% of the total investments.

. This has to be compared with B+ class and 1×32 optical splitting ratio architecture for which the infrastructure costs represent 49% of the total investments. With respect to this last architecture, 9 Central Offices are needed to cover the considered geographical area. Moreover, in this case, the power consumption cost is almost the same than for C+ / 1×32 optical splitting ratio architecture. According to these results, the maximum distance reached by B+ class and 1 × 32 optical splitting ratio architecture is 17 km while it is 29.5 km for C+/1×32. These results show it is necessary to find a trade-off between the consolidation effort (CO number reduction) and the infrastructure costs. Here, typically, B+ class / 1×32 optical splitting ratio architecture is a compromise between CO consolidation and investments limitation.

5.3 Fixed and Mobile Convergence

The FMC approaches can be used to explore new innovative solutions. The FMC presents several benefits for both operators and customers. Currently fixed (respectively. mobile) access networks presents 20% (respectively 22%) [5] of total CAPital EXpenditures (CAPEX). Converged fixed/mobile network architecture allows to reduce the cost for end users and operators by sharing fixed and mobile access/aggregation network infrastructures and hardware (equipment, fiber). The main benefits of the FMC networks are:

- Optimization of the number of caches and the cache locations,
- Simplification of network operation and management due to lower technology diversity,
- Aggregating data traffic from multiple access technologies (FTTH, 3G/4G),
- Lower complexity through a simpler network structure,
- An improvement of the network ressources usage and energy consumption,
- Reduced an investment infrastructure cost by supporting FMC (sharing control functions and a large part of infrastructure),
- Definition of general networking features that can be used by different fixed and mobile networking entities such as Deep Packet Inspection (DPI), identification and authentification means,
- Allowing a flexible use of general functions as resources provided to several networking functional entities (e.g. DPI used for both fixed and mobile gateways),
- Possible introduction of cooperation features between networks of different types (mainly 3GPP cellular and Wi-Fi in residential access),
- Separation between control and data plane by using SDN technology.

6. Conclusion

In this paper, an advanced solution called Next Generation Point of Presence (NG-PoP) is presented and a performance comparison of NG-PoP and legacy architecture is shown. In order to introduce the topic, first the main drivers and technological enablers motivating structural convergence of the fixed and mobile networks have been discussed. We argued that the intense use of some applications (most importantly: video streaming) and the advent of BBU hostelling are leading to the necessity of revising the network architectures. The introduction of concepts such as SDN and NFV in new architecture are typical enablers for structural convergence. The definition of a generic, IP-edge entity (available to be used by any type of network) is another typical enabler. Thanks to traffic analysis based on real traffic data supplied by Orange and Telef˜onica operators and studies of several traffic evolution scenarios, the capacity requirements of future aggregation network are defined. This traffic evolution shows the limitation of the legacy network architecture. Hence, an alternative network architecture, NG-PoP, is proposed in order to limit the occurrence of bottlenecks in fixed aggregation segment, on one hand, and in the core mobile one, on the other hand. The core idea of the NG-PoP architecture is to reorganize both access and aggregation segments in order to reduce traffic load in aggregation and core parts. This is encouraged by converged CDN cache closer to the end users and a distribution of SGW / PGW. Moreover, NG-PoP improves end-to-end QoS, thanks to a reduction of the number of aggregation nodes. The paper also demonstrates that it is important to find the trade-off between the number of customers to concentrate in a CO, the QoS, and the CAPEX driven by CO reduction.

Acknowledgments

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Moufida Feknous is a PhD student in Orange Labs and Telecom Bretagne, France. Moufida received her master degree in telecommunication systems from University of Rennes 1 in 2011, France. She was working as an engineer at Telecom Algeria, Oran, Algeria. Her research interests include optical access network, traffic forecast, and convergence of fixed and mobile networks

Bertrand Le Guyader received the master degree in engineering from Engineering School of Physics of Strasbourg, France, in 1997. His research interest is focused on the evolution of next generation optical systems for the optical access networks. He mainly performed some studies on new functions dedicated to Passive Optical Network technologies and initiated some studies on the technological functions dedicated to NG-PON2. Before joining Orange, he spent 6 years in the long haul transmissions studies.

Pal Varga is Associate Professor at Budapest University of Technology and Economics, Hungary, where he got his M.Sc. and Ph.D. degrees from. Besides, he is the Director of Telecommunications division at AITIA International Inc. His main interests are network and service management, network performance measurements, fault localization, traffic classification, end-to-end Quality of Service and Service Level Agreement issues. His recent research topics include hardware acceleration of high speed network elements, as well as collaborative automation systems.

Annie Gravey received her PhD degree in automatics and signal theory from Paris-Sud University, France, in 1981. Her research interests include the design and evaluation of traffic engineering methods for broadband networks, and of procedures related to QoS specification and management. In particular, in the last years, she has focused on broadband access networks (optical, wired and wireless), on the design of metropolitan optical packet networks, and on controlling the deployment of applications on different networks and network elements. She is currently a professor and the head of the Computer Engineering Department at Telecom Bretagne, in Brest (France). Before joining Telecom Bretagne in 2000, she spent almost 20 years in France Telecom Research Labs where she analyzed and designed mechanisms for specifying and controlling broadband traffic. She also participated for many years to both ITU and ETSI and contributed to the traffic management and QoS specification of ATM and IP standards. Dr. Gravey is member of SEE, IEEE and ACM.

Jose Alfonso Torrijos Gijon has a Computer Science degree from the Polytechnic University of Madrid in 1992. In 1994 he joined Telefónica I+D working in different projects for Telefónica regarding IP, DTV, xDSL and Satellite technologies. In 2004 he joined the Broadband Access Technologies Division managing ARTES-1 and FP6 projects such as SATLIFE and SATSIX. In 2008 he started to work in fiber optic projects for Telefónica Spain regarding FTTH access and photonic networks. From 2010, he has been leading the technical work of network efficiency projects for the Telefónica Group inside the CTO office, participating in the EU FP7 projects such as ACCORDANCE (OFDMA in PON systems) and COMBO (fixed-mobile network convergence) and following FSAN and BBF standardization activities related to fixed access networks.