Converged Network Infrastructure Enabling Resource Optimization and Flexible Service Provisioning (CONFES)

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Abstract: - A significant opportunity has arisen from the current deployment of passive optical networks (PONs) for fixed access to also use them for collecting traffic from mobile base stations. This serendipity if properly exploited can improve revenues and raise cash flows at the early capital-intensive deployment phase for both fixed and mobile operators. Such a strategy is in line with also longer term goals and presents favorable evolutionary prospects towards a denser base station tendency as well as fiber to the local loop fixed access. However, to fully exploit all the available flexibility in the new PON environment characterized by the shared medium, and in order to accommodate mobile traffic burstiness arising from the introduction of new generation high speed access technologies (e.g., HSPA/HSPA+, LTE) and new multimedia-intensive usage some adaptations both at PON and the Mobile Network Operator (MNO) functionality are necessary. This is the focus of the CONFES project on which this work is based.

Key-Words: LTE, PON, MAC, Wireless Backhauling, Wireless Optical Convergence

1 Introduction
The continuous evolution in mobile access network technologies (GSM/ GPRS/ EDGE, 3G/HSPA+/LTE) combined with the high usage of data services, driven by the availability of new mobile devices (smart-phones, tablets, other portable equipment) supporting faster data rates as well as the rapid rise of mobile applications, lead to dramatic increases of OPEX backhaul costs that may either threaten business model viability or be transferred to the end-user. Besides it is questionable whether the contemporary backhaul technologies could support these high traffic volumes and traffic variations; especially in an environment which should allow users to download at very high speeds (e.g. 20-30Mb/s). As a result, new future-proof backhaul technologies should be introduced/adopted aiming at cost minimization, without risking the Quality of Service (QoS), while addressing the high traffic fluctuations.

Revolutionary changes happen at the same time in the last mile of fixed line providers who are increasingly deploying PONs to concentrate traffic from residential and small business customers. A serendipitous synergy emerges between these two developments presenting the opportunity to accelerate cash flows for both the mobile and the fixed operator.

Traffic from mobile operators could fill a large part (e.g., 10 to 50%) of a PON serving as mobile backhaul network raising system utilization and easing the funding of the initial costly phase for the fixed network operator, but at the same time will enable the mobile operator to find at a reasonable cost a way to fully extend the capacity of a base station as demand for data services reaches that sensitive stage where the wireless infrastructure is lacking in capacity while it is too early to consider a dedicated fiber backhaul. This financially sensitive interim stage provides a window of opportunity
easing the high initial capital expenditure for both operators while raising revenue accrual.

An equally important advantage of this approach is the future-proof nature of access PONs evolving towards their next-generation upgrades e.g., through OFDM or WDM solutions that removes the danger of obsolescence featuring a well understood and studied evolutionary path to any desired rate and any degree of sharing up to dedicated lightpath links.

The initial paradigm change from a fixed pipe to a shared medium TDMA PON provides further flexibility and potential for multiplexing gain carrying further financial gain in the form of increased exploitation of the backhaul infrastructure. However, to exhaust the utilization potential without quality degradation risks, requires a novel functional block which will monitor and coordinate the bandwidth management offered to the mobile operator in a more sophisticated fashion than warranted by the residential or the other business users of the PON. The way this functionality is designed in the CONFES project is the focus of this work.

2 CONFES System Architecture

To address the technical and economic challenges, for both MNOs and PON operators, towards the development of a viable business model, CONFES project adopted a converged network architecture based on PON technology that may support multiple candidate users (e.g. mobile operators, residential users, corporate users). The generic CONFES features are listed below:

- The exploitation of Dynamic Bandwidth Allocation (DBA) capability of PON networks to achieve more economical models (as it may support more customers without needing infrastructure expansions) and at the same time to accommodate traffic bursts, peaks and seasonality variations (see winter or summer destinations), by taking advantage of the traffic lows. Dynamic allocation is the only solution in order not to over-dimension an LTE backhaul network because of the heavy fluctuation in traffic demand. An optimal network resource management should be developed.
- The introduction of new dynamic Service Level Agreements (SLAs) to cope with both predictable and unpredictable traffic events, adaptable to traffic fluctuations, upgradable temporarily to address a traffic demanding incident (see special events like concerts, sports events), capable of supporting the introduction of new services in a flexible way.
- The support for both critical real-time services (signaling, voice, call/session continuity) as well as traffic migration (e.g. multiple active data sessions on a high-speed moving train).
- The support for multiple charging models, incl. based on monthly fee, actual usage, etc.

*Figure 1* illustrates in principle the system under study which consists of a PON operator aiming to serve one or multiple MNOs (each having connected one or more mobile BTS1) on top of its regular users (business and residential customers). The CONFES system architecture is an overlay network infrastructure spanning across both PON and MNO operators. As shown, it consists of two main blocks:

- The PON-ODORA (Optical & Dynamic Optical Resource Allocation) CONFES Core agent, responsible for the PON MAC and SLA management functions, and
- The BTS-ODORA CONFES agent (per connected BTS), responsible for calculating BTS bandwidth needs and entering into SLA negotiations with the PON-ODORA CONFES agent on SLA modifications.

The main challenges of the CONFES functionality concern the dynamic management of the SLAs between the fixed and mobile operators, as well as the delay and MAC fine-tuning issues [4]. The novelty of the CONFES approach lies in the translation of the new possibilities offered by PON into negotiable SLA parameters for the benefit of the MNO. Hence, the DBA potential can be exploited according to the changing service needs of the BTS. As a result, there will be the same level of QoS offered with less committed resources (hence lower costs) than would be necessary without the ODORA unit.

As a starting point, the PON inherently possesses dynamic bandwidth management at ms timescales via its DBA residing in their MAC protocol [1]-[4]. Under its guidance, packets are classified per quality class and arrival time and arranged one behind the other in perfect and gapless succession multiplexed towards a single input port of the Optical Line Terminal (OLT). However, at a higher time scale level, the traffic service must be agreed for the purpose of quality control, billing and dimensioning. Hence, the need for SLAs and regarding simple

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1 Base Transceiver Stations, commonly called BTS, eNodeB or eNB depending on the technology; we keep the broader term BTS hereafter.
customers a peak rate is the main parameter under control.

With a PON serving time-sensitive traffic, a trade-off emerges between excessive over-provisioning leading to poor resource utilization and higher utilisation risking loss of QoS. Service prioritization can however protect sensitive traffic without significant over-provisioning in conjunction with the DBA which is a reservation protocol, i.e. arriving packets at the upstream (towards the core) queues request service indicating their queue length in a report field, and then the MAC controller at the head-end allocates upstream transmission grants enough to allow them to relieve the full content of their queues.

3 Service Level Agreements in CONFES

The CONFES consortium follows the methodology proposed by the TM Forum [7], in order to introduce a new type of SLA capable to support both mobile access technologies and business/home users over PONs. Example considerations of a SLA that could address a LTE MNO CONFES user are listed below:

- The increasing bandwidth requirements of LTE and LTE-Advanced mobile networks (up to 1Gb/s for a 3-sectored LTE site).
- Orientation to a dynamic backbone network resource allocation scheme, instead of the legacy static allocation of 2G and 3G networks performed by allocating one or more dedicated xDSL or wireless microwave links per BTS accommodating traffic fluctuations.
- Support of the sophisticated QoS capabilities offered by the LTE and ISPs to their end-users (by exploiting LTE Classes of Service - CoS). Backhaul networks should support different SLA parameters per CoS under a unique SLA between MNOs/ISPs and the PON operator.
- Guaranteed and additional traffic rate should be changed in an escalated manner and based on the user needs, as recommended by the NGMN Alliance [7] for mobile networks backhauling. More specifically, the NGMN Alliance recommends permitting the adjustment of the data traffic rate indices at 2 Mb/s steps for 2-30 Mb/s rates, at 10 Mb/s steps for 30-100 Mb/s rates and at 100 Mb/s steps for rates over 100 Mb/s.
- Scalable billing according to data traffic rates/usage (guaranteed και additional) per CoS should be considered.
- The data traffic rate indices should be aggregated on either per ONU basis or per one or more xPON of broader geographical areas.

Figure 1: Typical CONFES system architecture
• The KQIs, threshold values and their expressions shall be based on the following KPIs [7]: Data traffic rates (guaranteed/additional), Delay, Jitter, Packet loss, Bit error rate.

• SLAs should be applicable to GPON, EPON and other future PON technologies. For example, GPON technology (ITU-T G.984.3 standard [1]) offers two guaranteed bandwidth classes (fixed CIR and assured AIR) and two additional classes (non-assured & best-effort) with lower priority. Fixed (or committed) class offers guaranteed bandwidth through static allocation of resources, while assured class offers guaranteed bandwidth through DBA algorithm.

4 The PON-ODORA Management System

As mentioned, the full exploitation of the multiplexing gain opportunity requires a much more elaborate BW management scheme than is warranted for the residential traffic. Therefore, a central issue in this environment is how to respond to the different timescales of the traffic change and for this two hierarchical levels are envisaged in the PON-ODORA unit of Figure 1. One handles the pre-arranged SLAs and the slow long-term changes and the other handles the fast changes in an autonomic manner (Real-Time Measurement module) as shown in Figure 1. The first objective of the new functionality is to let each operator have control of his side of the negotiation so the mobile operator will issue bandwidth requests and the PON operator will respond with what is in a position to satisfy. This way a service bandwidth framework will be established defining the upper and lower limits of the traffic agreement.

4.1 Bandwidth Management Subsystem

The CONFES architecture interacts with the underlay technologies (see Figure 1) via the open North Bound Interfaces of each technology’s Network Management System (NMS). The PON-ODORA performs management according to the FCAPS (Fault, Configuration, Accounting, Performance, Security) model [9], including the blocks of:

- (F) Alarm Management which handles the alarms collected by the Collection of Alarms & Statistics block
- (C) Configuration-reconfiguration of PON network
- (A) Accounting is partially supported by the Resource Management & SLA Management
- (P) Performance Management
- (S) Security Management

To achieve optimal usage of PON resources offering services on a pay per use model, the SLA initialization unit provides the initial requirements based on agreements between PON and business customers, MNOs, residential customers (depending on the region, the number of customers, etc.). The agreed SLAs are maintained in DBs, along with the data collected by the blocks of the FCAPS model.

Starting from the initial SLA requirements and utilizing the Long-term estimator and Real-time measurement based resource allocation units, the PON-ODORA performs a detailed exercise to determine the network resources needed on daily, weekly and monthly basis per customer category, type of service, geographical region and the respective (re)configuration in order to offer the customers the optimal QoS. Concluding on this exercise, the Resource Management system reserves the required resources and interacts with blocks of the SLA Management, Performance Management and Alarm Management monitoring to verify that the usage of the network resources does not violate the threshold set. The latter are strictly linked with SLA terms, and are based on the PON operator’s business plan. In case a breach of SLA is identified (e.g. a threshold is exceeded, sudden increase of BS traffic, fiber cut, natural disaster in an area) the SLA Management block is triggered to take action.

Last but not least SLA Management is the heart of the Resource Management unit since it is responsible on one hand to check the SLA DB, and on the other hand to interact with the Real-time measurement and DBA block and other blocks of the PON network, and proceed with the appropriate actions for resolving traffic peak issues, so as to offer the guaranteed QoS to all customers. As soon as the appropriate action is concluded a real time (re)configuration of the PON network is triggered accordingly.

4.2 The Resource Management Subsystem

The heart of the autonomic resource management subsystem at the heart of the CONFES core (PON-ODORA), shown in Figure 2 is the Real-time measurement subsystem which carries out crucial traffic measurements and characterisation [8] and is based on the well-known concept of the Leaky Bucket (LB) embedded in a marking scheme [5].
The LB uses two parameters, the rate and the bucket size and in this case two such LBs are employed, one for the Peak Information Rate (PIR), which is the sum of CIR and EIR, with a small bucket size P (the size of about 5 average packet, i.e. about 5k bytes) and one for the CIR with a bucket size R (about 5% of the total ONU buffer size). These rates are set by the Resource Management subsystem. They may vary at different hours of the day or day of the week, based on historical data collected and kept in the historical DB. Flows constrained by the (CIR, R) LB set must always be served by the PON and they are counted as green. While not using their full rate, spare capacity can be used for other PON users. Packets exceeding the (CIR, R) LB but not (PIR, P) are counted as yellow and will be served only if spare capacity is available. Finally, packets exceeding the (PIR, P) constraint are counted as red and will be blocked.

The real-time module obtains parameters from the SLA management module (which carries out the negotiations with the BTS-ODORA via the message exchange subsystem) and reports back to it periodically and after certain events. When the number of yellow packets exceeds a threshold in any given hourly period, though not blocked (as are red packets) may trigger a renegotiation by the PON-ODORA towards BTS-ODORA and new higher CIR and EIR may be agreed. This is decided by the long-term estimator. Similarly prolonged lower usage may lead to lowering the reserved BW. Foreseeable events that will require increased BW (e.g. games, festivals, concerts) in the vicinity of the station, can be manually programmed into the NMS and create new reservations of limited duration that are passed into the subsystem for monitoring. When first the BTS-ODORA linking to the PON is commissioned, the initial SLA parameters can be tentative values defined by the MNO based on experience (historical data), but are gradually updated by the real-time measurements and in this fashion, the working profile of each BTS is created per hour of the day, day of the week and/or even month of the year (useful for BTS residing is summer holiday resorts, office areas, etc.). These data are kept in the historical DataDB and can be used in deciding and even predicting demand in the long-term estimator.

5 The BTS-ODORA Management System

The functional architecture of the proposed BTS-ODORA Management System is depicted in Figure 3, while the functionality of each identified module is described in what follows.

**Figure 2: The Resource management Subsystem**

**Figure 3: BTS-ODORA Functional Architecture**

**Conflict Resolution System:** The Conflict Resolution System receives alerts by the Alert
Receiving Module of the Message Exchange System and consists of two modules:

- **The Resource Negotiation Module:** When the PON is overloaded for a short period of time and is unable to satisfy the request for resources issued by the BTS-ODORA module, the Resource Negotiation Module is responsible for negotiating a reduced amount of resources, leading to a degradation of the QoS experienced by some mobile users.

- **The Handoff Triggering Module:** In case the PON cannot satisfy the demand for the required resources, either due to overloading or other reason, the Handoff Triggering Module initiates an inter-OLT handoff procedure as a fall-back solution, in order to avoid the degradation of the QoS offered to mobile users.

**Message Exchange System:** The Message Exchange System (MES) is the system responsible for the communication of the base station with the PON, and it consists of three modules:

- **The Alert Issuing Module:** Its main responsibility is to receive alerts from the Intelligent Prediction System, when a significant differentiation between the short-term and mid-term traffic demand predictions is detected. After receiving an alert, it informs the PON and issues a request for extra resources.

- **The Alert Receiving Module:** The Alert Receiving Module is responsible for receiving alerts issued by the PON, and informing the Conflict Resolution System accordingly.

- **The Request Dispatching Module:** This module retrieves the predicted resources demand from the Mid-term Prediction Module, and issues an appropriate request for resources to the PON.

**Database:** The Database is responsible for maintaining current network status at any given time as the later is provided the Monitoring System (MS). Thus, it keeps a record of the historical data of network conditions. Furthermore, it maintains the prediction performed by the Mid-term Prediction Module, as well as the short-term prediction provided by the Short-term Prediction Module, and the respective deviation. A record of backhaul resources allocated to the base station, as retrieved by the Resource Allocation Verification System, is also maintained in this database.

6 Conclusion

The widespread deployment of PON systems for fixed communications comes at a time that mobile backhaul systems are stressed by the spreading of smart phones and the concomitant fast rise in data rates due to the introduction of next generation access network technologies. Thus, the use of PON for mobile traffic backhauling provides an opportunity that cannot be missed as it offers a smooth migration path both in technical as well as financial terms for both operators. To take advantage of the PON utilization potential without quality degradation, novel functionality is required which will monitor and coordinate the bandwidth management between the two operators to mutual advantage. The design and development of this functionality is the focus of the CONFES project and as shown in this work the use of traffic measurements, traffic prediction and optimized SLA handling can improve the service offered without the waste of static over-provisioning.

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