Green WDM-PONs: Exploiting Traffic Diversity to Guarantee Packet Delay Limitation

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***Abstract*— In this paper we propose a scheme tailored for WDM-PONs, which employs dozing mode in transceivers not only at the user side but also at the central office. The objective is to reduce the energy consumption while minimizing the impact on the total packet delay. The proposed scheme is able to take into account the diverse delay requirement of multiple traffic classes by adapting the wakeup time of the transmitter. Simulation results confirm that the proposed scheme can significantly improve the power efficiency in WDM-PONs while maintaining the maximum packet delay at an acceptable level, in particular in cases where multiple traffic classes are considered.**

***Index Terms*—WDM-PON, energy efficiency, guaranteed packet delay, traffic diversity, dozing.**

I. Introduction

The power consumption of the entire information and communication technology (ICT) sector currently amounts to 8% of the energy consumed worldwide, and this percentage is only expected to grow in the future [1]. It is shown that network equipment is responsible for one third of the total ICT energy consumption [2]. Moreover, approximately 70% of this value refers to the power consumed in the access segment, mostly because of the large number of active equipment deployed. On the other hand, the average utilization of access network devices is lower than 15% [1]. Therefore, there is an evident inefficiency in the way access equipment is currently used. Such a scenario calls for energy-aware schemes that efficiently adapt to the traffic conditions in the access segment.

Optical fiber based access networks are the only future-proof alternative to support the growing bandwidth-per-user demand. In this context passive optical network (PON) is one of the most promising access network architectures. By avoiding active equipment in the outside plant the maintenance cost can be reduced. There are several types of PONs, each one using different multiplexing technologies, for example time division multiplexing (TDM) PON, and wavelength division multiplexing (WDM) PON. A typical TDM-PON (e.g., an Ethernet PON (EPON), or a gigabit capable PON (GPON)) is a point-to-multipoint network with a tree-based topology where an optical line terminal (OLT) located in the central office (CO) is connected (via a power splitter) to several optical network units (ONUs) at the users' premises. The OLT broadcasts the downstream traffic on a shared fiber medium. For the upstream traffic, the OLT assigns a time slot to each ONU in order to avoid conflicts. On the other hand, this time-multiplexing approach for the upstream traffic introduces an additional protocol delay, in particular for the long reach scenario [3]. For this reason TDM-PONs, may not be the best choice for applications with strict delay requirements e.g., mobile backhauling [4][5], where the maximum delay for packets is limited between 1ms and 5ms. Another disadvantage of TDM- PONs comes from the broadcast nature of the transmission paradigm (i.e., the traffic indented for one user is also broadcasted to all the others) making it difficult to offer high security for business applications.

In contrast, in WDM-PONs each ONU is assigned a dedicated wavelength for both the downstream and the upstream traffic. This means that WDM-PONs can provide high security and no additional protocol overhead (i.e., no extra delay) is needed to allocate upstream bandwidth among all the connected users. In this regard, WDM-PONs are better suited for business applications with strict delay requirements [6]. Data rate is also another aspect in which WDM-PONs may offer additional advantages. Thanks to the possibility of having dedicated wavelengths, WDM-PONs are able to deliver transmission speeds of 1Gbps and beyond to each ONU. Overall, WDM-PONs are becoming the technology of choice for future services, in particular for business customers and for mobile backhauling applications.

There are many studies available in the literature aimed at improving the energy efficiency in PONs. They can be grouped according to the layer that they specifically target, i.e., physical layer energy efficient techniques (e.g., component integration or low power circuits), data link layer power optimization strategies (e.g., cyclic sleep) as well as hybrid energy efficient approaches that work on more than one layer at the same time [7][8][9][10]. However, the majority of these studies target TDM-PONs while not much work has been done for lowering the power consumption in WDM-PONs. On the other hand, in WDM-PONs there is more space for improvement. In TDM-PONs only the transceivers at the user side can be put to sleep, while the (single) transceiver at the OLT side needs always to be active to accommodate the traffic coming from all ONUs. The OLT side of a WDM-PON, on the other hand, comprises an array of transceivers each one dedicated to a single customer. Therefore, if a specific ONU is not active it is then possible to put the corresponding transceiver at the OLT into the sleep mode. Moreover, it should be noted that reducing the power consumption at the OLT side is also critical in terms of operational cost saving, as operator needs to pay for the energy consumed by the devices at the CO. The energy cost of the ONU equipment is also significant, but customers typically cover it, and therefore it is not the prime interest of the operator.

Similarly to TDM-PONs, there are several energy saving techniques for WDM-PONs, i.e., *power shedding*, *dozing, deep* and *fast sleep* modes [8]. According to the power shedding concept, the ONU/OLT goes into a low power mode by putting into sleep mode only a subset of its components (e.g., Ethernet interface) while keeping both transmitter (Tx) and receiver (Rx) active. The purpose is to not introduce any additional transmission delays (e.g., for wakeup and/or synchronization) in the wake of any upcoming upstream and/or downstream traffic. On the other hand, with power shedding only a limited amount of power can be saved. With *deep* and *fast sleep* approaches, widely used in TDM-PONs, e.g., [7], the Tx and Rx at the ONU/OLT are in sleep mode when they are not in use (e.g., no upstream/downstream traffic from/to a specific ONU/OLT). This technique can achieve the best energy savings, but a synchronization phase is required to make sure that the OLT/ONU is aware that the transceiver on the other side is active. In addition, the length of the sleep period has a direct impact on packet delay. In fact, since both Rxs are inactive, the ONU/OLT cannot react to any incoming downlink traffic as long as it is asleep, and these packets have to be queued or dropped. Usually this technique is combined with some sleeping policies to optimize the energy savings performance, e.g., *cyclic sleep* [9].

Dozing is a compromise between the advantages of shedding (i.e., little impact on the transmission delay) and the energy saving performance achievable by *deep* and *fast sleep*. According to the dozing concept, only the Tx side is put into sleep mode while the Rx stays always on. One of the main challenges with a dozing approach is to know when to put the Tx into sleep mode and when to wake it up in the presence of incoming traffic. The most straightforward way would be to wake up the Tx as soon as there is traffic to be sent, and to put the Tx into sleep mode right after the transmission phase is over. This scheme is referred to as *immediate wakeup*. However, such an approach is not optimal because of the non-negligible transition time between sleep and active states, which leads to an energy overhead [11]. One way to overcome this drawback is to wait for a certain time, with the intent to collect a number of packets before transmitting them all together in a burst. In this way the number of transitions is minimized, but at the expense of an additional delay. This packet bursting idea, successfully applied in the copper based Ethernet (IEEE802.3az) scenario [12], is not directly applicable to the WDM-PONs case. There are several key differences between these two technologies, e.g., transmission distances (meters vs. kilometers), medium properties (electronic vs. optical), and transceiver characteristics. As a result, the propagation delay and the transition times (among different operating states) increase, from a couple of microseconds (typical of the Ethernet case) to several hundreds of microseconds, or even milliseconds in WDM-PONs. On the other hand the packet delay constraints for a certain traffic class do not change. As a result, a packet-bursting scheme specifically tailored for WDM-PONs is needed in order to achieve energy efficiency while maintaining packet delay at an acceptable level.

When looking at delay requirements there is an extra dimension to consider. They are not the same for all traffic types. Some are more stringent, while others are more flexible in allowing longer transmission times. This extra dimension can be leveraged to obtain better energy efficiency. This idea has already been presented in [9] for TDM-PONs where every traffic class is assigned an adaptive sleep period in function of the traffic type. The work presented in [10] extends this approach with the introduction of adaptable sleep periods. In these studies, once a transceiver is put into sleep mode it cannot be waken up to accommodate the arrival of high priority packet. As a result, these approaches cannot benefit from long sleep periods, if they want to guarantee low maximum packet delay constraints. Sleep periods in the range of 5-10ms are considered in [9] or even much higher (i.e., 100-200ms) in [10], thus making these scheme not applicable in cases where the delay requirement are more stringent, e.g., in mobile backhaul.

In this paper we address energy efficiency in WDM-PONs while exploring differentiated delay requirements. We propose a packet transmission scheme where transceivers at the OLT and at each ONU are dozing while still being able to guarantee the maximum delays required by each traffic class. In particular the paper focuses on backhauling scenarios, where some applications may have very low delay requirements per OLT-ONU segment, e.g., less than 1ms for long term evolution-advanced (LTE-A) and less than 5ms for LTE [13].

The remainder of this paper is organized as follows. In Section II the proposed mechanism is described. In Section III we explain the methodology used for the performance evaluation presented in Section IV. Finally, Section V gives some concluding remarks.

II. Power-Efficient Schemes with Maximum Delay Constraint Guarantee

In this section, we present the proposed power-aware scheduling algorithm for WDM-PONs able to guarantee, for each class of service, a predefined value for the maximum packet delay. Our scheme leverages on the dozing concept where the OLT and the ONU put their respective Txs into sleep to save energy. This method can be easily implemented in already deployed WDM-PONs without the need of any additional synchronization protocol for the transmission between the OLT and ONUs. We first explain how the scheme works with only one traffic class and then we extend it to a more general case, where multiple traffic classes are considered.

A. Computing the Tx wakeup time

The procedure for computing the wakeup time of the OLT/ONU Txs tries to maximize the time spent in sleep mode while keeping the impact on packet delay at an acceptable level.

When a packet p arrives, it is assumed that the Tx at the OLT/ONU is in one of the following two modes:

- *Active mode* (or under transition from sleep to active): p is transmitted immediately (or directly after the transition phase is over). The packet delay consists only of the transmission and the propagation time (and a part of the transition time if it applies).
- *Sleep mode* (or under transition to sleep mode): p is put in a queue waiting until the Tx wakes up.

To maximize the energy saved, the Tx should stay in sleep mode as much as possible. On the other hand, the longer the Tx is sleeping the larger is the delay experienced by packets, with a potential risk to exceed the maximum delay constraint (i.e., defined as the maximum acceptable time between a packet p arrives at the Tx and the time p is received at the other side of the link). In order to find a good compromise between these two quantities (energy consumption vs. delay) we propose a strategy to decide when the Tx should wake up and transmit (within the delay constraint) all the packets in its queue. *Fig. 1* shows a time diagram for the proposed Tx wakeup process. For simplicity, only one packet p is considered in the example.

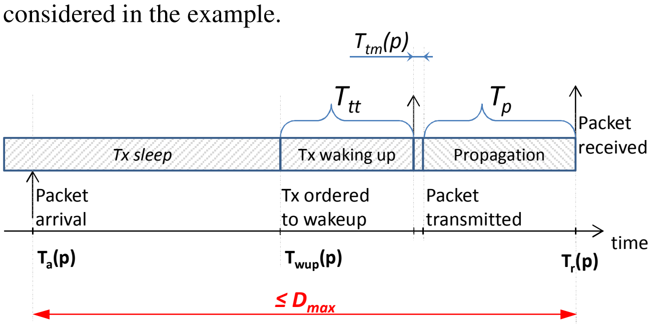

Fig. 1 Time diagram describing the transmission of a packet p.

The notation used in the example is described next:

- D_{max} – maximum packet delay,
- T_p – propagation delay (between OLT and ONU),
- T_{tt} – transition delay between sleep and active states[1],
- $T_{tm}(p)$: transmission time of p,
- $T_a(p)$: time at which p arrives to the Tx,
- $T_r(p)$: time at which p is received,
- $T_{wup}(p)$: time when the Tx should be waken up to meet the maximum delay requirement of p.

To ensure that the maximum delay constraint of p is met, the following inequality need to be satisfied: $T_r(p) – T_a(p) \leq D_{max}$. According to the diagram in *Fig. 1*, $T_{wup}(p)$ can be calculated as:

$$T_{wup}(p) = T_a(p) + D_{max} - T_p - T_{tt} - T_{tm}(p). \qquad (1)$$

If, for simplicity, D_{max}, T_p, and T_{tt} are constant (i.e., they do not change for all the packets belonging to the same class as p) then T_{maxq} can be defined as the constant representing the maximum period of time within which the Tx must finish transmitting a packet:

$$T_{maxq} = D_{max} - T_p - T_{tt}. \qquad (2)$$

Notice that the Tx always goes to sleep right after its queue is emptied. Thus, the following must always be guaranteed: $D_{max} > 2{*}T_{tt} + T_p + T_{tm}(p)$, to assure that a packet p arriving right after the Tx started the transition from active to sleep state will still be delivered within D_{max}.

In (1) only one packet is considered. On the other hand, it is important to consider a more general scenario where the presence of additional packets may influence the calculation of $T_{wup}(p)$. For any incoming packet p_i the Tx's wakeup time $T_{wup}(p_i)$ is calculated as:

$$T_{wup}(p_i) = T_a(p_i) + T_{maxq} - \Sigma_{1\leq j\leq i}\, T_{tm}(p_j), \qquad (3)$$

where $\Sigma_{1\leq j\leq i}\, T_{tm}(p_j)$ represents the time that is required to transmit p_i plus all the i-1 packets that arrived before p_i. If $T_{wup}(p_i)$ is computed at each packet arrival, then T_{WUP} is defined as the smallest among all the values of $T_{wup}(p_i)$. Obviously, T_{WUP} cannot take place in an instant earlier than the current time (T_{now}). Therefore, T_{WUP} can be computed as:

$$T_{WUP} = max[min_n(T_{wup}(p_n)),\, T_{now}],\ 1<n<i \qquad (4)$$

Let's consider the following example (*Fig. 2*). Three packets (i.e., p_1, p_2, and p_3) arrive in the order of their increasing index. $T_{wup}(p_2)$ is earlier than $T_{wup}(p_1)$ since it has to account also for the transmission of p_1. $T_{wup}(p_3)$ on the other hand is later compared to $T_{wup}(p_1)$ and $T_{wup}(p_2)$. As a result $T_{WUP} = T_{wup}(p_2)$. Once the Tx is on, all three packets are then transmitted.

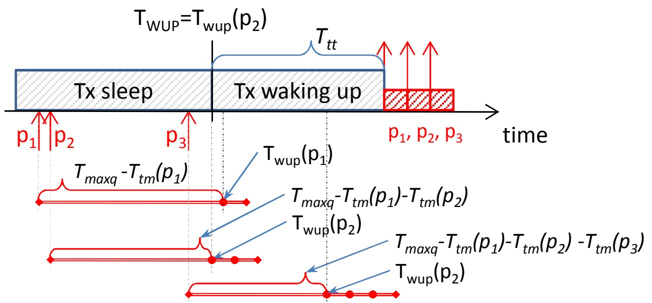

Fig. 2 Calculating wakeup time (T_{WUP}) with multiple packets.

B. Energy efficiency with traffic diversity

The procedure for computing the wakeup time of the OLT/ONU Txs described in the previous subsection is extended to account for traffic diversity, (i.e., classes with different delay requirements) in order to achieve better energy savings results, while still keeping the packet delay under control.

The wake up procedure explained in the previous section considers one traffic class only, i.e., D_{max} is the same for all packets. In the presence of traffic with different delay constraints one possible way to improve the energy efficiency

[1] On a more general note it is also possible to differentiate between the transitions from active to sleep (T_{ttAS}), and from sleep to active (T_{ttSA}). We assume here: $T_{tt} = T_{ttAS} = T_{ttSA}$.

is to make decisions on the wakeup time of the Tx based on traffic differentiation. For simplicity, in this work only two traffic classes are considered: high priority (HP) and low priority (LP) traffic. The maximum delay allowed for the HP class is D_{maxHP}, while the one for the LP class is D_{maxLP} (with $D_{maxHP} << D_{maxLP}$). As a results, also two values for T_{maxq} are defined, i.e., T_{maxqHP}, and T_{maxqLP}. The rationale for this service differentiation is to allow LP packets to wait in the queue as long as they can, without compromising the delay performance of HP packets, which usually have more stringent constraints. This in turn, may allow the Tx to be asleep on average for a longer time, thus gaining in terms of overall energy savings. In contrast, if a first-come first-serve (FCFS) policy is used (as in the example of *Fig. 2*) there might be a problem in meeting the delay constraints of some packets. Consider the following example. A HP packet arrives at the Tx with a substantial backlog of LP packets in the transmission queue. Even if the Tx is turned to active mode immediately as the packet arrives it might happen that, by the time the backlog is transmitted, T_{maxqHP} has already expired, violating the delay constraint for that particular packet. In other words, to take advantage of different traffic profiles coexisting in the PON it is necessary to prioritize packets differently, e.g., HP packets should not wait for transmission of LP packets.

With this objective in mind we propose an approach that applies multiple queues, one for each traffic class, used to store packets before they are transmitted. Which packets are sent first depends on the scheduling algorithm. In this work we choose a strict priority scheme, i.e., HP packets are always sent before LP packets. The calculation of $T_{wup}(p_i)$ is modified from the expression in (3) as follows:

- if p_i is a HP packet then:
  $$T_{wup}(p_i) = T_a(p_i) + T_{maxqHP} - \Sigma_{j\epsilon\{HP\ packets\ and\ j\leq i\}}\, T_{tm}(p_j), \quad (5)$$

- if p_i is a LP packet then:
  $$T_{wup}(p_i) = T_a(p_i) + T_{maxqLP} - \Sigma_{j\epsilon\{LP\ packets\ and\ j\leq i\}}\, T_{tm}(p_j) - \Sigma_{\{all\ HP\ packets\}}\, T_{tm}(p_j). \quad (6)$$

T_{WUP} is computed using (4). *Fig. 3* shows an example in which T_{WUP} is calculated in a scenario where p_1 and p_2 are LP packets and p_3 is a HP packet. Note that packets are transmitted in an order that is different from their arrival.

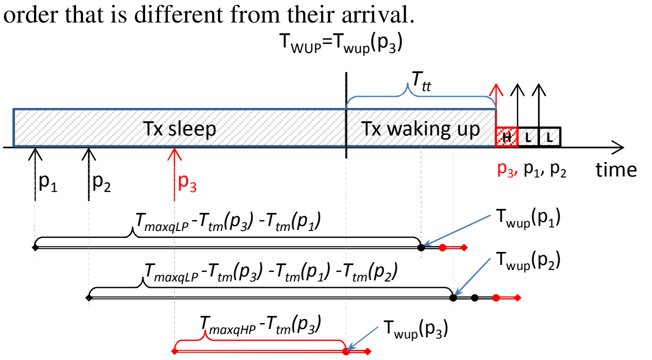

Fig. 3 T_{WUP} calculation with traffic diversity.

III. METHODOLOGY

The schemes presented in the previous section are evaluated in terms of packet delay and energy consumption using the OPNET package [14]. The OPNET state-machine representing the Tx at either OLT or ONU is shown in *Fig. 4*.

The states are:

- ***Init*** is called when the simulation starts. It initializes all variables used in the simulation. ***Init*** is a *"forced"* state, i.e., it does not wait for any event or condition, and it immediately goes to the next state, i.e., ***ActiveCheck***.
- ***ActiveCheck*** represents a Tx in active mode. Every time the machine reaches this state it checks if there are packets to be transmitted. If yes, the machine goes to the ***ActiveSending*** state, otherwise it goes to the ***GoingSleep*** state.
- ***ActiveSending*** is representing a Tx sending a packet from one of the queue(s), depending on the algorithm used in the specific experiment. Each time the machine is in this state one packet is sent. After sending a packet, i.e., the *PKT_SENT* event, the Tx goes back to the ***ActiveCheck*** state.
- ***GoingSleep*** represents a transition from active to sleep. The Tx stays in this state for T_{ttAS}.
- ***GoingActive*** represents a transition from sleep to active. The Tx stays in this state for T_{ttSA}.
- ***Sleep*** is representing a Tx in sleep mode. If a packet arrives while the Tx is in this state the value of T_{WUP} is calculated and the *WAKEUP* event is created or updated, according to the procedure explained in Section II. If no packets need to be sent while the Tx is in this state, the *WAKEUP* event is not created and the system stays in the ***Sleep*** state.

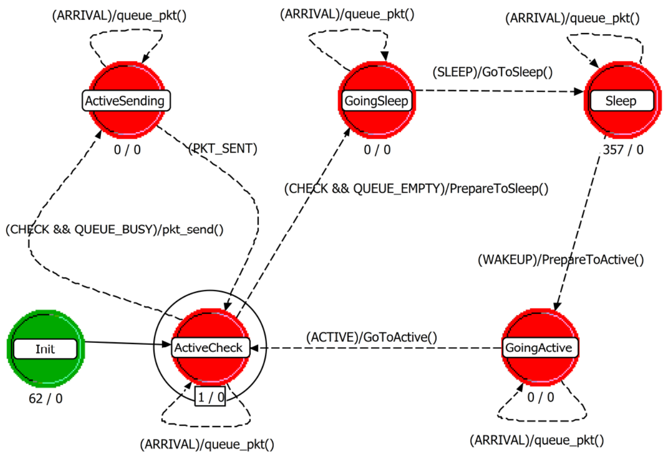

Fig. 4 OPNET state-machine model of a Tx.

An *ARRIVAL* event represents an incoming packet. Since this event can occur at any time, it corresponds to a loop in every state of the system. In the presence of an *ARRIVAL* event the incoming packet is buffered in the appropriate queue. There are two queues: *HP* and *LP*. Both of them are assumed to have an infinite buffer. The energy consumed in each state is recorded and contributes to the overall energy profile. The packet delay is logged for each packet and based on it an

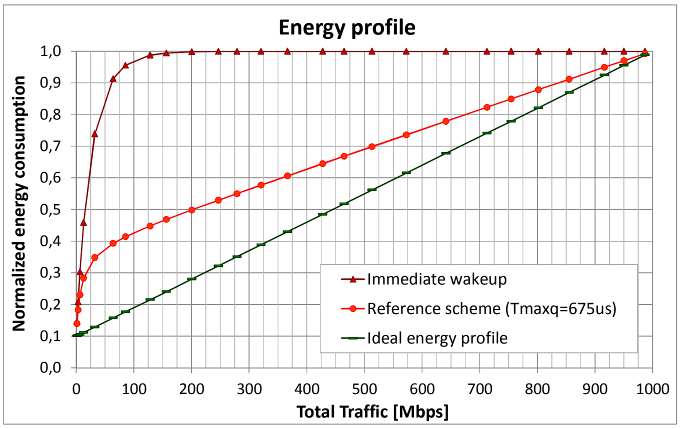

Fig. 5 Energy profile of Tx – reference scenario.

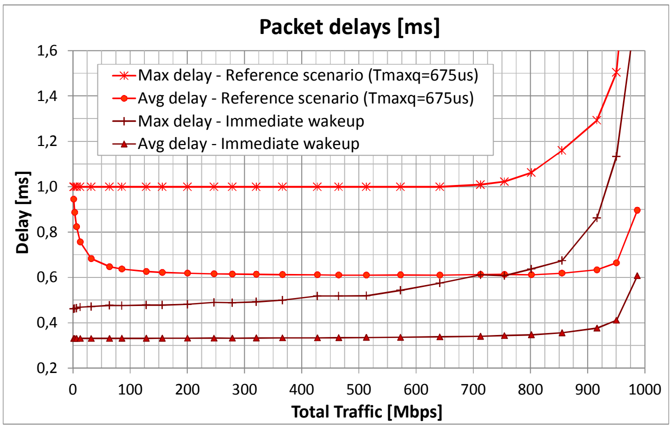

Fig. 6 Packet delays – reference scenario.

average and maximum delay is computed.

IV. RESULTS

In this section we compare three energy-efficient schemes: the scheme exploiting traffic diversity introduced in Sec. II, and two benchmarking approaches, i.e., *immediate wakeup scheme,* and *reference scheme*. In the first one, the Tx is active as soon as a packet is ready for transmission. In the second one, the delay requirement of each traffic class is ensured by treating all the packets as if they all belong to the class with the most stringent delay, i.e., D_{max} is set to D_{maxHP} in (1) and (2).

The simulation setup is the following. The data rate is 1Gbps. Each point in the curves corresponds to one simulation with one million packets. Packet arrivals follow a Poisson distribution while the packet length is uniformly distributed between 72 and 1526 bytes. We use separate generators for each traffic class, making sure that the desired low-priority vs. high-priority traffic-ratio is maintained. The transition time T_{tt} is assumed to be similar to the lowest available total overhead for the TDM-PONs as in [15][16]. The processing delay at the OLT and the ONU is assumed to be negligible. A summary of the simulation parameters is presented in the *Table 1*. The results for the power consumed by the ONU/OLT Tx are presented as an energy profile function, which shows normalized energy consumption as a function of the traffic load, as described in [17]. The total traffic load considered in this paper is referred to as the average data rate per connection between the OLT and ONU.

Table 1 Simulation parameters

Parameter name	*Symbol*	*Value*	*Unit*
Transition time between active and sleep states.	$T_{tt}=T_{ttAS}=T_{ttSA}$	125	µs
Distance between OLT and ONU.	d	40	km
Propagation delay between OLT and ONU.	T_p	200	µs
Max. delay for HP traffic, LTE-A [13].	D_{maxHP}	1	ms
Max. delay for LP traffic, LTE [13].	D_{maxLP}	5	ms
Max. time for a HP packet waiting in the queue.	T_{maxqHP}	675	µs
Max. time for a LP packet waiting in the queue.	T_{maxqLP}	4.675	ms
Energy consumption in active mode. (***ActiveCheck*** and ***ActiveSending*** states)	E_{on}	1	Unit
Energy consumption in sleep mode (***Sleep*** state)	E_{sleep}	0.1	Unit
Energy consumption during transition. (***GoingSleep*** and ***GoingActive*** states)	E_{tt}	1	Unit

A. *Reference scenario versus immediate wakeup scheme*

As shown in *Fig. 5*, the *reference scheme* provides significant energy savings when compared to the *immediate wakeup approach*. However, it may be possible to further improve the *reference scheme* since there is a notable difference compared with an *ideal energy profile*, i.e., a case which works exactly as the *immediate wakeup scheme*, but where the transition time between active and sleep mode is considered to be instantaneous, i.e., T_{tt}=0, without any energy overhead.

Fig. 6 presents average and maximum packet delay values for both the *immediate wakeup* and the *reference scheme*. The former approach achieves obviously lower delay than the latter, but the maximum delay for the *reference scheme* is kept below the specified requirement of 1ms (see *Table 1*) except when the load is high. The average packet delay for the *reference scenario* is below 620µs for the majority of the traffic load values. In very low traffic conditions (i.e., <50Mbps) the average delay rises up to 945µs. This can be explained by the fact that the majority of the arriving packets find the Tx in sleep mode, therefore they need to wait $T_{maxq}+T_{tt}$ before being received at the other side of the link. However when the total traffic is higher than 700Mbps, the maximum packet delay cannot be kept within the maximum delay requirement, i.e., it rises to 1.5ms at total traffic load of 950Mbps. The ratios of packets exceeding the maximum delay requirement are 0.001%, 0.054%, 1.98% and 5.0% of the total number of packets when the total traffic loads are 713Mbps, 802Mbps, 916Mbps and 950Mbps respectively. The reason for this behavior is the following. In the simulator, we allow for an instant arrival rate higher than the peak data rate (i.e., 1Gbps), while the queues for the traffic classes are implemented with an unlimited buffer size. This decision is mainly motivated by the desire not to drop packets if they are received while the OLT/ONU's Tx is asleep. On the other hand, having an unlimited buffer size may trigger the formation of packet bursts whose dimension may become excessively large. This is especially true at high traffic loads, when the Tx is not able to process packets for at least $2*T_{tt} = T_{ttAS}+T_{ttSA}$. In such a situation the transmission of these bursts may cause the maximum packet delay value to exceed the

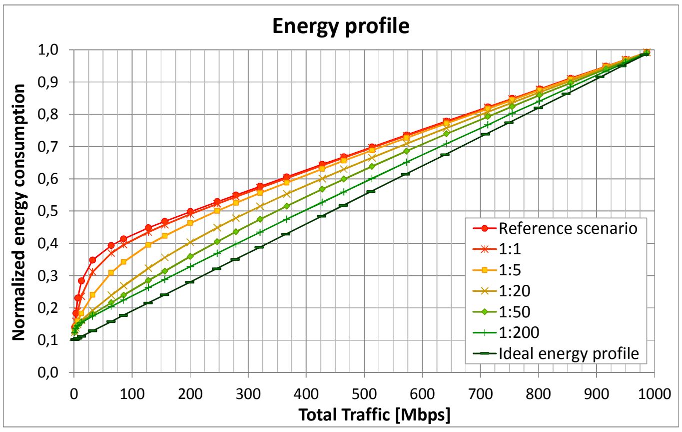

Fig. 7 Energy profiles when exploiting traffic diversity.

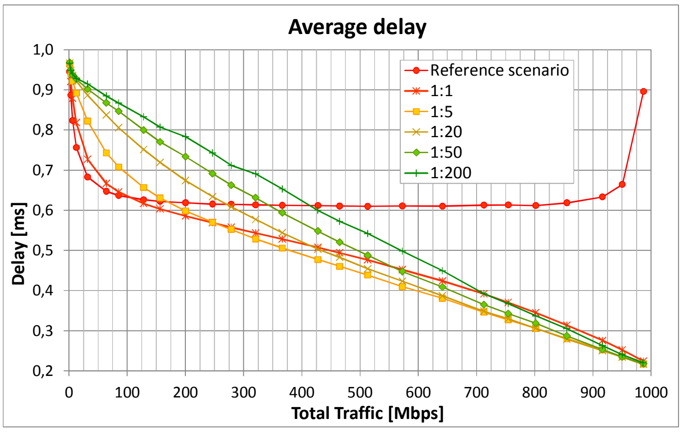

Fig. 8 Average HP packet delays when exploiting traffic diversity.

(1ms) delay constraint in both the *reference* and the *immediate wakeup scheme*. This phenomenon can be avoided by using buffers with limited size, at the price, on the other hand, of an increased packet loss rate.

B. Exploiting traffic diversity versus reference scenario

Fig. 7 shows energy consumption values for the *reference scenario* and compares them to the ones of the proposed scheme with traffic classes differentiation. In the proposed scheme, 5 different ratios between HP and LP traffic (i.e., 1:1, 1:5, 1:20, 1:50, 1:200) are considered. As shown in *Fig. 7*, the scheme with traffic classes differentiation can further improve the energy saving when compared to the *reference scenario*. It can also be observed that the lower portion of the HP traffic is, the higher the energy savings can be achieved. This can be expected since less HP traffic means that a Tx can sleep for longer time periods.

The proposed scheme also keeps the packet delay within the boundaries specified by the traffic requirements (see *Table 1*). As it can be seen in *Fig. 8*, the average packet delay values for HP traffic are lower than 1ms in all traffic conditions. It can also be noted that the higher the traffic load, the lower the average delay. It is because at high traffic load, the HP packets are more likely to find the Tx active at the arrival and they can then be transmitted immediately without any delay. Moreover, the measured maximum delay for HP packets in the service differentiated scenario is less than 999.4µs at any load, which does not exceed the D_{maxHP}. Meanwhile, the maximum packet delay of the LP traffic does not exceed D_{maxLP} in any considered scenarios.

V. Conclusions

In this article we propose a power-efficient scheme able to guarantee the packet delay requirements of the incoming traffic. The proposed scheme leverages on the dozing concept applied to the transceivers at both the OLT and the ONUs. For this reason it does not require any additional protocol for synchronization of OLT and ONUs, making it easy to be implemented in currently deployed WDM-PONs. Another important parameter worth studying is jitter. For this reason it is planned to enhance the technique presented in this paper to guarantee both delay and jitter limitations. In addition, different strategies to buffer the incoming traffic will also be explored to assess their impact on the performance of the overall system both in terms of delay and power consumption.

Acknowledgement

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 249025 (ICT-OASE) and n° 318137 (ICT-DISCUS).

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