Investigating the Energy Savings of Cyclic Sleep with Service Guarantees in Long Reach PONs

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Abstract: This paper evaluates what are the conditions, in terms of increased overhead time and number of optical network units (i.e., ONUs), in which cyclic sleep based techniques are effective in Long Reach PONs.

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1. Introduction

Site reduction (also known as *node consolidation*), is a technique by which a number of Central Offices (COs) are replaced by a single one. Operators are strongly supporting site reduction to simplify the operational complexity of their networks [1][2]. On the other hand, site reduction introduces a significant challenge in terms of large service area coverage. Long Reach Passive Optical Networks (LR-PONs) are a promising solution for enabling CO consolidation, thanks to their extended reach (i.e., up to 100km and beyond) and increased number of connected users (i.e., a thousand or more) [1][3]. Node consolidation also helps in decreasing the overall energy consumption of the network by reducing the number of energy-hungry COs. However, the need for active components to reach longer distances and to compensate for higher splitting ratio might, in turn, increase the power usage. Therefore, energy-efficient solutions are needed in LR-PON as well.

Standardization authorities so far have focused their attention on reducing the energy consumption of Time Division Multiple Access (TDMA) PONs [3]. ITU-T published a standard supplement (i.e., ITU-T G.Sup45) that defines energy efficient functions mostly based on cycles of "*on*" and "*off*" periods of the Optical Network Unit (ONU) at the customer side [4]. IEEE published the IEEE 803.2az standard, known as Energy Efficient Ethernet (EEE), in which Ethernet interfaces (up to 10Gb/s) can be set to sleep if low traffic conditions are experienced on a point-to-point link.

Despite many existing energy-efficient solutions for access networks in the literature, there has not been much work focusing on how to address the energy consumption issue in LR-PONs. For example in [5], an energy-aware planning approach is proposed for ring-and-spur LR-PONs, where power savings are achieved by improving resource utilization, hence decreasing the number of transceivers, based on different types of user behaviors (e.g., business and residential users have distinct daily bandwidth demand profiles). However, to the best of the authors' knowledge, the applicability of schemes based on sleep mode to LR-PON has not been investigated yet.

This paper focuses on sleep mode based schemes and analyzes their performance when utilized in LR-PONs. In particular, the *cyclic sleep mode with service based variable sleep period* (SB-cyclic sleep) scheme [6] is considered. Such scheme maximizes the sleep time at an ONU while guaranteeing the service delay requirement.

2. Applicability of Cyclic Sleep Mode with Service Based Variable Sleep Period in LR-PON

The concept of service-based variable sleep period was first introduced in [7] to save energy in ONUs while avoiding service degradation in the presence of traffic with requirements on performance (e.g., delay). In this approach, each Class of Service (CoS) is assigned a specific sleep period. If one ONU subscribes to multiple services with different CoS, the sleep period of the most demanding class is selected. The objective of this strategy is to maximize the energy savings while providing performance guarantees to the services subscribed by the ONU. However, the scheme proposed in [7] does not define a method for computing the sleep time as a function of the services subscribed by the ONUs.

The SB-cyclic sleep is based on the Sleep and Periodic Wake-up (SPW) (i.e., fast sleep) method proposed in [7] and it can be applied to any type of TDMA based PON, e.g., GPON, EPON, and hybrid Wavelength Division Multiplexing (WDM)/TDMA PON. In SPW, the choice of putting an ONU to sleep is based on the estimated downstream traffic arrival rate. Sleeping cycles are triggered by the Optical Line Terminal (OLT) by means of a specific field in the control messages sent to the ONU, called sleeping time T_{sl}, whose value is either greater than or equal to zero. In the former case the ONU is set to sleep for a period equal to the value of T_{sl}, while in the latter case the ONU is forced to stay awake. SB-cyclic sleep utilizes the same control method of SPW and uses a model of a polling system with gated service policy to compute T_{sl}. If one OLT and one ONU are considered, the maximum tolerable average delay W_q^{max} can be computed as the minimum of the average delays of all the services that the ONU is subscribed to. Then the polling system with gated service policy model is utilized to obtain an equation relating the maximum tolerable delay, the sleep time T_{sl} and the PON parameters, such as propagation delay between OLT and ONU (i.e., Round Trip Time *RTT*), average service time $\overline{S}$ for the frame transmission, and overhead time T_{OH} (i.e., the time for transition from sleep to active mode including synchronization) [6]:

$$T_{sl} = 2(W_q^{\max} - \overline{S} - RTT) - T_{OH} \quad (1)$$

When more ONUs are considered, this paper deals with a simplified scenario in which downstream transmission is based on fixed TDM scheduling and the sleep time T_{sl} is constant. Therefore, each ONU is active during its own time slot T_{slot} (i.e., T_c/N, where T_c is the cycle time and N is the number of the connected ONUs) while it sleeps during the slots reserved to other ONUs. In this scenario the energy efficiency η is defined as the percentage of energy saved by utilizing sleep mode with respect to not utilizing it:

$$\eta = \frac{E - E^{'}}{E} = \left(1 - \frac{P_{sl}}{P_a}\right)\left(\frac{N-1}{N} - \frac{T_{OH}}{T_C}\right) \quad (2)$$

where P_{sl} is the power consumed when the ONU is asleep, P_a is the power consumed when the ONU is active.

3. Evaluation Scenario and Results

The utilization of SB-cyclic sleep in LR-PON has been simulated using the OPNET Modeler© event driven simulator. For the sake of simplicity only one ONU and one OLT are considered. The considered CoS and their characteristics are summarized in **Table 1**. Data frames are assumed to arrive to the OLT with an inter-arrival time, which is negative exponentially distributed, thus generating a Poisson frame arrival process. Service data rates are generated by combining the frame arrival rate and a constant frame size of 1250 bytes for all the considered service types. Simulations are run by utilizing one source per service. In **Table 1**, two sets of delay constraints are considered. The set of ITU-T delay values is taken from [8] where an end-to-end connection (i.e., including backbone, aggregation and access segments) is considered. ITU-T delay can be, therefore, considered as an upper bound on the delay constraint. The set of OASE delay values is extracted from the delay requirement of an end-to-end connection and corresponds to one access segment [10]. P_{sl} and P_a are assumed to be 1W and 10W, respectively.

Table 1 CoS and constraints

Service type	QoS Class	Service	ITU-T delay [ms]	OASE delay [ms]	Data Rate [b/s]
Web Browsing	5	Best effort	Unspecified	200	30.4k
Internet Relay Chat	3	Transactional	400	100	1k
Multimedia on Web	4	Streaming	1000	40	28.8k-500k
Voice over IP	0	Real time	100	5	5.3k-64k

In **Figure 1** the energy efficiency is plotted as a function of the PON reach. The considered reach values go from 20 km to 100 km. Moreover the strictest delay constraints (i.e., Voice over IP) in both the ITU-T (where $W_{q,a}^{max}$ = 100 ms) and the OASE (where $W_{q,b}^{max}$ = 5 ms) set are considered. Results show that in the former case the reach has a negligible impact on the achieved energy efficiency while in the latter case the reach heavily affects the energy efficiency. This is due to the fact that the reach is directly proportional to the *RTT* as summarized by Eq. (1), i.e., an increase in reach has a higher impact on the sleep time (i.e., the energy efficiency) if the W_q^{max} is small, (i.e., $W_q^{max}=W_{q,b}^{max}$). **Figure 2** shows the energy efficiency as a function of T_{OH} (that varies in the [0,2] ms range), and of the reach *RTT* with a $W_q^{max}=W_{q,b}^{max}$. Results show that an increase in overhead time (i.e., an increased synchronization time) is more detrimental than a reach increase. In all the considered simulations, SB-cyclic sleep scheme can easily satisfy the required average delay constraint.

In

Figure 3 and **Figure 4** energy efficiency as a function of the number of ONUs (# of ONUs) is plotted based on Eq. (2) with a fixed T_c=2ms, T_{OH}=0.5ms and a capacity of 10Gb/s. Although

Figure 3 shows an increase in energy efficiency, such increase is due to a smaller time slot in each cycle per ONU. Therefore, for extremely high values of *N*, most of the time spent by the ONU is for synchronization purposes rather than for data transmission. Thus the bandwidth utilization per cycle is significantly affected as shown in **Figure 4**. A smaller slot time implies performance degradation, e.g., higher packet loss if the OLT has a limited buffer or increased delay in case of infinite buffer.

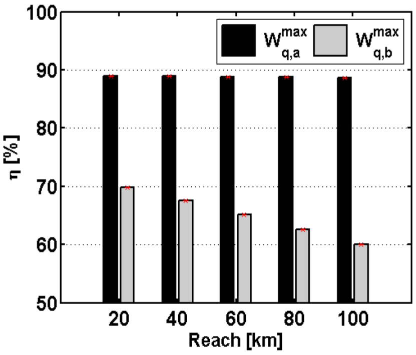

Figure 1 Energy efficiency as a function of the reach and of the delay constraint

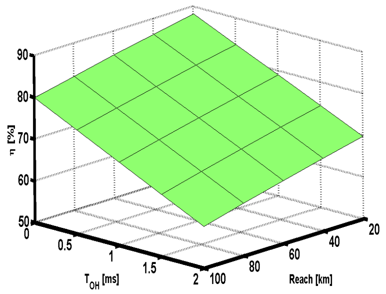

Figure 2 Energy efficiency as a function of overhead time T_{OH} and reach

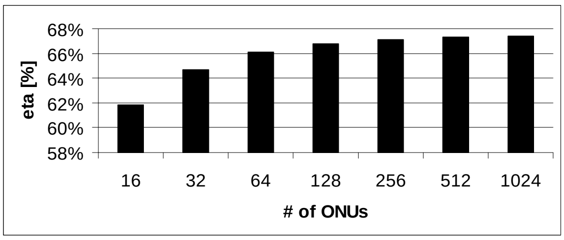

Figure 3 Energy efficiency as a function of the number of ONUs

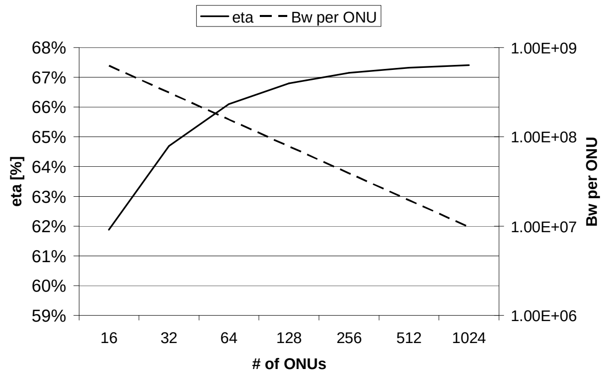

Figure 4 Energy efficiency and bandwidth per ONU as function of the number of ONUs (Bw ONU in log scale)

4. Conclusion

This paper evaluated the energy savings achievable in LR-PONs by the utilization of cyclic sleep mode. Results showed that by employing the SB-cyclic sleep scheme in LR-PON it is possible to guarantee services with the requested delay constraints and achieve noticeable energy savings. However, the reach might heavily impact these savings if the delay constraints are strict and the time to regain clock synchronization by the ONU after a sleep period is large. Moreover, if sleep mode is combined with fixed downstream bandwidth allocation the improvement in energy efficiency, as the number of ONUs increases, is due to a smaller time slot per cycle while the ONU spends always the same time for regaining clock synchronization. This implies that an increase in the number of ONUs decreases the energy consumption per ONU but at the expenses of a decreased bandwidth share, higher loss rate and delay.

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