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Grant management procedure for energy saving TDM-PONs

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ABSTRACT

In order to minimize energy consumption in Time Division Multiplexing-Passive Optical Network (TDM-PON), IEEE and ITU-T have mandated sleep mode mechanism for Optical Network Units (ONUs) in the latest TDM-PON standards (e.g. IEEE P1904.1 SIEPON, ITU-T G.sup45). The sleep mode mechanism is a promising mean for maximizing energy saving in an ONU. An ONU in sleep mode flips between *sleep* and *active state* depending on the presence or absent of upstream and downstream frames. To ensure Quality of Service (QoS) of upstream frames, the recent TDM-PON standards introduced an early wake-up mechanism, in which an ONU is forced to leave the *sleep state* on upstream frame arrival. When the Optical Line Terminal (OLT) of a TDM-PON allows early wake-up of its connected ONUs, it allocates gratuitous grants for the sleeping ONUs along with allocating upstream grants for the ONUs in *active state*. Note that, the gratuitous grants control message sent periodically by the OLT on Inter-Gratuitous grant Interval (IGI) time. After leaving *sleep state* due to the arrival of upstream frame, the ONU uses its allocated gratuitous grant to send a control message mentioning the amount of upstream bandwidth (upstream grant) required in order to forward the remaining frames in its buffer. However, the existing early wake-up process of ONU can lead to increase the energy consumption of an ONU. It is because of the ONU wakes-up immediately from the *sleep state* on arrival of the upstream frame, but even so, it needs to wait for forwarding the frame until its allocated gratuitous grant period, resulting in spending energy unnecessarily. In addition, current energy saving solution for TDM-PONs do not provide a clear solution on how to manage different types of grants (e.g. listening grant, upstream transmission grant) within a Dynamic Bandwidth Allocation (DBA) polling cycle. To address this problem, we propose a state-of-art Grant Management Procedure (GMP) in order to maximize energy saving in a TDM-PON with sleep mode enabled ONUs. GMP contributes in defining the location of the different types of grants during a DBA polling cycle. Furthermore, GMP devises a mechanism so as to allow an ONU to predict its assigned gratuitous grant control message arrival time, thereby allowing an ONU to remain its transceiver unit powered off until the arrival period of the next gratuitous grant control message, increasing the energy saving of the ONU. Results show that, with the increment of IGI, the energy saving performance of an ONU with GMP increases noticeably in compare to a conventional ONU (an ONU that does not use GMP) without imposing any additional upstream frame delay.

1. Introduction

Over the last several years, we have witnessed a significant amount of research effort in improving energy saving performance in Information and Communication Technology (ICT) equipment. The fact that motivated research from industries and academia is the stupendously growing footprint of ICT in increasing energy demand. In [1], it is reported that currently ICT is responsible of 8% of the global electricity consumption. Access networks equipment are contributing a significant portion in increasing overall ICT energy demand [2]. However, the utilization of access network equipment is only 15% [3,4].

Passive Optical Network (PON) is seen to be one of the key players in expansion of access network segment as it facilitates cost-effective services and high speed broadband Internet access to the end users. Around the world, PON is connecting approximately 130 million households [5]. The number of households supported by PON will be increased by threefold by 2019 [5].

Among the PON technologies, Time Division Multiplexing-PON (TDM-PONs) (e.g. Ethernet PON (EPON) and Gigabit-capable PON (GPON)) are widely adopted in Europe, Asia and North America. TDM-PON composed of mainly three equipment: Optical Line Terminal (OLT) installed at the central office of the service provider, Optical Network Unit (ONU) placed at the end user side, and passive splitter located at a remote side. In a TDM-PON, downstream frames (from the OLT to

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ONUs) are broadcasted to all connected ONUs through the passive splitter. An ONU accepts only frames designated to it by checking frame identifier (e.g. Logical Link Identification (LLID) in EPON). Whereas, upstream frames (from the ONUs to the OLT) are sent during the upstream time slot assigned to each ONU by the OLT.

Authors in [2] quantified that ONUs are responsible for consuming around 65% of the total TDM-PON energy consumption. Consequently, we can notice from research that most of the energy saving solutions of PONs are designed to make ONU more energy efficient (e.g. [6–9]). Commonly used approaches to decrease an ONU's energy consumption are TRx (transmitter and receiver) sleep and Tx (transmitter) Sleep. TRx and Tx sleep modes approaches are standardized in IEEE P1904.1 Standard for Service Interoperability in Ethernet Passive Optical Networks (SIEPON) [10] and ITU-T G.sup45 [11] (note that TRx sleep in SIEPON is equivalent to cyclic sleep in ITU-T, and Tx sleep in SIEPON is equivalent to doze mode in ITU-T G.sup45). In the TRx sleep, the transmitter and receiver of the fiber link and other energy consuming components (e.g. Photo Detector and Limiting Amplifier [7,12]) in an ONU are periodically switched on and off for defined period of time in the quest of saving ONUs energy while serving customers at the customer premises.

In OLT-driven energy saving approach (e.g. SIEPON [10]), the OLT is responsible for invoking an ONU to enter into a *sleep state* for a defined duration. In the SIEPON, a bunch of new control messages introduced to satisfy energy saving procedure (e.g. *sleep_allowed* and *earlyWakeUpONU* control messages). To send any control message, it is required to get a grant from the OLT to prevent upstream frame collision. However, the standard and current research efforts (e.g. [13–15]) did not define how to organize the upstream grants on each Dynamic Bandwidth Allocation (DBA) cycle with details. Furthermore, it has been found in [7,16] that control message overhead related to energy saving can contribute in reducing energy saving performance of an ONU. If grants are not properly allocated, it lead to have grants conflict. Moreover, inappropriate placement of a different types of grants can decrease upstream bandwidth utilization due to unallocated time slot during a DBA cycle [13].

In this paper, we introduce a procedure that answers the question on how to manage different type of grants for ONUs. Thus, we defined the location of different types of possible grants in each DBA cycle and we draw an algorithm for this procedure. Furthermore, we develop an algorithm to handle control messages overhead and reduce an ONU energy consumption as much as possible.

The organization of this paper is as follows. Section 2 presents related work. In Section 3, we introduce our proposed procedure and system model. Section 4 discusses important results. Finally, we conclude our findings in Section 5.

2. Related work

The OLT in a TDM-PON works as a master device that controls all connected ONUs. The OLT uses DBA algorithm to calculate the upstream duration (*upstream grant*) for each ONU within a DBA cycle time. ONUs send *report* control message at the end of each upstream grant to inform the OLT its current buffer status [6,10,17]. The OLT collects *report* control messages and estimates required upstream grant for the next DBA cycle, and then sends a *grant* control message to each ONU.

The OLT in a TDM-PON with sleep mode can generate three different types of grants (i.e. *upstream grant* [6,10,17], *listening grant* [18] and *gratuitous grant* [10,19]). *Upstream grants* are created by the OLT on each DBA cycle to all active ONUs, whereas the *listening grant* can be created at the end of the sleep period for the ONU that invoked to enter into *sleep state*, and the *gratuitous grants* are periodically created by the OLT for sleeping ONUs on every Inter-Gratuitous grant Interval (IGI) time (based on the system configuration). Accordingly, these three different types of grants can exist on each DBA cycle when sleep mode is enabled in a TDM-PON. It has to note here that an ONU can receive a single grant on each DBA cycle (i.e. *upstream grant*, *listening grant* or *gratuitous grant*). However, existing TDM-PONs energy saving procedures did not provide explicit solution regarding the management of different types of grants during a DBA cycle time. For instance, authors in [13–15] did not point to all type of grants. Furthermore, authors in [6–9] assumed that the OLT can assign a small time slot during a DBA cycle for each sleeping ONUs. This allows the ONUs in sleep mode to make upstream bandwidth request to the OLT in presence of traffic. However, the arrangement of grants is out of the scope in [6–9]. Thus, it is important to provide a trenchant solution that handle different types of grants during DBA cycle time.

The SIEPON standard [10] specifies that PON components (i.e. OLT and ONU) should support early wake-up function (EWF). EWF allows ONUs to move from the *sleep state* to *active state* prior to the end of assigned sleep period [10]. It has to note here that in a TDM-PON the OLT is responsible for issuing grants to all connected ONUs to prevent upstream traffic conflict due to the nature of shared medium (two ONUs must not send traffic at the same time). To support EWF, the SIEPON standard identifies that the OLT should periodically issues *gratuitous grant* for sleeping ONUs. It is important to mention here that the SIEPON standard [10] recommends that a sleeping ONU should leave *sleep state* before receiving a gratuitous grant; however, it does not define the Inter-Gratuitous grant Interval (IGI) for a sleeping ONU. Authors in [19] report that an IGI can make big deal on both energy saving and upstream efficiency. However, authors [19] evaluate the effectiveness of SIEPON's sleep techniques without introducing any method to portend the arrival time of the *gratuitous grant*. Fig. 1 sketches how EWF works.

We can notice from Fig. 1 that on arrival of upstream frames the ONU wakes-up and waits for the *gratuitous grant* from the OLT to send *earlyWakeUpONU* control messages and reports its buffer status. The main drawback of immediate wake-up of an ONU is that the ONU might need to wait for long time after leaving *sleep state* to receive the gratuitous grant, even so the ONU remains idle until the arrival of

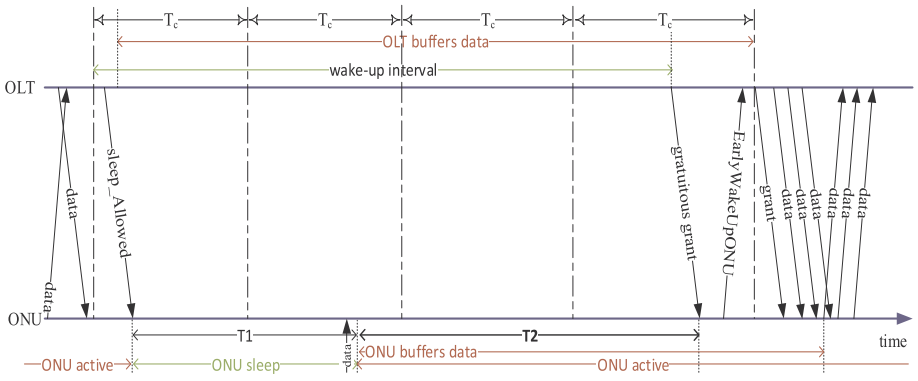

Fig. 1. Wake-up procedures in SIEPON.