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Performance analysis of TCP traffic and its influence on ONU's energy saving in energy efficient TDM-PON

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ABSTRACT

The majority of the traffic over the Internet is TCP based, which is very sensitive to packet loss and delay. Existing research efforts in TDM-Passive Optical Networks (TDM-PONs) mostly evaluate energy saving and traffic delay performances under different energy saving solutions. However, to the best of our knowledge, how energy saving mechanisms could affect TCP traffic performance in TDM-PONs has hardly been studied. In this paper, by means of our state-of-art *OPNET Modular* based TDM-PON simulator, we evaluate TCP traffic delay, throughput, and Optical Network Unit (ONU) energy consumption performances in a TDM-PON where energy saving mechanisms are employed in ONUs. Here, we study the performances under commonly used energy saving mechanisms defined in standards for TDM-PONs: cyclic sleep and doze mode. In cyclic sleep mode, we evaluate the performances under two well-known sleep interval length deciding algorithms (i.e. fixed sleep interval (FSI) and exponential sleep interval deciding (ESID)) that an OLT uses to decide sleep interval lengths for an ONU.

Findings in this paper put forward the strong relationship among TCP traffic delay, throughput and ONU energy consumption under different sleep interval lengths. Moreover, we reveal that under high TCP traffic, both FSI and ESID will end up showing similar delay, energy and throughput performance. Our findings also show that doze mode can offer better TCP throughput and delay performance at the price of consuming more energy than cyclic sleep mode. In addition, our results provide a glimpse on understanding at what point doze mode becomes futile in improving energy saving of an ONU under TCP traffic. Furthermore, in this paper, we highlight important research issues that should be studied in future research to maximize energy saving in TDM-PONs while meeting traffic Quality of Service requirements.

1. Introduction

Maximizing energy saving in Information and Communication Technology (ICT) becomes an important goal due to rise of energy price (operation expenditure) and environmental impact. Authors in [1] forecast that without any improvement in power saving in technologies, the total networks power consumption in 2025 could reach up to 75% of the world electricity supply of the year 2010. Access networks consume significant portion of overall ICT energy consumption. This is principally because the access networks consist of a huge number of components (i.e. Customer Premises Equipment (CPE)).

TDM Passive Optical Networks (TDM-PONs) (e.g. Ethernet PON (EPON) and Gigabit-capable PON (GPON)) are promising access network technologies (in terms of data rate and energy consumption), and thus they have been widely deployed. Equipment of a TDM-PON are: Optical Line Terminal (OLT), Optical Network Unit (ONU), and passive splitter. In a TDM-PON, ONUs are placed at the CPE side which can support number of users; whereas, the OLT is placed at the central office of the service provider.

The operation of a TDM-PON is point-to-multipoint network in which the OLT connects multiple ONUs via optical medium through passive splitter. The OLT plays the vital role as the master device and it controls multiple slave ONUs. The main role of the

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OLT is to assign upstream grant time to connected ONUs to send their traffic.

An ONU in a TDM-PON sends control messages (e.g. '*Report*' control message in EPON) to the OLT mentioning its queues status. The OLT collects this information and, then uses a Dynamic Bandwidth Allocation (DBA) algorithm for calculating required upstream bandwidth for all connected ONUs. The OLT notifies the amount of allocated bandwidth to an ONU through '*Grant*' control message. The downstream traffic (from OLT to ONUs) is broadcasted to all connected ONUs. An ONU filters frames by checking frame identifier (e.g. Logical Link Identification (LLID) in EPON) of the incoming frames, and accepts frames destined to it.

Research findings reveal that access networks are the main contributor for overall ICT energy demand [2]; however, the equipment deployed in access networks are poorly utilized (findings in [3] claim that the utilization of access networks is less than 15%). This has motivated many researchers to put effort on maximizing energy saving of different access network technologies including WiMAX and Fiber-to-the-Home (FTTH).

It has been quantified in [2] that the ONUs consume 65% of the total energy consumption of a PON. Therefore, most of the energy saving research efforts are centered on maximizing energy saving at ONUs. In this perspective, researchers from academia and industry are attracted to develop and propose energy saving techniques and protocols for ONUs in TDM-PONs.

A widely used approaches to reduce an ONU's energy consumption are cyclic sleep mode and doze mode. In cyclic sleep mode, the transmitter and receiver of the fiber link in an ONU are turned '*off*' and turned '*on*' periodically. Whereas, doze mode aims to power the transmitter '*off*' in absence of upstream traffic while keeping the receiver always '*on*. Note that there is an overhead time for ONUs to turn '*on*'/'*off*' its transceiver. The OLT uses an algorithm to decide sleep interval length. However, predicting proper sleep interval lengths is very difficult due to the bursty nature of traffic in access networks [4,5].

The majority of Internet traffic is Transmission Control Protocol (TCP) based [6], which provides reliable connection to numerous types of Internet services, and is very sensitive to packet loss and traffic delay. Note that there is a strong trade-off relationship between delay and energy saving performance of a network. The longer a node (e.g. ONU) sleeps, the less energy it consumes, but the higher the downstream traffic delay, and vice versa [5]. In wireless networks domain, there has been many studies (e.g. [7–9]) to understand and improve TCP performance when mobile terminals use energy saving techniques (e.g. sleep mode). However, to the best of our knowledge, investigating TCP traffic performance in a TDM-PON where energy saving approaches are employed in ONUs has been barely studied.

In this paper, we evaluate TCP traffic performance under two commonly used energy saving approaches of TDM-PONs: cyclic sleep mode and doze mode. We study TCP traffic delay and throughput behavior along with energy saving performance of an ONU that adopts those energy saving approaches to maximize its energy saving. As far as we know, this is the first effort towards understanding influence of energy saving on TCP performance in TDM-PON. Here, we analyze the relation among TCP traffic delay, throughput and ONU energy consumption. Under cyclic sleep mode, we evaluate the performance using two regularly utilized sleep interval length deciding algorithms; fixed sleep interval (FSI) and exponential sleep interval deciding (ESID). Results show that TCP throughput, delay and ONU energy performances are depended on number of TCP traffic flows. However, as the traffic increases in cyclic sleep mode, these performances can be similar for both FSI and ESID. When long sleep interval length is assigned to an ONU, it is likely to occurs OLT buffer overflow which leads to TCP downstream packet drop, chiefly under high TCP traffic flows. This consequently decreases TCP traffic throughput significantly. Moreover, in this paper, we strengthen the need for enhancing TDM-PON energy saving methods while meeting traffic Quality of Service (QoS) requirement.

The rest of the paper is organized as follows. Section 2 reviews background and related work. The system model and assumptions are described in Section 3. Section 4 presents the performance evaluation. In Section 5, we discuss and conclude our findings, and provide future direction.

2. Related work

In this section, we introduce energy saving mechanisms recommended in the standards, popular sleep interval length deciding algorithms, and related TCP performance analysis in PONs.

2.1. Energy saving in TDM-PONs

Early standards of TDM-PONs (e.g. IEEE 802.3ah [10]) did not consider ONUs' energy saving performance. Accordingly, an ONU transceiver remains always '*on*'. Four types of energy saving mechanisms have been recommended in ITU-T G.sup 45 [11] in order to reduce ONUs' energy consumption. These energy saving mechanisms are: cyclic sleep, doze mode, power shedding and deep sleep. Each scheme has its own energy saving strategy.

In cyclic sleep, an ONU enters into sleep state whenever there is no upstream and downstream traffic for it (cyclic sleep is known as TRx sleep in SIEPON IEEE 1904.1 [12]). Here, the OLT uses an algorithm to calculate ONU's sleep duration and notifies the ONU. Measuring a proper sleep duration is very critical in order to avoid frame delay and queue overflow at both ONU and OLT [5,4]. When an ONU moves into sleep state, it turns '*off*' some of its energy hungry components including its transceiver. The OLT buffers all downstream traffic designated to the sleeping ONU(s) of a TDM-PON. A sleeping ONU wakes up when its allocated sleep duration expires. Additionally, a sleeping ONU needs to leave sleep state on arrival of upstream traffic from user premises, as considered in SIEPON IEEE 1904.1 [12] and ITU-T G988 [13] (this phenomenon is termed as early wake-up [12,13]). In the doze mode, only the transmitter is turned '*off*'; so that, an ONU can save energy in absence of its upstream traffic. Note here that doze mode is equivalent to Tx sleep in SIEPON IEEE 1904.1 standard.

Shedding aims to power '*off*' or decrease the energy of unnecessary functions of an ONU while keeping the fiber link in full operation. In case of deep sleep mechanism, both the transmitter and receiver are turned '*off*' during the sleep state.

2.2. Sleep interval deciding algorithms

The cyclic sleep mode is a promising approach to save energy in TDM-PON. However, the sleep interval length in cyclic sleep is very crucial and truly formidable affair since there is a significant trade-off between traffic performance and energy saving. We found in literature that the most popular algorithms in TDM-PONs for deciding sleep interval length of ONUs under cyclic sleep (TRx sleep) mode are: (1) fixed sleep interval (FSI) and (2) variable sleep interval.

The FSI algorithm is widely adopted in literature (e.g. [14–17]). For instance, authors in [14] introduced a mathematical expression in order to understand energy and delay performances under FSI. In [15], authors proposed an analytical model in order to optimize the energy saving in the FSI based cyclic sleep mode. They evaluated the energy saving and delay performance varying buffer size, sleep interval length and arrival rate of an ONU. Authors concluded