

Sleep Mode on Delay Sensitive Traffic on Optical Network Unit

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Abstract— The search for energy efficient solution in communication networks has been a priority both in academia and in industrial research, especially in Access Networks. It is known that PONs contribute a significant amount of percentage (about 70 percent) of the fixed communication network energy consumption in fiber to the home system especially at ONU which consume about 60 percent of the power usage which originates from the user's site. In this paper, the simulation of fast sleep mode technique is conducted to test both the power and latency performance of the ONU for delay sensitive traffic in Time Division Multiplexing (TDM) PON.

Keywords— Optical fiber, Optical network unit (ONU), Passive optical network (PON), Power consumption, Sleep mode.

I. INTRODUCTION

Energy consumption in the information and communication technology sector has increased dramatically. Passive optical networks (PONs) are more energy efficient than traditional access networks, but the power consumption of PON systems remains significant and requires further investigation [1]. The main reason for the high-power consumption of PON is that the optical network unit (ONU) is on the customer's premises. Several studies are ongoing to reduce the power consumption of access networks.

According to ITU 2016, 84% of the world's population currently has access to broadband services [2] and this will increase in the near future. This expansion will require increased energy consumption, with approximately 59% of the world's energy generation going through thermal power plants, and the burning of fuel will emit greenhouse gases (GHG) [3]. About 21% of these greenhouse gas emissions in the ICT sector come from the telecommunications sector. By 2020, energy consumption is projected to reach 40 GW and by 2024 it is projected to reach 0.13 TW, or about 7% of the world's energy supply [4]. Therefore, carbon dioxide emissions can be minimized by an efficient energy saving scheme. In a previous report, it was already mentioned that access network power consumption accounts for 70% of the telecom sector, ONUs consume up to 60% and OLTs only 7%. The study shows that energy aware PON equipment can reduce power consumption by up to 58% [5].

This paper details the principle concept of fast sleep mode of ONU in attempt to reduce the ONU power consumption. The simulation of fast sleep mode technique was carried out for delay sensitive traffic in order to perform the power and latency performance of ONU in TDM PON system.

II. ONU POWER CONSUMPTION

Based on the current optical network access, passive power splitters operate in the field to evenly distribute power among users. This power is a huge waste of energy because all connections, including unused connection and nearby connection receive the same amount of power. In addition, the densely populated central offices and infra-structure facilities consume excess power.

Figure 1 shows the detailed distribution of FTTH power consumption. To reduce energy consumption, ONU needs to be very energy efficient. In the TDM-PON system, timeslots are shared between ONUs and each ONU can only transmit at certain time intervals. The ONU of the current PON system is activated most of the time, even if there is no usable transmission. This indicates that when they do not transmit or receive data, energy is wasted on ONU. If the distribution ratio is increasingly important to end users, then the amount of energy wasted is even more important.

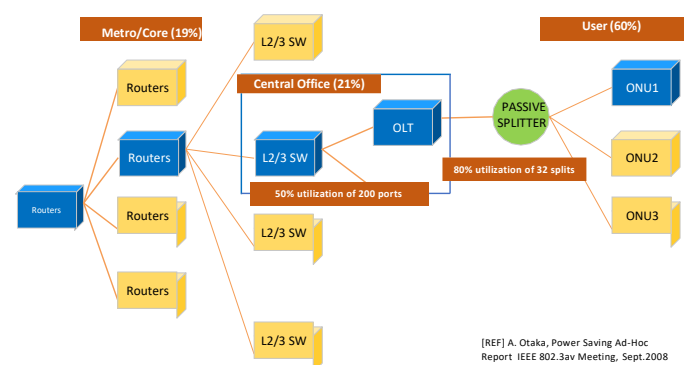


Figure 1. The Power Consumption of PON System

III. ONU SLEEP MECHANISM

The idea behind ONU in Sleep Mode is to turn off receivers when downstream data is not intended for them. Potential power savings if ONUs are only active during reception and switch to sleep in empty time slots. Significant power savings can be achieved by controlling the statistical multiplexing property of downstream traffic. Traditionally, the TDM PON system has not been able to benefit from sleep mode. This is because downstream data is continuously routed for clock synchronization between OLT and ONU. If the ONU stops receiving downstream transmission, the ONU clock synchronization is lost and the current ONU architecture requires a longer clock recovery time when the ONU wakes up from sleep. In addition, lack of synchronization between different ONU clocks can cause upstream data collision in the OLT.

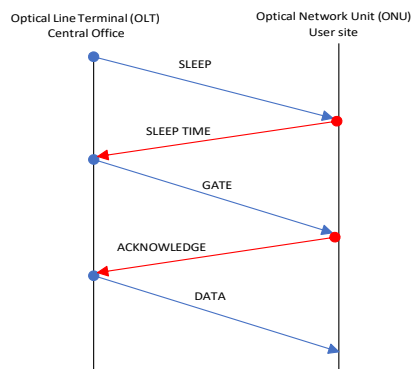


Figure 2. The Basic Principle of Power Saving Method

Figure 2 shows the basic concept of the power saving method. If there is no data to send, the OLT requests the ONU to go to sleep mode, and the sleep mode send also goes to sleep mode. The user network interface becomes inactive in the power bypass circuit and when the network is idle. The ONU sleep time is set to 2ms. After this, the ONU will automatically wake up from sleep mode. The OLT's internal circuitry continuously monitors incoming signals. If a signal is received during this period, the OLT will send a GATE message to signal the ONU to wake up. The ONU then sends an ACK signal to confirm this message, the ONU becomes active and begins receiving data from the OLT. This sleep-to-wake or wake-to-sleep process also consumes some power, but still less than the standby power loss.

The current ONU takes some time (~2ms) to restore the OLT clock from downstream data when the ONU switches from the sleep mode to active mode. Due to high synchronization delay, ONU cannot save energy within a standard TDM data cycle. The ONU thus normally wakes up to perform synchronous tasks and decreases energy efficiency. Sleep mode ONU with fast wake-up capabilities can address this problem to minimize overhead clock synchronization.

Various energy saving methods have been proposed for PON. Techniques in which the ONU transceiver is turned off

are of particular interest to research. An important concern is how to manage ONU's timely response to QoS requirements. To enable ONUs starting with OLT to wake up, the sleeping ONU transceiver should be turned on regularly to prevent possible wake messages from OLT. This state of constant transition between sleep and waking is often called cyclic sleep.

In addition, the time to wake up from the doze state is much shorter than the time to wake up from the sleep state, which means that doze states can be scheduled at finer granularity. This requires a better understanding of the energy saving potential of different implementation variants of cyclic sleep. The system used to predict patterns of arrival of new traffic based on information from previous periods is fundamental to the effectiveness of this fast sleep method approach.

IV. THE SIMULATION AND RESULTS

Past inter-arrival time for packets has been recorded to forecast future arrival patterns [6]. This simulation therefore is focused on the inspection of inter-arrival time packets and adjustment of sleep period accordingly. Two distinct methods of collecting inter-arrival time history were considered. That is, there is an arithmetic mean consisting of eight samples and an exponentially smoothed mean with appropriate smoothing parameters. Two methods of selecting sleep time are considered for each of these two approaches to predicting inter arrival times. The Matlab code used for the simulations generates the distribution of inter-arrival times emulating the downstream traffic transmitted from the OLT to one ONU.

The first method is a simple function with two minimum (6ms) and maximum (10ms) sleep period thresholds and a linear region between them where the sleep time is equal to the expected inter-arrival time. The second method [6] has a similar feature, but without an upper limit for the duration of sleep and where the duration of sleep is increased by a fraction of the expected duration (1/16), an inter-arrival time incremental scheme is added.

According to the analysis [7, 8], highly delayed sensitive services require a high level of interaction and / or real-time content delivery. Such as video phone calls, multiplayer online games or telecommerce. To guarantee quality performance, these services require the delay of IP packet transfer in less than 100 ms [7, 8].

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The inter-arrival time of frames in the simulations follows an exponential distribution, provided that downstream frames

arrive at the ONU in a Poisson distribution. The simulation does not fully describe the technique of the fast sleep mode because only certain estimates were made. First, the presence of upstream traffic is ignored and the message between OLT and ONU is not included in the simulations. Therefore, the functionality that made it possible to clear the outstanding sleep request in the OLT buffers could not be simulated. In fact, the queries run immediately because the simulations do not contain any messages. In addition, the search function for inactive periods in the downstream transmission is not available in the simulations since the distribution generated never allows this mechanism to be activated.

To perform the fast sleep technique, all control parameters had to be assumed with unique values. Firstly, eight samples ($N = 8$) are used to calculate the arithmetic average. Next, up to 6 times the wake-up time from the sleep period is set as a minimum schedule. Finally, one-sixteenth of the expected sleep time value was used as the shortest scheduled sleep time value for high latency traffic.

Some simulation parameters must be defined to achieve numerical results that describe the power and latency of the fast sleep technique. The ONU wakeup time is therefore estimated to be equivalent to 1ms; the active ONU power consumption is 10W and the ONU sleep state consumption is 2W. Both simulations are replicated ten times and the outcomes are averaged over this number. In the first simulations, the proposed technique and the simplified technique are applied to several exponential distributions of inter-arrival time. Each distribution composed of 100 samples and a different average value is characterized.

Figure 3 demonstrate the sleep-state time ratio in response to the mean values of inter-arrival time distributions for delay-sensitive traffic. The term Method 1 means propose technique which indicates a technique of fast sleep mode with adjustment of exponentially smoothed average. The term Method 2 is, however, technique 2 which is a simplified version of the proposed technique that uses an arithmetic mean to predict the inter-arrival times.

If the average frame arrival interval is less than ~4 ms, the ONU does not need to sleep, so the sleep time is zero. The graph shows that method 1 triggers the sleep period with a shorter average inter-arrival time than method 2. This is because there is a much longer inter-arrival times than the average, which causes the exponentially smooth mean of the previous sample values to collapse. Due to this fact, Method 1 triggers some sleep time earlier compared to the simplified method 2.

Once the average inter-arrival time exceeds ~6 ms, Method 1b also begins to turn off the ONU. Method 1 demonstrates greater energy saving potential than method 2 from this stage and up to ~10.5ms and ~80ms of average inter-arrival time. This is because when the arithmetic mean estimation has

reached the triggering threshold, it declines less quickly than the Method 1.

Indeed, the first Method 1 can adjust more quickly to the changes of traffic conditions without the risk of resetting its forecast to a value below the triggering threshold, as the average values of the inter-arrival times are quite far from it. Figure 3 also shows that the two methods appear to present the same efficiency when the average inter-arrival time is very high ~100ms.

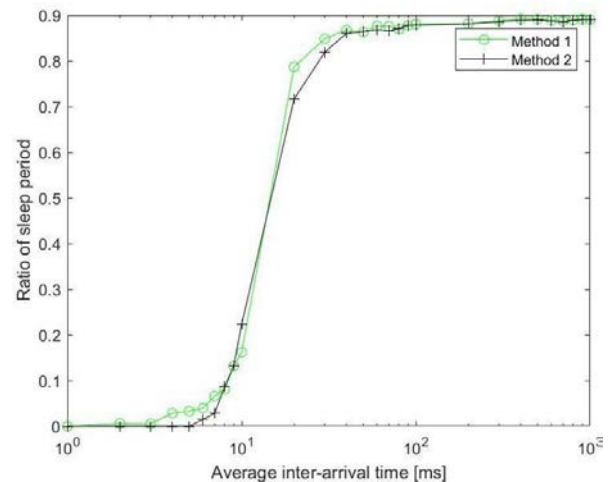


Figure 3. Ratio of sleep period in response to average inter-arrival time.

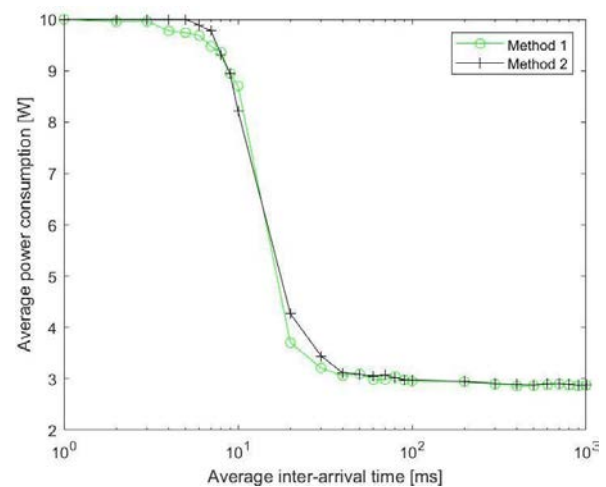


Figure 4. Average power consumption in response to average inter-arrival time.

The results shown in Figure 3 are reflected in Figure 4 using power consumed by one ONU as a function of the average frame inter-arrival time. Method 1 adopted for delay-sensitive traffic is only useful if the average cost of arrival intervals exceeds approximately 100ms. It is important to point out that this behavior is strongly dependent on simulation parameters.

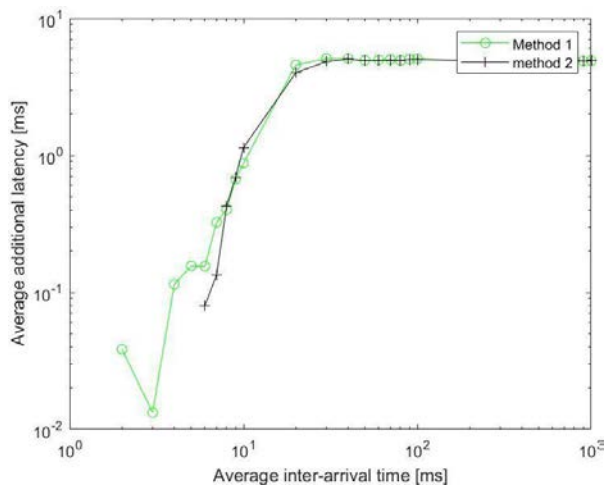


Figure 5. Average additional latency in response to average inter-arrival time.

A similar trend occurs when the delay-sensitive traffic requires less tolerance on the additional queuing delay. In this case, the maximum schedulable time in delay sensitive traffic is shorter, which worsens the power efficiency. This fact is shown in Figure 5 which determines the maximum tolerable additional delay for delay-sensitive traffic to 5ms.

V. CONCLUSIONS

Various solutions offering energy-saving capabilities in TDM-PONs and other PON types have been studied by researchers around the world and by standardization bodies. Many of them are based on the techniques known as sleep mode. In accordance with the mechanism defined by the technique, the ONU (optical network devices, customer premises and components) is turned off (partially or completely) for a certain period. In this way large quantities of energy can be saved as ONU is the main cause for power consumption in TDM-PONs.

The simulation results show that, in general, Method 1 leads to more efficiency saving than the technique based on a simpler method (Method 2) if the frame arrivals obey a Poisson distribution. As the traffic rate gets smaller, this becomes more and more apparent. Method 1b, on the other hand, usually produces fewer than 90 additional traffic latencies than Method 1. When the interarrival times of the frame follow an exponential distribution with a mean value that varies over time, the situation changes. In this case, in most experiments, Method 1 demonstrates better latency performance than Method 2. This is due to the prediction methodology introduced in Method 1 that adapts to changing traffic conditions more quickly.

However, further modelling of delay-sensitive traffic behavior is needed to separately determine if the traffic coming to ONU is either from IPTV, VOIP, or data communications, which can save a lot of energy by using the

sleeping mode technique with acceptable delay and latency of the services and without degrading QoS.

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