On Forecasting the ONU Sleep Period in XG-PON Systems Using Exponential Smoothing Techniques

Panagiotis Sarigiannidis*, *Member*, *IEEE*, Athanasios Gkaliouris*, Vasiliki Kakali†,
Malamati Louta*, *Senior Member*, *IEEE*, Georgios Papadimitriou†, *Senior Member*, *IEEE*,
Petros Nicopolitidis†, *Senior Member*, *IEEE*, Mohammad Obaidat‡, *Fellow*, *IEEE*
*Dept. of Informatics and Telecommunications Engineering, University of Western Macedonia, Kozani, Greece
†Dept. of Informatics, Aristotle University of Thessaloniki, Greece
‡Dept. of Computer Science, Monmouth University, West Long Branch, USA
Corresponding author email: psarigiannidis@uowm.gr

***Abstract*—Power management has been advanced on a crucial factor in the design of modern access networks. Furthermore, the proliferation of optical networking in the last mile led major Telecom unions, such as the International Telecommunication Union (ITU), to emerge energy consumption as a critical objective of the next generation passive optical networks (NG-PONs). In particular, the standardization of the 10-gigabit-capable PON (XG-PON) entails well-defined specifications towards power management and energy reduction, especially regarding the power control of optical terminal devices such as the optical network units (ONUs). In this way, the optical line terminator (OLT) along with ONUs are able to cooperate with each other in order to succeed energy reduction, by applying doze or cyclic sleep periods to idle ONUs. However, the sleep period determination remains a quite challenging research area. In this study, we endeavor to provide XG-PON networks with an effective forecasting mechanism that is capable of estimating the time duration of the forthcoming sleep session. To this end, we apply the exponential smoothing technique to best estimate the sleep duration based on the monitoring time series observations. The obtained evaluation results sound quite promising, since the proposed model accomplishes to advance the trade-off between the energy reduction and network efficiency.**

***Index Terms*—bandwidth allocation; energy efficiency; exponential smoothing; passive optical networks; XG-PON**

I. Introduction

Optical networking offers high rates of bandwidth to end users and allows the fulfillment of modern service provisioning. As the optical fiber continuously gains ground in the access network arena, the next generation passive optical networks (NG-PONs) pose as the most promising architecture to realize a cost effective all-optical access network. The vast growth of the PONs is accompanied with an analogous increasing in subscriber terminals, optical devices, and transceivers [1]. Inevitable, as the optical access network is spread across the last mile the power needs become more demanding. For various reasons such as the cost reduction, the environmental balance, and the maintenance overhead, both industry and academia push for scaling down the energy consumption in modern access networks. Hence, the energy efficiency remains one of the most challenging topics in the agenda of telecom companies and suppliers.

In deploying a PON the tree topology is the most typical. The main network components are a) the optical line terminal (OLT), which is located at the central office (CO) and provides the end users with access to the backbone network, b) the optical network units (ONUs), which are responsible of connecting end users to the OLT and vice versa, and c) the passive optical connector/splitter, which is a green device without consuming power and realizes an all-optical network deployment by multiplexing various optical signals to a single one and vice versa. End users are directly connected to the ONU and utilize the uplink direction, from the ONU to the OLT, to send data to the CO. In reverse, data originated from the backbone network are collected by the OLT which broadcast the incoming data to the ONUs in the downlink direction.

The 10-gigabit-capable PON (XG-PON) has been identified by the full service access network (FSAN) group as the most promising optical network for cost effective deployment [2]. One of the major assets of the XG-PON architecture lies in its powerful configuration regarding the power management. In particular, the International Telecommunication Union (ITU) indicates a flexible configuration of the ONUs in relation with the power management. Given that the ONU is a core device that interconnects the final user with the OLT, which constitutes the gateway to the backbone, it could vigorously contribute towards energy reduction. According to the T-REC-G.987.3 specifications [3], the ONU is configured to enter into a low power mode provided that it remains idle. This low power mode entails either a doze or cyclic sleep mode. Entering an ONU in doze mode entails that no traffic exists in its uplink interface. Practically, this means that the uplink queue, which gathers data packets from the end users connected to the ONU, remains empty. On the other hand, a cyclic sleep session is rather more rare, since it requires idleness in both uplink and downlink ONU interfaces. A power management scheme is responsible of handling the behavior of the ONU in mode switching. Under optimal conditions, this scheme succeeds as much as possible energy savings without harming the network operation. However, the determination of the sleep period is not a straightforward objective, because of the traffic variations and network dynamics.

The number of research efforts towards the determination of the ONU sleep time is deemed as marginal. In [4], the sleep

978-1-4799-3512-3/14/$31.00 ©2014 IEEE

duration is extracted using a well-defined cost function which associates the state transition delay with the estimated power consumption in an ONU. A Poisson process is considered to model the inter-arrival procedure. The work examines the way the cyclic sleep mode affects the network performance. The work in [5] studies the impact of the ONU buffer size on the effective implementation of the cyclic sleep mode. Through analytic modeling, the ONU operation is examined in a cyclic sleep mode when upstream arrivals exist. Numerical simulations are used to calculate the optimal ONU buffer size, while the authors demonstrate the average delay upstream traffic of an ONU being in a cyclic sleep mode. The authors in [6] attempt to evaluate various energy efficient methods in NG-PONs. None of the above efforts support an efficient power reduction mechanism with forecasting capabilities. Since the current access networks experience dynamic changes and unexpected traffic alterations an effective energy efficient scheme is necessary to ensure guaranteed energy savings without network performance disorientation.

In this paper, we aim at addressing this challenge. The subtle properties of the XG-PON systems are identified and an effective energy-efficient mechanism is proposed. The added value of the mechanism lies in its ability to accurately forecasting the sleep period independently of the sleep mode. The ONU mode alterations are appropriately modeled and a powerful prediction technique is devised based on the exponential smoothing method. The merits of the adopted forecasting method are identified in the way of computing the data points taken over time. As will be discussed later, the exponential smoothing perfectly fits in estimating such periodical data, like the ONU sleep time, since it is capable of discovering the underlying trend and seasonality.

The remainder of this paper is organized as follows. Section II reveals the sleep capabilities in XG-PON systems. In Section III, the proposed energy-aware mechanism is thoroughly described, while Section IV presents evaluation results accompanied by detailed comments. Finally, Section V concludes this paper.

II. Power Modes in XG-PON

In a XG-PON system, the OLT via the ONU management and control interface (OMCI) mechanism manages the connected ONUs. Among others, the OMCI signaling mechanism deals with the power management message exchanging between the OLT and the ONUs. The XG-PON power management mechanism consists of a number of power state machines. A state is defined as a specific mode in which an ONU operates for a certain time period. The states are connected with each other and form two mutually exclusive subsets, the full power and the low power subset. The full power subset comprises two distinct management states: the ActiveHeld and the ActiveFree state. During the ActiveHeld state, the system operates normally with full power consumption. In the ActiveFree state, the ONU monitors the upstream traffic reaching at its interface and the downstream traffic that is collected by the Service Node Interface (SNI) located at the OLT to be sent to the ONU. Based on the collected information, the ONU decides on whether a sleep mode could be applied.

The low power subset consists of two low power modes, the doze and cyclic sleep mode. During the doze mode, the receiver remains switched on, whereas the transmitter is switched off. Thus, in this mode the ONU is able to receive downstream traffic. On the other hand, in the cyclic sleep mode both transmitter and receiver are switched off. In the XG-PON power management mechanism, each sleep mode has a pair of states. The doze mode includes the DozeAware and the Listen state, while the cyclic sleep mode comprises the SleepAware and the Asleep state. During the DozeAware and SleepAware states, it is decided whether these states will transmit to the Listen and Asleep state, respectively. The DozeAware state monitors the upstream traffic, while the SleepAware checks both upstream and downstream traffic.

III. Proposed Energy-Aware Mechanism

A. Motivation and Objectives

Two main implementation directions are distinguished in the standardization of the XG-PON by the ITU-T. The fairness provisioning and the extensive power management specification. The fairness provisioning could be ensured by designing a fair, dynamic bandwidth allocation scheduler in both uplink and downlink directions. On the other hand, the power reduction issue is much more complicated. Currently, both industry and academia pose the power switching of the ONU device in sleep mode as one of the most promising solutions to provide energy savings at low cost. However, this endeavor is not a straightforward task, since the frequency and the degree of a potential sleep period seriously depends on the traffic needs the ONU handle in both uplink and downlink interface. A sleep session should be avoided while the ONU carry through traffic because of network performance degradation. Hence, the determination of the sleep period is of paramount importance. In the light of the aforementioned remarks, our main objective in this study is to improve the trade-off between energy reduction and network efficiency.

B. Exponential Smoothing Forecasting

When a periodic phenomenon is monitored a set of time series data is formed. Actually, these observed data points may present some exploitable features such as auto-correlation, trend, or seasonal variation [7]. If so, a data forecasting analysis could be feasible. In the present study, we endeavor to devise a model in order to proceed to forecasting. The model is incorporated in each ONU and it aims at taking precise decisions on determining the sleep period of either the doze or cyclic sleep mode. The exponential smoothing technique is charged for this specific task. The rationale in adapting the smoothing operation is that recent observations are given relatively more weight in forecasting than the other observations [8]. This feature allows an understanding of the underlying traffic pattern that produces the observed data. In a nutshell, the smoothing technique can cope with traffic dynamics in an access network such as the XG-PON. In addition, it sheds light on potential underlying trend or seasonal correlation.

The basic smoothing function is based on the following formula $S_i = \alpha R_{i-1} + (1-\alpha)S_{i-1}, i > 2$, where S_i represents the smoothed, i.e., estimated value, the R_i denotes the actual data and the parameter α stands for the smoothing constant, $0 < \alpha \leq 1$. The parameter i stands for the current time period. The aforementioned equation could be expanded to be more coherent as $S_i = \alpha \sum_{j=1}^{i-2}(1-\alpha)^{j-1} R_{i-j} + (1-\alpha)^{i-2} S_2, i \geq 2$. Here, the weights decrease geometrically. Furthermore, the smoothing constant governs the convergence speed, since the bigger the value of α a more quick convergence is achieved. The value of S_2 is often given by the first actual observation, i.e., R_1.

C. Double Exponential Smoothing

It is considered that time series which demonstrate trend but not seasonality is attached to the double exponential technique. The subtle difference between the double and the simple smoothing lies in the $trend\ \ determination\ \ equation$. The double smoothing employs a second equation in order to demonstrate the potential trend of the data series. In this manner, the S_i adjustment is given as $S_i = \alpha R_i + (1-\alpha)(S_{i-1} + b_{i-1})$. The parameter b_i yields the $trend\ \ determination\ \ equation$, $b_i = \gamma(S_i - S_{i-1}) + (1-\gamma)b_{i-1}$. In essence, the b_i equation yields the difference between two last, consecutive estimating values. Nonetheless, the parameters α and γ should be determined for optimal results. In the method initialization the following statements take place: $S_1 = R_1$ and $b_1 = R_2 - R_1$.

D. Triple Exponential Smoothing

When both trend and seasonality identities co-exist in time series data the triple exponential smoothing technique is more efficient. The seasonal dimension is represented by the $seasonal\ \ determination\ \ equation$: $E_i = \beta \frac{R_i}{S_i} + (1-\beta)E_{i-P}$. The parameter β is a convergence factor in function of seasonality. The variable P is associated with the related period that corresponds to a complete season's data. A season could be arbitrarily defined denoting a period time duration such as a year, a month etc. Accordingly, the complete smoothing function is given as $S_i = \alpha \frac{R_i}{E_{i-P}} + (1-\alpha)(S_{i-1} + b_{i-1})$. Lastly, the $trend\ \ determination\ \ equation$ is derived as $b_i = \gamma(S_i - S_{i-1}) + (1-\gamma)b_{i-1}$. Given that there are $P = 3$ periods of data of two past seasons, i.e., $R_1, R_2, R_3, R_4, R_5, R_6$ actual values, the initialization process includes: $b_1 = \frac{1}{3}(\frac{R_4 - R_1}{3} + \frac{R_5 - R_2}{3} + \frac{R_6 - R_3}{3})$ and $E_1 = (\frac{R_1}{M_1} + \frac{R_4}{M_2})$, $E_2 = (\frac{R_2}{M_1} + \frac{R_5}{M_2})$, $E_3 = (\frac{R_3}{M_1} + \frac{R_6}{M_2})$, where M_i denotes the mean value of each season, i.e., $M_i = \frac{\sum_{j=1}^{3} R_j}{3}, i = 1, 2$.

E. Forecasting Model Formulation

The adopted forecasting model maintains a large set of data points and tries to effectively estimate the forthcoming values. The model is incorporated in a distributed fashion, where each ONU is enhanced with an individual model. This is attached to the traffic independence, meaning that each ONU connects different end users providing differentiated services, so the ongoing traffic differentiates from ONU to ONU, and therefore the sleep opportunities in each ONU are variant. The data points represent sleep time periods in terms of msec. The model consists of two individual forecasting components, one for each sleep mode. The time series data are monitored for a time window equal to 1 sec. This time window is further divided into 20 periods of 50 msec each. The rationale behind this lies in the sleep period upper bound according to the standard specifications, where an upper limit of 50 msec sleep time is defined. The smoothing equation yields the estimation sleep period for each mode, that is $S_i^d = \alpha^d \frac{R_i^d}{E_{i-P}^d} + (1-\alpha^d)(S_{i-1}^d + b_{i-1}^d)$ for doze mode while $S_i^c = \alpha^c \frac{R_i^c}{E_{i-P}^c} + (1-\alpha^c)(S_{i-1}^c + b_{i-1}^c)$ for cyclic sleep mode. Due to the initial time window, the forecasting model begins performing estimations after 1 sec of network operation. Accordingly, the $trend\ \ determination\ \ equation$ of each component is determined as $b_i^d = \gamma^d(S_i^d - S_{i-1}^d) + (1-\gamma^d)b_{i-1}^d$ and $b_i^c = \gamma^c(S_i^c - S_{i-1}^c) + (1-\gamma^c)b_{i-1}^c$ for doze and cyclic sleep mode respectively. Finally, the $seasonal\ \ determination\ \ equation$ for each mode are given as $E_i^d = \beta^d \frac{R_i^d}{S_i^d} + (1-\beta^d)E_{i-P}^d$ and $E_i^c = \beta^c \frac{R_i^c}{S_i^c} + (1-\beta^c)E_{i-P}^c$, where $P = 10$.

F. Energy-aware Mechanism

The model described in the previous subsection takes place in the context of an energy-aware mechanism that is incorporated within the ONUs in a XG-PON system. Algorithm1 demonstrates the proposed energy-aware mechanism that incorporates the introduced forecasting method. The mechanism takes place in the ONU as the ONU is responsible of deciding whether and how long a sleep session will be initiated. During the system setup the OLT investigates the sleep capabilities of the connected ONUs via the OMCI. Next, the mechanism is triggered each time a downstream frame coming from the OLT reaches an ONU. At this time, the ONU checks its buffers to infer about the ongoing traffic requests for both directions. Hence, a normal mode can be sustained, a doze mode can be initialized, or a cyclic sleep mode is launched. In case that a sleep opportunity exists the ONU applies the exponential smoothing method to forecast the next sleep period. Upon the termination of the sleep session the ONU calculates the actual sleep time. This time could be a) lesser than the estimated period, so an extended sleep period occured, b) larger then the estimated period, hence the obtained energy savings are limited, or c) ideally exact as the estimated period. It is worth mentioning that the sleep period is counted in times of 125 μsec which is the downlink frame length [3].

IV. Assessment and Numerical Results

In this Section the assessment environment, the performance evaluation of the proposed mechanism, and the corresponding simulation results are presented.

Algorithm 1 The proposed energy-aware mechanism

The OLT utilizes OMCI to discover the ONUs' power management capabilities
for each ONU **do**
  for each received downstream frame **do**
    The ONU monitors its uplink interface for uplink traffic requests
    The ONU monitors its downlink interface for incoming traffic data
    if both interfaces are idle **then**
      The ONU decides to enter into a cyclic sleep mode
      The ONU applies either the double or the triple exponential smoothing forecasting model in order to estimate the cyclic sleep period S_i^c as a count of 125 μsec
      The ONU sends a PLOAM message to the OLT advertising its intention to enter a cyclic sleep mode as well as the determined period S_i^c
      The ONU enters into a cyclic sleep period
      The ONU returns to normal mode
      The ONU calculates the actual cyclic sleep period R_i^c as a count of 125 μsec
    end if
    if uplink interface is idle only **then**
      The ONU decides to enter into a doze mode
      The ONU applies either the double or the triple exponential smoothing forecasting model in order to estimate the cyclic sleep period S_i^d as a count of 125 μsec
      The ONU sends a PLOAM message to the OLT advertising its intention to enter a doze mode as well as the determined period S_i^d
      The ONU enters into a doze period
      The ONU returns to normal mode
      The ONU calculates the actual doze period R_i^d as a count of 125 μsec
    end if
  end for
end for

A. Assessment Scenario

In order to ensure a robust evaluation scenario we implemented a XG-PON architecture in OPNET. For comparison reasons we devised five total energy-aware mechanisms: a) a first fixed energy efficient mechanism, denoted as $Fixed1$, where the doze and cyclic sleep times are fixed and equal to 10 msec, b) a second fixed energy efficient mechanism, denoted as $Fixed2$, where the doze and cyclic sleep times are fixed and equal to 20 msec, c) a third fixed energy efficient mechanism, denoted as $Fixed3$, where the doze and cyclic sleep times are fixed and equal to 30 msec, d) the $2ESM$, where the doze and cyclic sleep times are dynamically adjusted by applying the double exponential smoothing mechanism, and e) the $3ESM$, where the doze and cyclic sleep times are dynamically determined by functioning the triple exponential smoothing mechanism. It is important to mention that both the $2ESM$ and the $3ESM$ initially operate like the $Fixed1$ until a reasonable sleep times record is formed. Then, they apply the exponential smoothing technique.

The inter-arrival time of the generated traffic follows a Poisson distribution, with an average value of $lambda$, while each generated packet is formed as an Ethernet frame of $[64, 1518]$ Bytes. Each ONU is supplied with a buffer of 100MB, which is large enough to avoid buffer overflows. The operation of the buffer does not consume energy. Moreover, it is assumed that each ONU is needed 5 μsec time for responding to each downstream frame. The power consumption of an ONU is set to 4.69W for the ActiveHeld and ActiveFree states, 2.76W for the DozeAware and SleepAware states, 1.7W for the Listen state and 0.9W for the Asleep state [3].

The RTT of the ONUs follows a uniform distribution within $[4000, 44000]$ meters far from the OLT. The uplink transmission rate is set to 2.48832 Gbps whereas the downlink rate is 9.95328 Gbps. Each simulation scenario has been conducted for 20 min of network operation. It is considered that no PLOAM messages are exchanged between the OLT and the ONUs. All smoothing parameters are set to 0.5, i.e., $\alpha^c = \alpha^d = \beta^c = \beta^d = \gamma^c = \gamma^d = 0.5$. Table I summarizes the main simulation parameters.

The performance of the energy efficient mechanisms under comparison is investigated in the context of two main efficiency metrics. The first one is called $green\ \ impact$ and it is obtained by combining the energy consumption in conjunction with the induced packet delay due to extended sleep periods. An extended sleep period occurs when the ONU is set to a doze or asleep mode and uplink or/and downlink traffic arrives. For instance, if an ONU remains in doze mode for 10 msec and a data packet arrives in the 8th msec, then the induced packet delay is equal to 2 msec. Hence, the $green\ \ impact$ equally combines the energy consumption in Watts and the mean packet delay in msec indicating the trade-off between energy reduction and efficiency. Thus, the $green\ \ impact$ is defined as follows: $green\ \ impact = average\ \ ONU\ \ energy\ \ consumption * average\ \ packet\ \ delay$. For example, the $green\ \ impact$ for a strategy that offers an average ONU energy consumption of 4.1 Watts and causing an overhead of 0.8 msec of delay is 3.28. Obviously, a strategy that succeeds a $green\ \ impact$ of 3 is better than the previous one, since it offers either a more energy efficient method or limited overhead. The second performance metric is the $mean\ \ percentage\ \ error$, which reveals the accuracy of the applied energy-aware method. The $mean\ \ percentage\ \ error$ is defined as $100\frac{|estimated\ \ value - actual\ \ value|}{actual\ \ value}$. The actual value is given by the actual sleep time, whereas the estimated value is the outcome of the applied mechanism. The percentage error of a mechanism that yields a sleep period of 10 msec while the optimal length was 8 msec is 25%.

Parameter	Value
ONUs distances	$[4000, 44000]meters$
Downlink Transmission rate	9.95328 Gbps
Uplink Transmission rate	2.48832 Gbps
ActiveHeld consumption	4.69W
ActiveFree consumption	4.69W
DozeAware consumption	2.76W
SleepAware consumption	2.76W
Listen consumption	1.7W
Asleep consumption	0.9W
ONU responding time	5 μsec
Simulation time	20 min
ONU Buffer size	100MB
α^c,α^d,β^c,β^d,γ^c,γ^d	0.5

TABLE I
MAIN SIMULATION PARAMETERS

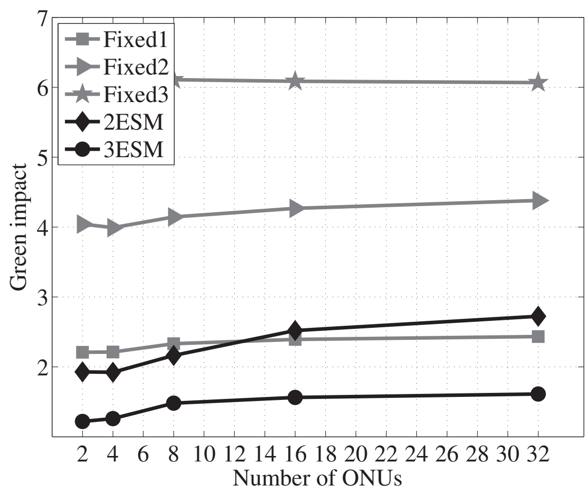

Fig. 1. Green impact vs number of ONUs.

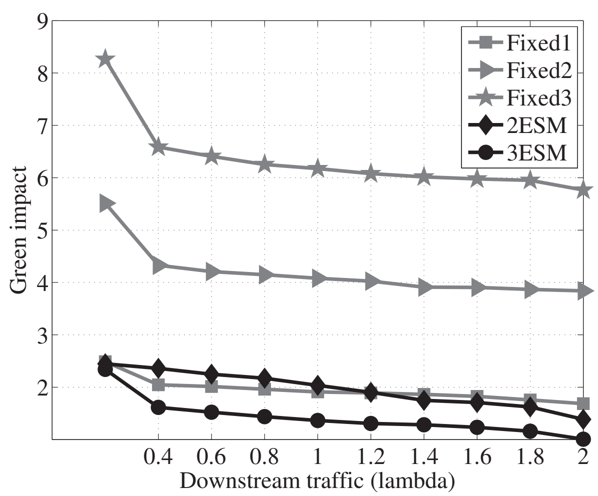

Fig. 2. Green impact vs downlink load.

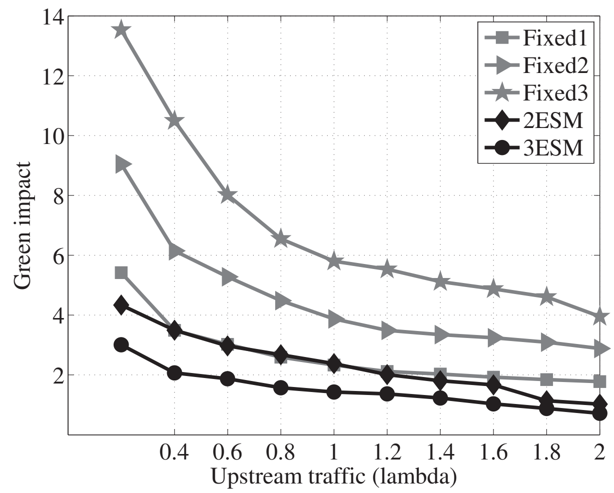

Fig. 3. Green impact vs uplink load.

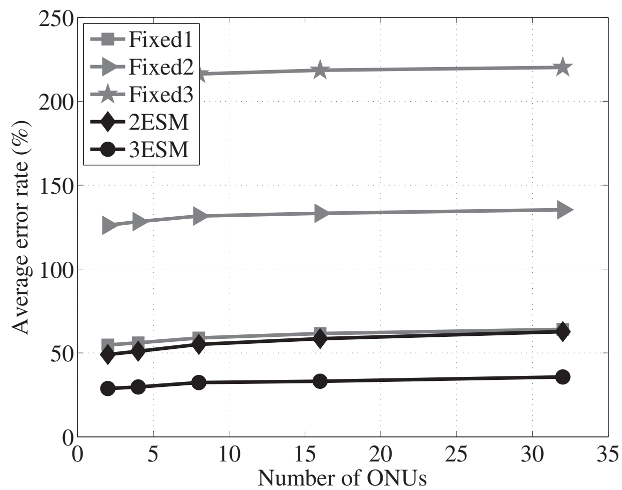

Fig. 4. Mean error vs number of ONUs.

B. Numerical Results

Simulation experiments have been conducted to assess the impact of the compared energy-aware mechanisms in terms of the $green\ \ impact$ and $mean\ \ percentage\ \ error$. Figure 1 demonstrates the $green\ \ impact$ as the number of ONUs in the XG-PON system alters. The number of ONUs changes from 2 to 32 ONUs, while both the uplink and downlink traffic (inter-arrival time) remains stable and equal to $lambda = 1$ (data packet per 1 msec). In general, the $green\ \ impact$ is kept steady for all schemes. However, the $3ESM$ achieves the most efficient impact in the network. On the contrary, both $Fixed2$ and $Fixed3$ seriously fail to ensure an acceptable trade-off since they define a large sleep period. The $Fixed1$ scheme offers similar results as the $2ESM$ technique; this is attached to the fact that it succeeded to select a fixed and predefined sleep period quite near to optimal. However, this is a 'lucky' option, since upon network traffic alterations this option could be also impaired. It is clear that both the proposed scheme attain a good outcome. The $3ESM$ presents better results, since it exploited the revealed

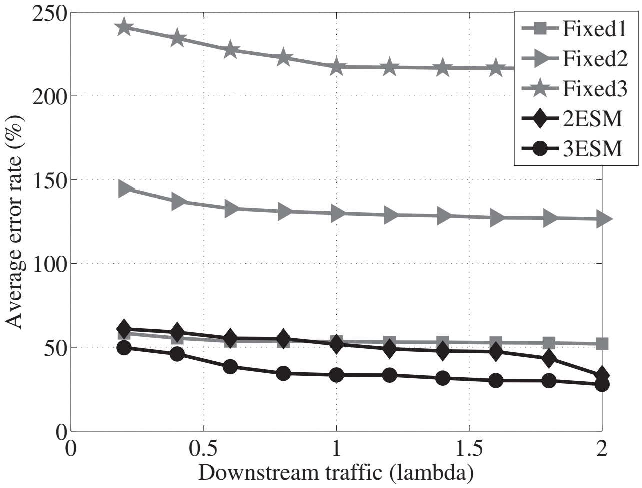

Fig. 5. Mean error vs downlink load.

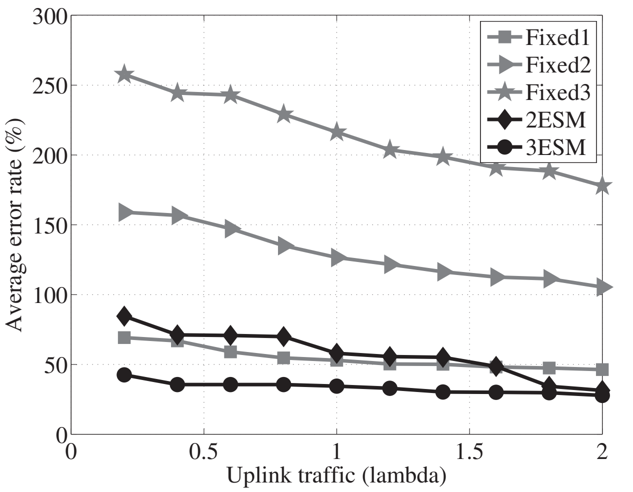

Fig. 6. Mean error vs uplink load.

periodicity of the underlying network traffic. Figure 2 and Figure 3 illustrate the $green\quad impact$ outcome when the downlink and the uplink inter-arrival time varies respectively. Once more the results indicate the superiority of the $3ESM$ method. In Figure 2 the uplink traffic remains stable and equal to $lambda = 1$, while in Figure 3 the downlink traffic is kept steady and equal to $lambda = 1$. As the network traffic presses the energy-aware mechanisms exploit less sleep opportunities. Nonetheless, both exponential smoothing methods accomplish a balanced trade-off without knowing a priori the network conditions. Thus, they are able to cope with unaware traffic parameters and accurately determine the proper sleep period in order to avoid overwhelming the ongoing network operation.

The next three figures shed light on the error rate variation. Figure 4 examines the forecasting error rate as the number of ONUs becomes large. Again, both inter-arrival times remain $lambda = 1$. As a general observation, it is clear that the error rate is mostly high. For example, the function of the $Fixed1$ mechanism results in a quite high error over 200%, because the selection of the sleep period is quite erroneous. The error observed in the curve of $3ESM$ is the lowest one and it is deemed as acceptable since it is below 35% at average. The reason behind this lies in the $3ESM$ intelligence; it manages to effectively utilizes the potential feasible features of the time series. Figure 5 depicts the error rate as the downlink traffic changes. The error rate degree is presented higher when the traffic load is low. This happens because the data points obtained by the observation are limited, so the estimation is based on lesser data. Nonetheless, the smooth techniques manages to keep the error limited, yet the error of the $2ESM$ method tends to be shrink as the traffic becomes pressing. Lastly, Figure 6 presents similar remarks by comparing the error rate with the uplink traffic alterations. It is worth mentioning that in this case the $2ESM$ manages to limit the error sooner, since the number of samples permit a more effective forecasting.

Summing up, the exponential smoothing enhancement is proven beneficial to the XG-PON systems since it supports quite accurate predictions as well as balanced trade-off between the energy savings and network efficiency.

V. Conclusions

A rigorous forecasting framework was presented in this study for determining the ONU sleep period in XG-PON systems. The rationale behind the forecasting utilizes the powerful exponential smoothing technique. The provided estimations proved quite precise and effective compared to methods that sustain a predefined sleep time. The main merits of the proposed mechanism is the ability of acquiring the trend as well as the periodicity of the underlying network dynamics. Extensive simulation results indicated that the impact of the proposed method is beneficial to the network performance providing guaranteed energy savings.

References

[1] Y. Luo, X. Zhou, F. Effenberger, X. Yan, G. Peng, Y. Qian, and Y. Ma, "Time- and wavelength-division multiplexed passive optical network (twdm-pon) for next-generation pon stage 2 (ng-pon2)," *Lightwave Technology, Journal of*, vol. 31, no. 4, pp. 587–593, Feb 2013.

[2] F. Effenberger, "The xg-pon system: Cost effective 10 gb/s access," *Lightwave Technology, Journal of*, vol. 29, no. 4, pp. 403–409, Feb 2011.

[3] "10-Gigabit-capable passive optical networks (XG-PON): transmission convergence (TC) specifications, ITU-T G.987.3," October 2010.

[4] H. Bang, J. Kim, S.-S. Lee, and C.-S. Park, "Determination of sleep period for cyclic sleep mode in xg-pon power management," *Communications Letters, IEEE*, vol. 16, no. 1, pp. 98–100, January 2012.

[5] H. Bang, J. Kim, Y. Shin, and C.-S. Park, "Analysis of ont buffer and power management performances for xg-pon cyclic sleep mode," in *Global Communications Conference (GLOBECOM), 2012 IEEE*, Dec 2012, pp. 3116–3121.

[6] S. Lambert, B. Lannoo, D. Colle, M. Pickavet, J. Montalvo, J. Torrijos, and P. Vetter, "Power consumption evaluation for next-generation passive optical networks," in *Digital Communications - Green ICT (TIWDC), 2013 24th Tyrrhenian International Workshop on*, Sept 2013, pp. 1–4.

[7] E. S. G. Jr., "Exponential smoothing: The state of the artpart {II}," *International Journal of Forecasting*, vol. 22, no. 4, pp. 637 – 666, 2006. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0169207006000392

[8] S. Gelper, R. Fried, and C. Croux, "Robust forecasting with exponential and holtwinters smoothing," *Journal of Forecasting*, vol. 29, no. 3, pp. 285–300, 2010. [Online]. Available: http://dx.doi.org/10.1002/for.1125