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Power Consumption Analysis of Energy-aware FTTH Networks

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***Abstract*—With increasing usage of the Internet, energy consumption of network equipment has become a crucial challenge from both an economic and an environmental point of view. This paper combines users' behavior of accessing the network with energy saving algorithms for energy-aware network equipment, and investigates potential energy savings in the access network. The study is based on a set of traffic data that collected from a real residential fiber-to-the-home (FTTH) network during three continuous months in 2013. The results show that on average every household link in the access network can potentially save at least 18% energy consumption with sleep-mode enabled equipment.**

Keywords- energy efficiency; user behaviour; traffic measurement; FTTH; access netowork.

I. INTRODUCTION

With increasing usage of Internet and its related services, the volume of global IP traffic is growing enormously [1]. Recent reports states that the world's Information-Communication-Technologies (ICT) ecosystem approaches 10% of the world's electricity generation [2]. Other papers estimate that about 37% of the ICT electricity is generated in the telecommunication networks, whereas the rest is mainly generated in data centers and user devices [3]. Therefore, energy consumption has become a particularly important economic and environmental interest when the global IP traffic grows at such dramatically fast pace.

In the recent years, a number of studies have been published focused on energy consumption in telecommunication networks. For example in [4], the power consumption of nodes and links in a backbone network was investigated. Further, according to [5][6], the access networks account for about 70% of the networks' total electricity generation. Also, according to [7], in a Fiber-To-The-Home (FTTH) network, a major part of the electricity consumption is due to the optical network unit (ONU) at the end-user's home and the access line utilization is quite low, which means that the majority of the spent power could be saved with power-saving solutions. In [8], a benchmark for current network devices was presented, and the results showed that the power consumption of the Ethernet switch depends on the number of active ports, which means that switching off unused ports can reduce power consumption.

Further, in [5][9] some existing energy saving approaches used in fixed network and optical access networks were summarized. Two common approaches are idle mode (also called sleep mode) and adaptive link rate (ALR) [10][11].

The idle mode concept is adopted by the Energy Efficient Ethernet (EEE, also known as IEEE 802.3az) [12][13], which was published in 2010. EEE allows network components to sleep, i.e. standby at a low power idle state to save the energy consumption, when there is no data packets transmitted in the link. The ALR approach dynamically associates the energy consumption of the network equipment with the actual data rate or workload transmitted in the network, so that the energy dissipation can be allocated according to the traffic load pattern. In [12][13], the potentials of EEE for reducing energy consumption was evaluated, however, not including data from real operational networks.

In order to develop efficient ways of reducing energy consumption in the networks, it is essential to also understand the users' behavior when accessing the networks [14][15]. However, there are only a few papers that use real data traces to investigate energy consumption and energy saving solutions for telecommunication networks. In [4], a real aggregated traffic profile was used in order to study the power consumption of nodes and links in a backbone network. In [16], a daily Internet usage pattern from 2008 was used to calculate potential energy saving from an ALR approach. However, both these papers used one generic example of the traffic pattern for their analysis. In reality, different households can have very varying traffic patterns depending on each household's Internet usage behavior.

This study uses traffic measurement data from real residential users in a FTTH access network, and estimates the potential amount of energy savings when sleep-mode enabled energy-aware equipment were applied. The main novelties are: firstly our investigation covers 2627 households with ultra-fast internet access service in a FTTH network during the 3 months period, so that our results give a practical evaluation of the performance of energy saving approaches in connection to a real network user case; secondly this paper proposes a method of mapping users' traffic behavior to link states, which then can be mapped to

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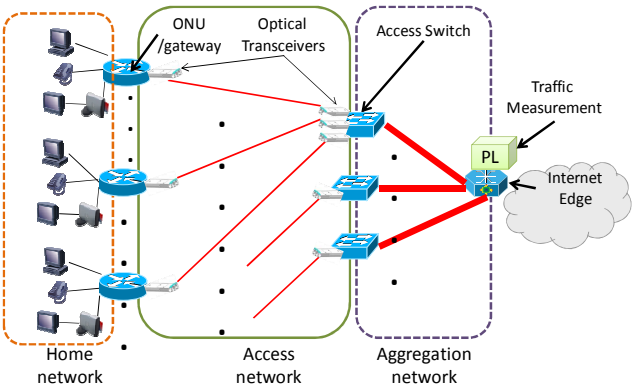

Fig.1. Network architecture

corresponding power consumption in the network devices; thirdly, two ONU energy models are proposed and compared according to the characteristics of traffic measurement data, the first model includes sleep-mode feature, and the second model includes both sleep-mode and off-mode feature.

The paper is organized as follows. First a description of the network scenario, energy consumption models, and the scope of the work are presented in Section II. In Section III, we propose a mapping between Internet user behavior and energy models, and then analyze how much energy can be saved in different energy consumption models when Internet user behavior pattern applied in Section IV. A conclusion is drawn in Section V.

II. METHODOLOGY

A. *Network and measurements*

The analysis in this paper is based on measurements in a real operational FTTH residential network in Sweden. The FTTH network is an active optical network (AON), which is currently the most deployed fiber access solution in Europe representing 78% of overall deployment at the mid of 2012 [17]. As Fig. 1 shows, every household has a 100 Mbps Internet service subscription and connects to the network via an Optical Network Unit (ONU) acting as a home gateway. Further, the ONU is connected to the network operator's access switch via a dedicated fiber link.

The access Ethernet switch, also called optical line termination (OLT) for Point-to-Point (PtP) FTTH, is located at the border between the aggregation network and access network. Every downlink port of the access Ethernet switch is connected to one household. The uplink interface towards aggregation network is shared among all households connected to the switch.

Traffic measurements were performed by the network operator, and post processed, anonymous data were made available to the authors for analysis. The traffic measurement probe was PacketLogic (PL) [18], a commercial traffic management device, which can track and identify several hundred thousand simultaneous connections. The PL was placed at the Internet edge of the network, see Fig. 1, and the volumes of traffic for each household, in both inbound and

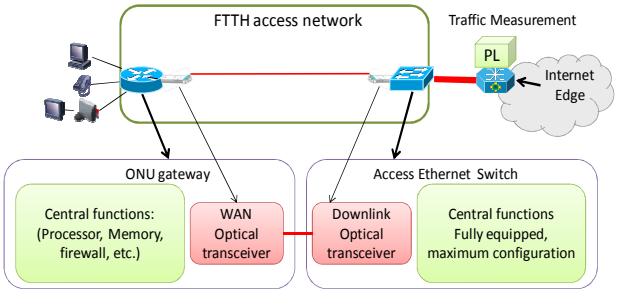

Fig.2. Network scenario

outbound directions, were recorded at 5 minutes intervals. The collected data comprise 2627 households and the study is based on data from 2013-March-01 to 2013-May-31.

B. *Investigated scenario*

In this paper, we focus on the access (first mile) part of the network, more specifically the ONU (optical network unit) with home gateway functions, the access Ethernet switch and optical transceivers as described in Fig. 1. The ONU terminates the fiber optical signal from the FTTH network and converts it to electrical signal which is then communicated with other home network devices, e.g., TV, PC, IP telephony, etc.

The power consumption of the ONU can be assumed to come from two parts. The first part is the home gateway central functions, for example, the processor, memory for routing, firewall, OAM and user interfaces [19]. The second part is the wide area network (WAN) interface, i.e., the optical transceiver, which directly connects to the access switch.

Further, in this paper, we consider the power consumption of the downlink Ethernet switch center functions and optical transceiver that connects towards users. However, the uplink interface was excluded, since we assume that the possibility of this shared interface to be idle is low.

A more detailed illustration of the investigated network scenario is shown in Fig. 2.

III. ENERGY CONSUMPTION

In this section, we describe the proposed energy models used in this paper. The objective of our analysis has been to investigate the potential energy-savings that can be obtained with energy-aware equipment, based on data from a real operational network.

The European commission code of conduct for 2013 [19] defines three power states for energy-aware equipment using idle or sleep mode approach. The first power state is the "Active state", which means that the link is actively used and that the device is processing user traffic at its best performance. The second power state is the "Idle state", which indicates that the device is not processing or transmitting any user traffic, but that the link is established and ready to detect activity. The third power state is the "Off state", which corresponds to that the device is totally

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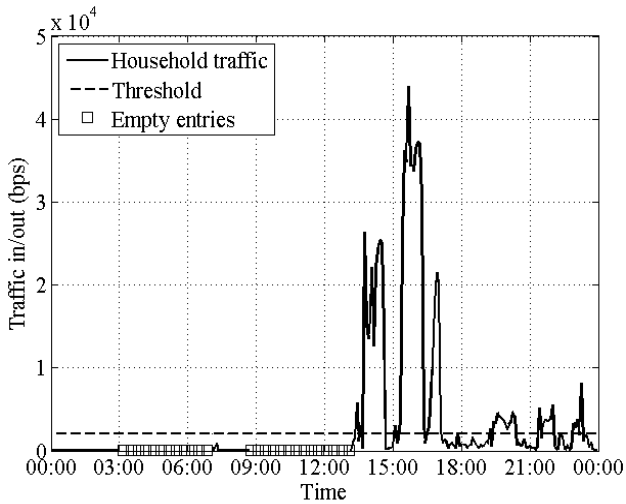

Fig. 3. An example of measured household traffic volumes during one day. The measured traffic rate is shown by the solid line. Empty entries are intervals where no traffic was detected. The threshold value is used to separate the Active and Idle power states.

powered off and not providing any functionality, which means that the link cannot send any traffic.

A. Mapping from traffic volumes to link states

To be able to analyze the effects of energy-aware equipment, we need to map the measured traffic volumes to link states, which then can be mapped to corresponding power consumption in the devices. In this subsection we describe the mapping from the measured traffic volumes to link states.

The measurements registered the average traffic rate (in bits per second) during five minutes intervals for each household, as illustrated in Fig. 3. For each interval, the total incoming and outgoing traffic rate was measured. If substantial traffic was observed by the PL, the household was assumed to be actively using the Internet, and therefore, the link was determined to be in the Active state. If a low rate of traffic was observed by the PL the network devices are powered on, but the household was assumed to not actively use the Internet, and therefore, the link can be determined to be in the Idle state. The small amount of traffic was assumed to be control and management (C&M) communications between the ISP and the ONU gateway.

If no traffic was observed by the PL during an interval, this was registered as an empty entry in the database. This can be due to two main reasons. Either the household's traffic was too small to be recorded, or the ONU gateway was powered off by the household. When there was an empty entry in the database, the link was considered to be in an Off state.

To separate the Active and Idle link states, we need a threshold value. In this paper, we use two cases for the threshold value. In the first case we use a threshold value of 100 bps. In this case, we assume that the C&M communications constitute maximum 100 bps for each household. If the registered data rate is smaller or equal to 100 bps we assume that the gateway is not processing and transmitting any user requested data, therefore we determine that the link is in the Idle state. In the second case, we use a threshold value of 0 bps, which leads to an extreme case where the Idle state can be activated only when there is no traffic observed at all in the ONU gateway.

TABLE I AVERAGE POWER OF ONU AND ACCESS SWITCH. VALUES WERE EXTRACTED FROM [19]

Link	ONU gateway	Access switch
Active	G_{active}=5 watt	E_{active} = 4 watt / port
Idle	G_{idle}=2.9 watt	E_{idle} = 2.7 watt / port*
Off	G_{off}=0 watt	E_{idle}

*This value was not available in [19]. We assumed 2/3 of active power

B. Power values

The power values for the ONU gateways and the Ethernet access switches used in this paper were extracted from [19]. TABLE I summarizes the proposed link states and corresponding power of the network equipment. The power values for the ONU gateway are denoted as G_{active}, G_{idle}, and G_{off} for the respective link states. The power values for the Ethernet access switch are denoted as E_{active} and E_{idle} for the respective power states. The Ethernet access switch is assumed to not have an energy-aware Off state. Therefore, the switch can use the same power as in the Idle state also when there is no traffic.

C. Energy models

In this subsection, we present our proposed energy models that we use to investigate the potential energy-savings with energy-aware equipment.

For one household k, the total power consumption, P_k, is modeled as (1). $P_g(k)$ is the total power consumption of the household's ONU gateway, and $P_e(k)$ is the total power consumption related to the household's port in the access Ethernet switch.

$$P_k = P_g(k) + P_e(k) \tag{1}$$

To estimate the power consumption for each device, we need to know the amount of time that the device works in its respective power state. We estimate the power states by using our traffic measurements. Each data point in the measurement (corresponding to a five minutes interval) is mapped to a corresponding power state, according to the procedure described in the previous subsection. The total time that the devices for household k is considered to be in Active power state is denoted $T_{active}(k)$, the total time for Idle power state is denoted $T_{idle}(k)$, and the total time for the Off power state is denoted $T_{off}(k)$.The values are calculated as accumulated five minutes intervals.

Thereafter, the total power consumption for the Ethernet access port switch corresponding to household k can be derived as

$$P_e(k) = E_{idle} \cdot (T_{idle}(k) + T_{off}(k)) + E_{active} \cdot T_{active}(k) \tag{2}$$

TABLE II AVERAGE ENERGY CONSUMPTION PER HOUSEHOLD DURING THREE MONTHS. STD = STANDARD DEVIATION. 95% CI = 95% CONFIDENCE INTERVAL

	ONU	Access switch / port	ONU + switch	STD	95% CI
No Energy-awareness	11.04 kwh	8.83 kwh	19.87 kwh	0	0
ONU Model 1 TH 100bps	7.28 kwh (-34.1%)	6.50 kwh (-26.4%)	13.78 kwh (-30.7%)	1.39	0.05
ONU Model 2 TH100bps	4.59 kwh (-58.4%)		11.09 kwh (-44.2%)	3.06	0.12
ONU Model 1 TH 0bps	8.76 kwh (-20.7%)	7.42 kwh (-16%)	16.18 kwh (-18.6%)	2.36	0.09
ONU Model 2 TH0bps	6.07 kwh (-45.0%)		13.49 kwh (-32.1%)	4.34	0.17

where E_{idle} and E_{active} are the power values for the Ethernet access switch found in TABLE I. Since the access switch is assumed to not have an energy-aware Off state, both the household's mapped Idle and Off states correspond to the Idle power value.

In this paper, we propose and evaluate two energy models for the ONU gateway, in order to show the effects when an energy-aware Off state is implemented in the ONU. Therefore, the first ONU gateway model (in the following called ONU1) only has "Active" and "Idle" power states, whereas the second ONU gateway model (in the following called ONU2), instead has all power states, "Active", "Idle" and "Off.

For model ONU1, the total power consumption for the ONU gateway belonging to household k is given by

$$P_g(k) = G_{idle} \cdot (T_{idle}(k) + T_{off}(k)) + G_{active} \cdot T_{active}(k) \quad (3)$$

where G_{idle} and G_{active} are the respective power values for the ONU gateway found in TABLE I. Both the link's Idle and Off states correspond to the Idle power value.

For model ONU2, the total power consumption for the ONU gateway belonging to household k is instead given by

$$P_g(k) = G_{off} \cdot T_{off}(k) + G_{idle} \cdot T_{idle}(k) + G_{active} \cdot T_{active}(k) \quad (4)$$

IV. RESULTS AND DISCUSSION

The main objective of our investigations was to evaluate the amount of energy savings that can be achieved with energy-aware equipment based on the households' Internet usage. Each household's energy consumption during the three months measurement period was therefore estimated using both energy models and the two threshold values for the links.

A. *Average energy savings*

TABLE II shows the estimated average energy consumption per household when compared to a benchmark case without energy-aware equipment. The potential energy savings are shown in the parentheses of TABLE II). As can be seen in the table, each ONU gateway consumes in average 11 kWh whereas each connected port on access switch consumes in average 8.8 kWh without energy-aware equipment. However, with energy-aware equipment, large energy savings can be achieved. The most striking result is

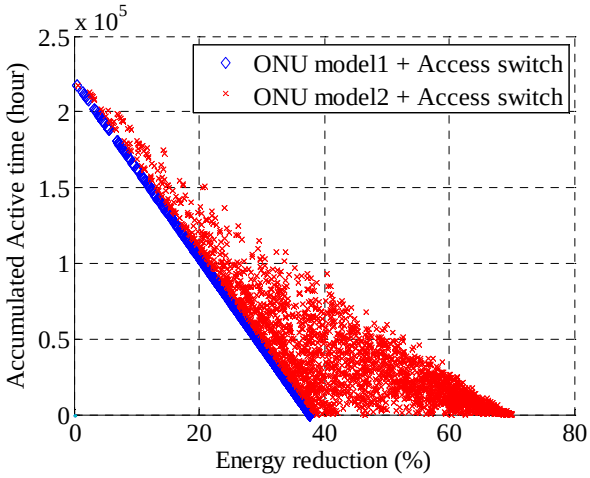

Fig. 4. Relationship between accumulated active time per household and the potential energy savings. Each data point corresponds to one household.

that 58% of the ONU energy consumption can be saved in the case where the ONU uses an Off mode (ONU Model 2) and the link state threshold 100bps. Even when ONU Model 1 is used, without Off mode, and the link state threshold value of 0 bps is applied (which is very strict), there is still a potential of 21% average energy savings for the ONUs. Energy-aware access switches can also have significant potential energy savings, about 26% and 16% on average for the two cases respectively.

B. *Households' Internet usage and energy-savings*

Fig. 4 shows the relationship between the accumulated active time (T_{active}) for each household and the potential energy savings calculated from the energy models with threshold of 100bps. Every data point in the figure corresponds to one household. The results clearly show that the most active households only have small benefits from using energy-aware equipment. However, for the households who have less active time, significant potential energy savings can be achieved by using energy-aware equipment. Using ONU model 1, without Off mode, the households who are the least active can save about 36% of the energy consumption, while for ONU model 2, with Off mode, the savings can reach as high as 67% compared to the case without energy-aware equipment. When energy-aware equipment is not deployed in the access networks, these "light" Internet users will consume the same amount of energy as the "heavy" Internet users.

Further, the graph indicates the potential benefits of introducing an Off state in the ONU gateway. The shorter active Internet time a household has, the more energy-savings from the Off state will the household have.

C. *Cumulative distribution functions*

Fig. 5 shows the cumulative distribution function (CDF) for the households in relation to the potential ratio of energy savings that the households can achieve, when ONU Model

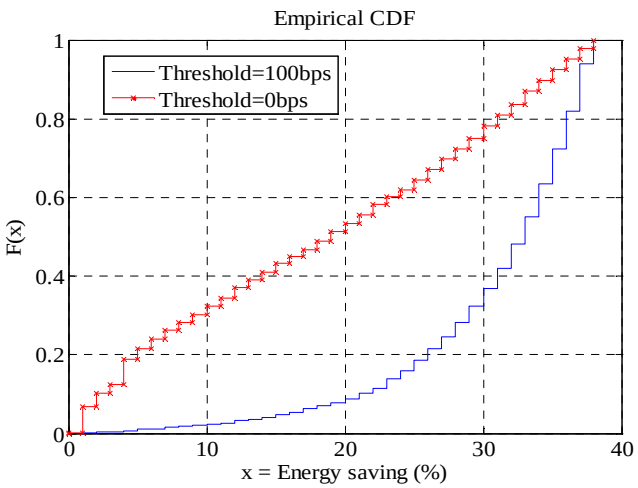

Fig. 5 Distribution of households in relation to the amount of energy savings using ONU model 1. The blue line corresponds to the link state threshold of 100bps, and the red crossed marker corresponds to the link state threshold of 0bps.

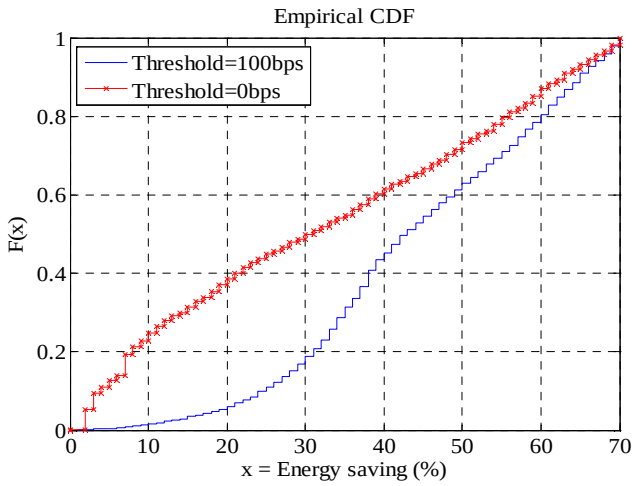

Fig. 6 Distribution of households in relation to the amount of energy savings using ONU model 2. The blue line corresponds to the link state threshold of 100bps, and the red crossed marker corresponds to the link state threshold of 0bps.

1, without Off state, is applied. Both link state thresholds are shown in the figure. As can be seen in the figure, for the 100 bps threshold case, the CDF curve increases exponentially. About 30% of the households in the network can save only up to about 30% of the energy using energy-aware equipment, whereas the rest of households can save from 30% to 36% of the energy with energy-aware equipment. There is a significant difference in the 0bps threshold case, where the CDF shows a clear linear trend. In both cases, the maximum energy saving is about 36%. Since it is the households with the lowest active time that have the maximum energy savings this result indicates that the households with the most energy saving have too little accumulated active time to be influenced by the threshold values.

Fig. 6 shows the cumulative distribution function using ONU model 2, with Off state, and both link state thresholds. In this case, the maximum potential energy-saving reaches as high as 67%. With the 100 bps threshold, about 83% of the households can save more than 30% of the energy, whereas even in the 0 bps threshold case there are still 51% of households that can achieve more than 30% energy savings.

V. CONCLUSION

The study uses real traffic data traces from a residential FTTH access network to investigate energy consumption and energy saving solutions of energy-aware equipment. The paper has proposed a method of mapping users' traffic behavior to link states that then can be mapped to corresponding power consumption in the network devices. The results show that on average every household link in the access network can potentially save at least 18% energy consumption with sleep-mode enabled equipment. With an additional off-mode feature on ONU, the amount of energy can be further reduced about 14% when compared to sleep-mode only ONU. The link state threshold value has significant impact on the amount of energy savings.

Currently, 70% energy of the whole telecommunication network is consumed in the access network, when we put our experiment results of access network into an end-to-end network scope, we can see that the total potential energy savings of a whole network can reach up to 31% with energy-aware equipment. Even if in a strict case, when ONU Model 1 is used, without Off mode, and the link state threshold value of 0 bps is applied, the estimated end-to-end network energy savings can achieve 13%

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