On the Effect of Cooperation Between Power Saving Mechanisms in WLANs and PONs

---

Citation:

Ko Togashi, Hiroki Nishiyama, Nei Kato, Hirotaka Ujikawa, Ken-Ichi Suzuki, and Naoto Yoshimoto, "On the Effect of Cooperation Between Power Saving Mechanisms in WLANs and PONs, " IEEE International Conference on Communications (ICC), Budapest, Hungary, Jun. 2013.

URL:

http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=6655603

On the Effect of Cooperation Between Power Saving Mechanisms in WLANs and PONs

Ko Togashi[1,*], Hiroki Nishiyama[1,†], Nei Kato[1,‡], Hirotaka Ujikawa[2,§], Ken-Ichi Suzuki[2,♭], and Naoto Yoshimoto[2,♮]
[1]Graduate School of Information Sciences, Tohoku University, Sendai, Japan
[2]NTT Access Service Systems Laboratories, NTT Corporation, Yokosuka, Japan
E-mails: {togashi[*], bigtree[†], kato[‡]}@it.ecei.tohoku.ac.jp
{ujikawa.hirotaka[§], suzuki.kenichi[♭], yoshimoto.naoto[♮]}@lab.ntt.co.jp

***Abstract*—In order to realize environmentally friendly networks, energy-efficient technologies are essential. In Fiber Wireless (FiWi) networks that consists of optical and wireless networks, there are two main power saving mechanisms, namely, Power Saving Mode (PSM) and Optical Network Unit (ONU) sleep. PSM works in wireless networks, and ONU sleep works in optical networks. These two mechanisms work independently in FiWi networks. Since both PSM and ONU sleep turn off the node's transmission device to save energy, the throughput of the network decreases. Thus, a trade-off relationship between throughput and energy consumption exists. Therefore, taking account of this relationship is essential when discussing energy efficiency in these networks. In this paper, we focus on the effect of PSM and ONU sleep on throughput and energy consumption. We analyze both the energy consumption and the throughput in FiWi networks. Through analysis, we point out energy and throughput inefficiencies in FiWi networks and propose a novel method that determines the optimal ONU sleep period and behavior in order to increase throughput and decrease the energy consumption. Furthermore, we validate our proposed method through numerical analysis, and confirm that it improves both throughput and energy consumption.**

I. INTRODUCTION

The energy consumed for communications has seen a substantial increase due to the growth of the number of network users and the volume of data being transmitted [1]. That renders energy efficiency in the Information and Communication Technology (ICT) industry as one of the most important research directions [2]. To address this serious problem, it is essential to reduce wasteful energy consumption. Therefore, all network devices should minimize the amount of energy consumption as much as possible.

Fiber-Wireless (FiWi) networks are access networks, which integrate optical networks and wireless networks. Wireless networks provide ubiquitous and flexible communication as long as the client is within the communication range of the network, but their capacity is small. On the other hand, optical networks provide high capacity and long distance communication, but cannot provide flexible and ubiquitous communication. However, by combining these two networks, FiWi networks can leverage their advantages. Accordingly, FiWi networks are access networks, which provide wide coverage and high capacity, and are expected to be widely deployed in the future [3]. Therefore, in this study, we focus on the energy efficiency of FiWi networks. We focus our attention on FiWi networks that have a Wireless Local Area Network (WLAN) [4] for the wireless network part and a Passive Optical Network (PON) [5] for the optical network part of the FiWi network, shown in Fig. 1. WLAN using the IEEE 802.11 standard have been deployed widely in university campuses, airports, and office rooms. In a WLAN, a wireless device STAtion (STA) communicates wirelessly and uses limited-capacity batteries to power its operation. Therefore, it is desired that a STA conducts communication with an Access Point (AP) while consuming low energy. To conserve battery energy and enable long-lasting communication, a novel power saving mechanism is Power Saving Mode (PSM).

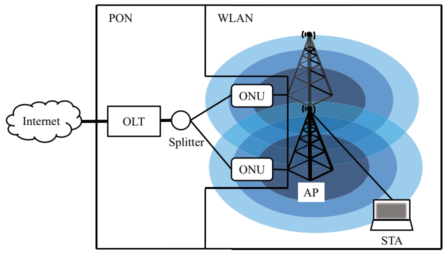


Fig. 1. An example of FiWi network.

Passive Optical Networks (PONs) are one of the most popular optical access networks. A PON consists of an Optical Line Terminal (OLT), Optical Network Unit (ONU), splitter, and optical fiber cable. The data frames transmitted by an OLT reach multiple ONUs through optical fiber cable, which is divided by a passive splitter. According to [6], energy efficiency in PON systems have been the focus of extensive research; attention is being paid on ONU sleep that periodically suspends some mechanisms on an ONU and reduces energy consumption.

In this paper, we refer to a FiWi network with PSM and ONU sleep as a Smart Fiber Wireless network (SFiWi network). Generally, when discussing energy efficiency, we need to consider the relationship between the energy efficiency and network throughput. On SFiWi networks, it is expected that the impact of the two power saving mechanisms on the delay and the throughput will be large, because both power

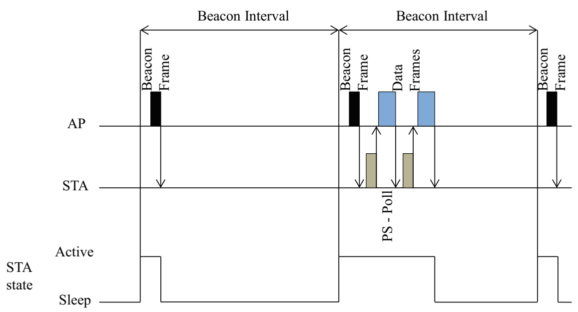


Fig. 2. PSM operation

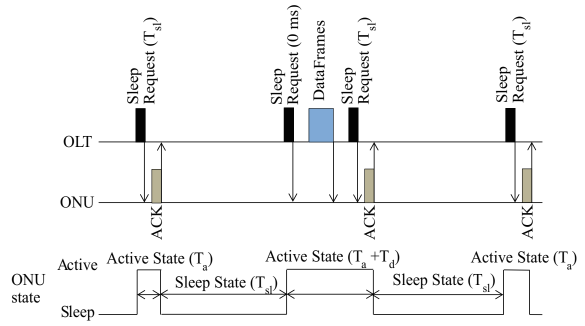


Fig. 3. ONU sleep operation

saving mechanism contribute to the delay. Therefore, in our research, we clarify their impact on latency and energy consumption. Secondly, we point out the throughput and energy inefficiencies in a SFiWi network, and propose a novel scheme to reduce delay and improve the energy efficiency. Finally, we show the superiority of our scheme, through numerical analysis, in terms of latency and low energy consumption.

II. RELATED WORKS

A. *PSM in WLAN*

A STA in PSM supports two energy consumption states, the active state and the sleep state. In the active state, a STA can send and receive data frames but energy consumption is high. In the sleep state, a STA cannot send or receive data frames, as a result, the energy consumption is much lower than in the active state.

An example of a STA communicating in PSM is shown in Fig. 2. At first, each STA in the AP coverage area notifies the AP whether it uses PSM or not. Therefore, the AP understands in which mode each STA is. If the AP receives data frames addressed to a STA in PSM, the AP does not relay them immediately and fills its buffer with these data frames. To exchange certain information, a beacon frame is sent every fixed interval called beacon interval (usually 100 ms [7]). The AP informs the STA of the AP's buffer contents through the Traffic Indication Map (TIM) included in the beacon frame. The STA switches from the sleep state to the active state every beacon interval to check the beacon information. If the TIM indicates that the AP is storing data frames addressed to the STA, the STA request them from the AP by sending a specific frame called PS-Poll until it receives all stored data and the STA reenters into the sleep state until the next beacon interval, otherwise the STA reenters into the sleep state immediately. Thus, the STA remains in the sleep state during the idle period, therefore the PSM can considerably reduce energy consumption.

Meanwhile, since all data frames addressed to the STA in PSM are buffered at the AP until the next beacon, PSM leads to additional delay and the observed latency becomes quite long for a connection [7].

In [8], He et al. investigated the energy consumption of the Continuously Active Mode (CAM) and PSM. They provided a sufficient study on the impacts of beacon interval and background traffic on energy efficiency.

B. *ONU sleep in PON*

An ONU in the ONU sleep mode supports two energy consumption states, i.e., the active state and the sleep state. In the active state, an ONU can send and receive data frames but the energy consumption is high. However, in the sleep state, the ONU cannot receive any down stream traffic because the ONU turns off some of its functions and the energy consumption is low. Therefore, the ONU enters into the sleep state while the ONU is idle to reduce energy consumption, and the ONU enters into the active state periodically to avoid missing down stream traffic.

An example of communication with ONU sleep mechanism is shown in Fig. 3. Basically, the OLT manages the ONU sleep period. The OLT sends a sleep request message, which includes the sleep period, T_{sl}, to the ONU. Then, the ONU sends an ACK to the OLT and switches to the sleep state. If the OLT receives data frames addressed to an ONU in the sleep state, the OLT stores the data frames until the end of the current ONU sleep state. After waiting, the ONU wakes up and the OLT sends a sleep request message to the ONU, which indicates a sleep period of 0 ms, followed by the data frames addressed to the ONU.

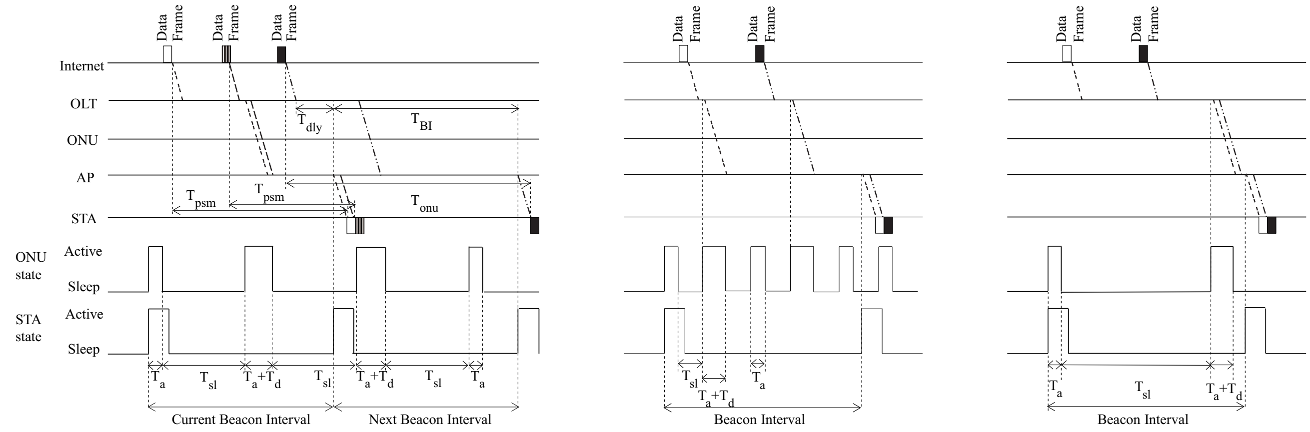
ONU sleep leads to additional delay since down stream traffic is temporarily stored at the OLT. Hence, there is a trade-off relationship between energy saving and throughput.

In [9], Kubo et al. proposed a novel power saving mechanism for the Ethernet PON (EPON). This method includes a sleep control method and adaptive link rate (ALR) control method, and achieved to offer an effective power management of ONUs on the basis of the traffic conditions. Moreover, although the effect of PSM or ONU sleep on the network performance has been also studied separately in [7], [10], [11], it is not known how the communication performance is affected in a SFiWi network.

III. NETWORK PERFORMANCE IN SFIWI NETWORKS

A. *The effect of PSM and ONU sleep on the latency*

An example of a data stream in a SFiWi network is shown in Fig. 4(a). There are two lengths of latency in a SFiWi Network.



(a) A data relay process affected by two sleep mechanisms in SFiWi networks.

(b)A Short-ONU sleep period.

(c)A long-ONU sleep period.

Fig. 4. Data relay process in SFiWi networks

The first length of latency is only affected by PSM. We refer to this latency as PSM-latency, T_{psm}. The second length of latency is affected by ONU sleep in addition to PSM. We refer to this latency as a ONU-latency, T_{onu}. The time when the data frame arrives at the AP determines whether it has a PSM-latency or ONU-latency.

Whenever a data frame arrives to an AP, as long as it arrives to the AP in the current beacon interval, the latency is a PSM-latency, the data frames are sent to the STA at the same time. Therefore, as shown in Fig. 4(a), even if a delay occurs at the OLT due to ONU sleep, latency is not affected. In other words, irrespective of the length of the delay caused by ONU sleep, the delay can be ignored as long as the data frame arrives at the AP during the current beacon interval. Then, assuming that the expected PSM-latency is $E[T_{\mathrm{psm}}]$, we can approximately calculate $E[T_{\mathrm{psm}}]$ as follows:

$$E[T_{\mathrm{psm}}] = T_{\mathrm{lat}} + \frac{T_{\mathrm{BI}}}{2}, \tag{1}$$

where T_{lat} is the actual latency in a FiWi network without ONU sleep and PSM. T_{BI} is the beacon interval time.

However, sometimes, the data frame does not arrive at the AP during the current beacon interval since the conventional ONU sleep method determines the ONU sleep-active cycle without taking account of the AP beacon interval cycle. In this case, the latency is a ONU-latency, and the data frames are buffered in the AP until the next beacon. Therefore, as shown in Fig. 4(a), the ONU-latency is total time of the actual latency, beacon interval and a part of the delay, T_{dly}, caused by ONU sleep. Then, assuming that the expected ONU-latency is $E[T_{\mathrm{onu}}]$, we can approximately calculate $E[T_{\mathrm{onu}}]$ as follows:

$$E[T_{\mathrm{onu}}] = T_{\mathrm{lat}} + T_{\mathrm{BI}} + E[T_{\mathrm{dly}}], \tag{2}$$

where $E[T_{\mathrm{dly}}]$ is the expected time of T_{dly} which takes between 0 ms and T_{sl} ms. $E[T_{\mathrm{dly}}]$ is caluculated as follows:

$$E[T_{\mathrm{dly}}] = \int_0^{T_{\mathrm{sl}}} T_{\mathrm{dly}} \times \left(\frac{T_{\mathrm{sl}} - T_{\mathrm{dly}}}{\int_0^{T_{\mathrm{sl}}} T_{\mathrm{dly}}\ dT_{\mathrm{dly}}} \right) dT_{\mathrm{dly}}, \tag{3}$$

where T_{sl} is the period of ONU sleep. The fraction in Eq. (3) is the probability that T_{dly} ms delay occuers. Using Eqs. (1), (2) and (3), we can derive $E[T'_{\mathrm{lat}}]$, which is the expected latency in a SFiWi network, as follows:

$$E[T'_{\mathrm{lat}}] = E[T_{\mathrm{psm}}] \times (1 - P) + E[T_{\mathrm{onu}}] \times P, \tag{4}$$

where P is the probability that the latency may be a ONU-latency, T_{onu}, which can be given as:

$$P = \int_0^{T_{\mathrm{sl}}} \frac{T_{\mathrm{dly}}}{T_{\mathrm{BI}}} \times \frac{1}{T_{\mathrm{sl}}}\ dT_{\mathrm{dly}}\ , \tag{5}$$

where the first fraction reflects the probability that the latency may become a ONU-latency when T_{dly} ms delay occurs. The second fraction is the probability that T_{dly} ms delay may occurs. In this way, in SFiWi networks, the latency becomes longer due to the delays caused by both the PSM and ONU sleep. In order to reduce the expected latency, $E[T'_{\mathrm{lat}}]$, it is important to avoid the data frame arrival at the AP during the next beacon interval.

B. Energy consumption in an ONU

In SFiWi networks, ONU energy consumption in a beacon interval, J, is obtained as follows:

$$J = J_{\mathrm{a}} + J_{\mathrm{s}}, \tag{6}$$

where J_{a} and J_{s} represent the ONU energy consumption per beacon interval in the active and sleep states, respectively. They can be expressed as follows:

$$J_{\mathrm{a}} = W_{\mathrm{a}} \times \left\{ T_{\mathrm{d}} + \frac{T_{\mathrm{a}}}{T_{\mathrm{sl}} + T_{\mathrm{a}}} \times (T_{\mathrm{BI}} - T_{\mathrm{d}}) \right\}, \tag{7}$$

$$J_{\mathrm{s}} = W_{\mathrm{s}} \times \left\{ \frac{T_{\mathrm{sl}}}{T_{\mathrm{sl}} + T_{\mathrm{a}}} \times (T_{\mathrm{BI}} - T_{\mathrm{d}}) \right\}. \tag{8}$$

T_{a} is the active period in an ONU sleep-active cycle. D is the amount of transmitted data frames and R is link rate between the OLT and the ONU. Here, T_{d} is the data transfer time need to send data frames from the OLT to the ONU in a beacon interval. It can be calculated as:

$$T_{\mathrm{d}} = \frac{D}{R}. \tag{9}$$

An example of communication with ONU sleep and PSM is shown in Fig. 4(b). Usually, if the ONU sleep period becomes short, then the ONU's energy consumption increases and the latency decreases since the waiting time in the OLT becomes short. However, in SFiWi networks, the AP does not send the data frames until the next beacon due to PSM operation. Therefore, even if the ONU sleep period is very short and the data frames arrive at the AP quickly, the data frames are buffered at the AP. Hence, it does not make sense to shorten the ONU sleep period excessively. Fig. 4(c) shows the communication under the same condition as Fig. 4(b), except that the ONU sleep period length is similar with the beacon interval. As can be observed from Figs. 4(b) and 4(c), there is almost no change in both latency. It means that shortening the ONU sleep period is almost ineffective and wastes energy consumption in SFiWi networks. From that, to reduce energy waste, it is important AFthat ONU wakes up just one time during the beacon interval and make the ONU sleep period long.

IV. PROPOSED METHOD TO IMPROVE NETWORK PERFORMANCE

As described in the previous section, there are inefficiencies in SFiWi networks. Therefore, in this section we propose a novel method to solve these inefficiencies. It is composed of two parts, namely, AP-ONU Synchronization (AOS) and Dynamic Sleep Period every Beacon (DSPB), which effectively determine the behavior and ONU sleep period, respectively. They can shorten the delay for a connection and reduce ONU energy consumption. In this section, we first describe our proposed method, and then analyze its latency and energy consumption.

A. Proposed method

1) AP-ONU Synchronization (AOS): in AOS, the ONU enters into the sleep state just after the AP sends a beacon, and the ONU wakes up and relays the data traffic to the AP before the AP sends the next beacon. Accordingly, the ONU sleep energy consumption state cooperates with the AP beacon interval.

Since the conventional ONU sleep method determines the ONU active-sleep cycle without taking account of the AP beacon interval, the data frame cannot always arrive at the AP during the current beacon interval and the latency becomes a ONU-latency. However, in AOS, because the data arrives at the AP during the current beacon interval, the latency does not become a ONU-latency.

2) Dynamic Sleep Period every Beacon (DSPB): in DSPB, the ONU sleep period is determined based on condition in AP coverage area. Namely, when there is no STAs or the present STAs are in PSM, the ONU sleep period is set to be T'_{sl}, which are given as:

$$\begin{aligned} T'_{\mathrm{sl}} &= T_{\mathrm{BI}} - (T_{\mathrm{a}} + E[T_{\mathrm{d}}]) \\ &= T_{\mathrm{BI}} - (T_{\mathrm{a}} + T_{\mathrm{d}} + \sigma), \end{aligned} \tag{10}$$

where $E[T_{\mathrm{d}}]$ is the expected data transfer time required to send the data frames from the OLT to the ONU after the ONU wakes up. σ is the prediction error. Our method needs to estimate the next data transfer time, $E[T_{\mathrm{d}}]$, in order to determine the next ONU sleep period, T'_{sl}. In this paper, we assume that we can expect the next data transfer time correctly, i.e., $\sigma = 0$. In contrast, when there are some STAs in CAM in the AP coverage area, let ONU sleep period be 0 ms.

In the conventional ONU sleep method, since ONU sleep period is fixed and determined without taking account of PSM operation, ONU wastes energy. In DSPB, ONU wakes up only one time between the beacon interval, and ONU conserves energy. And if there is a STA in CAM, ONU sleep period is set to 0 ms and therefore DSPB does not harm the STA throughput.

B. Expected performance enhancement

1) Latency analysis: in our method, the data frames are buffered at the OLT. An ONU sleep ends before the AP sends a beacon because of the AOS. Then, the data frames buffered in the OLT during the ONU sleep period are transmitted to the AP. Thus, all data frames arrive at the AP in the current beacon interval. Therefore, latency is not affected by ONU sleep. Latency is affected by only PSM. Thus, we can calculate the observed latency on SFiWi network under our proposed method as follows:

$$E[T'_{\mathrm{lat}}] = T_{\mathrm{lat}} + \frac{T_{\mathrm{BI}}}{2}. \tag{11}$$

In comparison with Eq. (4), this latency does not include T_{onu} and we can expect it to be a PSM-latency.

2) ONU energy consumption analysis: in the conventional method, the ONU wakes up several times during the beacon interval, and consumes energy inefficiently. However, the ONU wakes up just one time during beacon interval in our method. Therefore, the energy consumption of the ONU in a beacon interval is calculated as follows:

$$J_{\mathrm{a}} = W_{\mathrm{a}} \times (T_{\mathrm{a}} + T_{\mathrm{d}}), \tag{12}$$

$$J_{\mathrm{s}} = W_{\mathrm{s}} \times \{T_{\mathrm{BI}} - (T_{\mathrm{a}} + T_{\mathrm{d}})\}. \tag{13}$$

In comparison with Eqs. (7) and (12), the energy consumption in the active state decreases because the time in the active state decreases as much as the wake up time decreases.

V. NUMERICAL ANALYSIS

In this section, we perform a numerical analysis by using Eqs. (4), (6) and (11) to evaluate the performance of our proposed method. We consider that the communication is conducted over a SFiWi network such as Fig. 1. Every STA conducts communication while PSM is operational to conserve energy. Energy consumption of an ONU in the active state, P_{a},

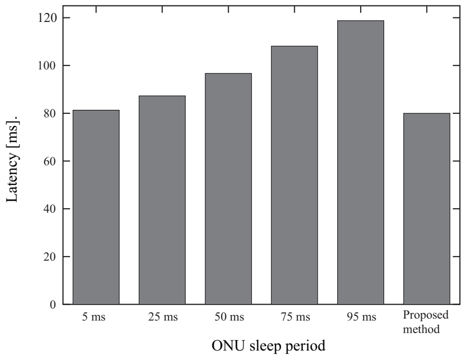


Fig. 5. Expected latency on SFiWi network.

is 6.35W, and its energy consumption in the sleep state, $P_{\rm s}$, is 0.7W [12]. The beacon interval, $T_{\rm BI}$, is 100 ms. The ONU sleep period, $T_{\rm sl}$, is changed to 5, 25, 50, 75 and 95 ms. The ONU active period, $T_{\rm a}$, is 0.5 ms [12]. The link rate between an OLT and an ONU is 1 Gbps.

Fig. 5 shows the plot of latency using Eqs. (4) and (11). In this evaluation, we set the actual latency to 30 ms to clearly see the impact of delay impact [8]. From the result, we can see that as the ONU sleep becomes long, latency also becomes long. The result also shows that our proposed method exhibits the shortest latency. Since smaller latency increases the throughput, our proposed method is expected to have improved throughput.

Fig. 6 shows the ONU energy consumption in a SFiWi network. The X-axis shows the amount of transmitted data frames from the OLT to the ONU. The Y-axis shows the energy consumption. From the result, the energy consumption in the ONU using our proposed method is much lower than the short sleep period. In comparison with the sleep period of 5 ms, our method cuts off the energy consumption by more than a half. Energy reduction is attributed largely to sleep periods. In our proposal, sleep periods are similar to the beacon interval in our scheme.

From Figs. 5 and 6, it is evident that the latency and the energy consumption in the conventional method have a trade-off relationship. By contrast, our scheme shows superior performance in both metrics without affecting either's performance.

VI. CONCLUSION

Two power saving mechanism exist in SFiWi networks, namely, PSM and ONU sleep. Both were developed for other specific networks and not for use in SFiWi networks. Therefore, when these power saving mechanism work at the same time in SFiWi networks, they are inefficient. Thus, in this paper, we focus on the relationship between these power saving mechanisms. We analyzed the impact of these power saving mechanisms and clarified their drawbacks, i.e., increasing latency and wasteful energy consumption. In order to address these drawbacks, we proposed a new method which determines the ONU sleep period and behavior efficiently. Our analysis showed that STAs under our proposed method experience shorter latency than STAs under the conventional method. Furthermore, the ONU reduces the energy consumption without decreasing the throughput. Therefore, our proposed method improves both energy consumption and throughput without sacrificing either in the SFiWi networks.

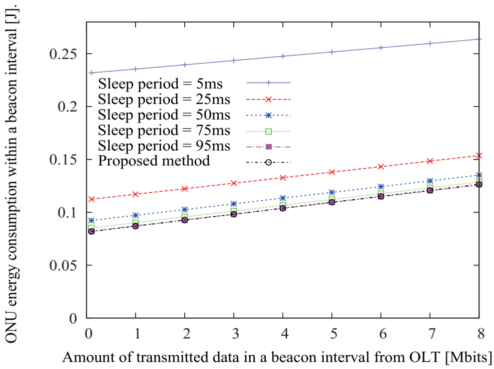


Fig. 6. Power consumption on an ONU.

REFERENCES

[1] J. Baliga, R. Ayre, K. Hinton, W.V. Sorin, and R.S. Tucker, "Energy consumption in optical ip networks," Lightwave Technology, Journal of, vol. 27, no. 13, pp. 2391-2403, Jul. 2009.

[2] L.X. Cai, H.V. Poor, Yongkang Liu, T.H. Luan, Xuemin Shen, and J.W. Mark, "Dimensioning network deployment and resource management in green mesh networks," Wireless Communications, IEEE, vol. 18, no. 5, pp. 58-65, Oct. 2011.

[3] N. Ghazisaidi and M. Maier, "Fiber-wireless (fiwi) access networks: Challenges and opportunities," Network, IEEE, vol. 25, no. 1, pp. 36-42, Jan.-Feb. 2011.

[4] B.P. Crow, I. Widjaja, L.G. Kim, and P.T. Sakai, "Ieee 802.11 wireless local area networks," Communications Magazine, IEEE, vol. 35, no. 9, pp. 116-126, Sep. 1997.

[5] G. Kramer and G. Pesavento, "Ethernet passive optical network (epon): building a next-generation optical access network," Communications Magazine, IEEE, vol. 40, no. 2, pp. 66-73, Feb. 2002.

[6] R. Kubo, J.-i. Kani, H. Ujikawa, T. Sakamoto, Y. Fujimoto, N. Yoshimoto, and H. Hadama, "Study and demonstration of sleep and adaptive link rate control mechanisms for energy efficient 10g-epon," Optical Communications and Networking, IEEE / OSA Journal of, vol. 2, no. 9, pp. 716-729, Sep. 2010.

[7] R. Krashinsky and H. Balakrishnan, "Minimizing energy for wireless web access with bounded slowdown," Wireless Networks (WINET), ACM, vol. 11, pp. 135-148, Jan. 2005.

[8] Y. He, R. Yuan, X, Ma, and J. Li, "The IEEE 802.11 Power Saving Mechanism: An Experimental Study," Wireless Communications and Networking Conference, 2008. WCNC 2008. IEEE , pp.1362-1367, March 31 2008-April 3 2008

[9] R. Kubo, J.-I. Kani, Y. Fujimoto, N. Yoshimoto, and K. Kumozaki, "Sleep and adaptive link rate control for power saving in 10g-epon systems," In Global Telecommunications Conference, 2009. GLOBECOM 2009. IEEE, pp. 1-6, Dec. 2009.

[10] E. Tan, L. Guo, S. Chen, and X. Zhang, "Psmthrottling: Minimizing energy consumption for bulk data communications in wlans," In Network Protocols, 2007. ICNP 2007. IEEE International Conference on, pp. 123-132, Oct. 2007.

[11] S. Wong, L. Valcarenghi, S. Yen, D.R. Campelo, S. Yamashita, and L. Kazovsky, "Sleep mode for energy saving pons: Advantages and drawbacks," In GLOBECOM Workshops, 2009 IEEE, pp. 1-6, Dec. 2009.

[12] L. Shi, B. Mukherjee, and S. Lee, "Energy-efficient pon with sleep-mode onu: progress, challenges, and solutions," Network, IEEE, vol. 26, no. 2, pp. 36-41, Mar.-Apr. 2012.