

Power Saving Analysis in Integrated Optical and Wireless Access Network Using User Profile Dimensioning

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Abstract— The paper presents the network user profile and energy savings potential based on actual traffic data in the integrated optical wireless access network (IOW). The total power consumption and energy efficiency of the IOW link were analysed with an active fraction of Integrated Optical and Base Station (IOBs) ranging from 0.3 to 0.8. When power saving is implemented, energy consumption decreases with the increasing fraction of IOBs. Furthermore, the proposed model is compared with a conventional approach; the findings show significant differences, highlighting the higher accuracy of the proposed model in estimating network power consumption and energy savings. This research identifies sleep modes as practical tools for achieving energy efficiency, with 11% energy savings observed when 50% of the Integrated Optical Backhaul (IOB) units are active. The analysis also shows the impact of various power consumption components on energy savings, emphasizing the efficiency of sleep mode under specific network conditions.

Keywords—Integrated optical wireless access (IOW), Integrated Optical and Base Station (IOB), Power consumption, Sleep mode. User profile.

I. INTRODUCTION

With the global demand for high-speed connectivity and various high-bandwidth applications, the integration of optical and wireless access networks has become inevitable in today's communication networks. The integration which is commonly known as Fiber-Wireless networks, incorporates fiber optic networks with wireless technologies to enhance the overall capacity and coverage of networks. Integrating these two systems has been seen as a way of providing a viable and flexible network architecture that can meet the increasing needs for bandwidth and coverage in various applications [1].

The access segment, which comprises the optical network unit (ONU) that is usually sited at the customer's premises, accounts for a large portion of the energy consumed in fiber to the home (FTTH) networks. To overcome this challenge, several power-saving mechanisms and techniques have been suggested and implemented with the aim of enhancing the energy efficiency of the optical access networks. The power-saving mechanisms are incorporated in the design and operation of integrated optical wireless access networks to

enhance the energy efficiency of the user profile dimensioning process while ensuring that the recommended quality of service (Qos) and capacity are met (2). The subscriber profile, which is a key component of network optimization strategies includes several parameters such as device profile, service-level agreement, quality of service, and behavioral profile (3). All these parameters are vital in gauging the network's capability of meeting the various needs of the users, optimization of resources and improvement of the quality of service. With the help of smarter devices, the network user is now more empowered and assertive and expects the network to always be available and for faster data transmission.

From the available options for enhancing energy efficiency, sleep schemes have been identified as the most effective method of minimizing power usage in access networks. The present research aims at implementing the sleep mode concept in integrated networks with reference to the GPON backhaul and the WiMAX/LTE access at the front end. The possibilities of power-shedding mechanisms for the ONU and the idle mode procedures for the FBS are discussed together with user profile dimensioning as a tool for enhancing energy savings and network performance [4-7].

This paper presents a comprehensive analysis of power-saving mechanisms in integrated optical and wireless access networks, with a specific focus on the Brunei user profile. Leveraging actual measurements from operational networks, it investigates the impact of user profiles on network performance and provides actionable insights for the design of more energy-efficient and adaptive communication systems. The findings demonstrate how Fiber-Wireless networks can effectively decrease energy usage, increase sustainability, and meet the current challenges of providing efficient and robust communication networks.

II. USER PROFILE DATA

The energy efficiency of the integrated access network was evaluated using a specific scenario: Gadong area, Bandar Seri Begawan. To obtain realistic traffic profiles, actual measurements from an operational network were utilised. A comprehensive one-week profile was analysed, reflecting the average number of profiles recorded over the course of the

week. Figure 1 presents the normalized traffic profile against the peak traffic value observed at midnight. This normalization allows for a clear comparison of traffic patterns throughout the week. Typically, the early morning hours, from 12 a.m. to 7 a.m., show a significant decrease in traffic activity, reflecting the period of minimal network usage. During this time, traffic levels are consistently lower, likely due to reduced user activity, which aligns with typical human sleep patterns. This off-peak period provides a valuable opportunity for implementing power-saving techniques without significantly affecting network performance.

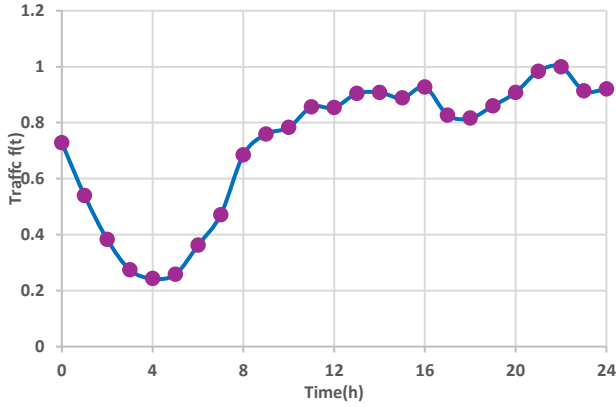


Figure 1. Normalised weekly user traffic data profile

Based on the analysed traffic profile, the duration for which the network remains in sleep mode, as well as the periods during which it is transitioned to sleep mode are detailed in Table 1 for various active fractions of Integrated Optical Base Station (IOBs). The parameter x in the table represents the ratio of active IOBs to the total number of IOBs in the network, with values ranging from 0.3 to 0.8.

Table 1. Summary of average user traffic data profile

No	x (active IOB fractions)	Sleep (time)	Duration (hours)	Put to sleep (time)	Duration (hours)
1	0.3	3am – 6am	3	0am-3am	3
				6am – 24am	18
2	0.4	2am – 7am	5	0am – 2am	2
				7am – 24am	17
3	0.5	2am – 8am	6	0am – 2 am	2
				8am – 24am	16
4	0.6	1am – 8am	7	0am – 1am	1
				8am – 24am	16
5	0.7	1am – 9am	8	12am – 1am	1
				9am – 24am	15
6	0.8	0am–10am	10	10am–24am	14

This range indicates different operation states, where lower values of x correspond to fewer active IOBs, enabling more aggressive power-saving strategies, while higher values maintain a greater number of active stations to accommodate traffic demand. Table 1 highlights how traffic variations influence sleep durations across these configurations, providing

a comprehensive view of potential energy savings in relation to network load.

III. ANALYSIS OF DATA TRAFFIC

For the analysis, a single Optical line terminal (OLT) line card within the integrated access network was considered. The power consumption of each OLT port carrying traffic, denoted as $f(t)$. The initial power consumption for an OLT port is calculated as follows [8,9]:

$$P(t) = P_{OLT} + SR \cdot P_{IOB} f(t) \quad (1)$$

To incorporate the effect of network traffic, equation (2) was derived as follows:

$$P(t) = P_{OLT} + SR(b + af(t)) \quad (2)$$

where P_{OLT} is the power consumption of OLT, SR is the split ratio and P_{IOB} is the power consumption of integrated optical and base station, a is the idle power of ONU and BS, and b is power per 1 bit of ONU and BS. Note that in this analysis, the normalized values of the three power components were considered so that their sum equals one when traffic is at its peak. Consequently, the power consumption model was generalized so that it is applicable to all IOB technologies and no longer specific to a single technology. Clearly, the values of P_{OLT} , a and b depend on the OLT and IOB technology and model, but the $SR \cdot b$ will predominate in most cases.

A. Energy Consumption Based on Traffic Profile Data

Based on the traffic profiles outlined, the daily energy consumption of an integrated optical-wireless access link, where all Integrated Optical Base Stations (IOBs) are continuously active (i.e., no power-saving mechanisms are applied) E_{nps} , is calculated using the following equation:

$$E_{nps} = \int_0^T (P_{OLT} + SR(b + af(t))) dt$$

$$= 24(P_{OLT} + SR \cdot b) + SR \cdot a \int_0^{24} f(t) dt \quad (3)$$

When power-saving (PS) mode is implemented, certain IOBs transition into a sleep state during periods of low traffic, effectively reducing power consumption. In this context, daily power consumption fluctuates based on the active or sleep state of the IOBs. Assuming power-saving mode is active between 2:00 a.m. and 8:00 a.m., when traffic load is reduced, and defining $x=0.5$ with $f(t)=0.5$, the power consumption in PS mode, E_{1-x} is determined as follows:

$$E_{1-x} = \int_0^2 (P_{OLT} + SR(b + af(t))) dt + \int_8^{24} (P_{OLT} + SR(b + af(t))) dt + (8 - 0)P_{IOB-S}$$

$$= 16(P_{OLT} + SR.b) + SR.a \left(\int_0^2 f(t)dt + \int_8^{24} f(t)dt \right) + 8P_{IOB-S} \quad (4)$$

During the periods from 12 a.m. to 2 a.m. and from 8 a.m. to midnight, the IOBs carry their own traffic, while during the sleep mode period (2 a.m. to 8 a.m.), their power consumption is reduced. In contrast, when some IOBs remain fully active while others enter sleep mode per the PS configuration, E_x the total daily energy consumption, can be described as:

$$\begin{aligned} E_x &= \int_0^2 (P_{OLT} + SR(b + af(t)))dt \\ &\quad + \int_8^{24} (P_{OLT} + SR(b + af(t)))dt \\ &\quad + \int_2^8 (P_{OLT} + SR(b + a\frac{1}{x}f(t)))dt \\ &= 16(P_{OLT} + SR.b) + SR.a \left(\int_0^2 f(t)dt + \int_8^{24} f(t)dt \right) + 8(P_{OLT} + SR.b) \\ &\quad + 2SR.a \int_2^8 f(t)dt \end{aligned} \quad (5)$$

The average energy consumption of an integrated optical-wireless access link, when a fraction $1-x$ of Integrated Optical Base Stations (IOBs) is put into sleep mode according to the power-saving (PS) configuration and the remaining fraction x remains active, can be determined by considering the energy consumption during both active and sleep states. The total energy consumption in this scenario accounts for the fraction of IOBs that stay fully operational and the fraction that enters sleep mode during low-traffic periods. The average energy consumption is calculated as follow:

$$E_{PS} = (1-x)E_{1-x} + xE_x \quad (6)$$

Consequently, the energy savings achieved through the implementation of the power-saving (PS) configuration can be quantified by comparing the energy consumption of the network under the PS configuration to the baseline scenario where all Integrated Optical Base Stations (IOBs) remain fully active without any power-saving measures. The energy savings, denoted as θ , represent the percentage reduction in energy consumption due to the use of PS, and can be calculated using the following formula:

$$\theta = \frac{E_{nps} - E_{PS}}{E_{nps}} \times 100\% \quad (7)$$

Therefore, it can be defined that three distinct configurations for an integrated optical-wireless access link, each representing different operational modes in terms of energy consumption and power-saving strategies: a link without power saving (E_{nps}), a link configured for PS operation (E_{1-x}), and a link that remains on to handle traffic from a sleeping link (E_x). These configurations were analysed to assess their energy consumption and efficiency in the integrated access network.

Figure 2 presents the average daily energy consumption for these links. The bar chart illustrates the energy consumption of an integrated access link with active IOB fractions ranging from 0.3 to 0.8. The energy consumptions are normalized to a maximum value of 24 for easier comparison. From the chart, it can be observed that the energy consumption of a link without power saving remains constant at approximately 22.56 for each fraction of active IOBs. This energy consumption is slightly lower than 24 due to the power consumption model considering traffic loads, resulting in lower energy consumption during periods of low traffic.

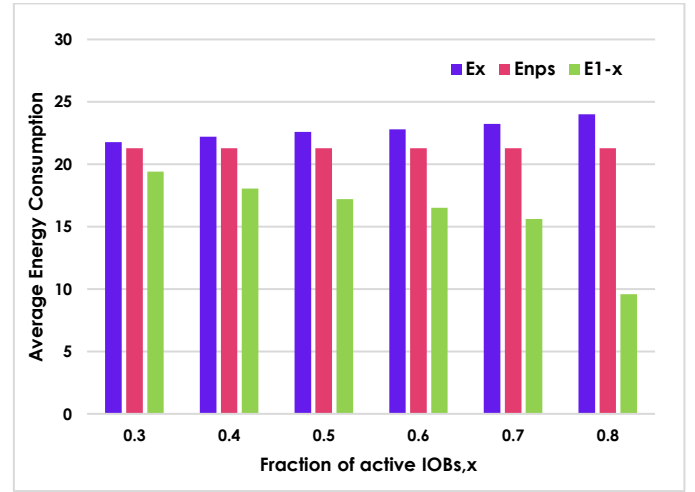


Figure 2 : Average energy consumption in a day by an integrated optical-wireless access network

When the PS configuration is implemented, as depicted by the E_{1-x} link, the energy consumption decreases further. The energy consumption of the E_{1-x} link decreases with increasing fractions of active IOBs. This reduction is due to a longer sleep mode period for a higher proportion of active IOBs, resulting in reduced power consumption. However, it is important to note that the energy consumed by a link that remains on, represented by the E_x link, is slightly higher than that of a link without power saving. This is because the active IOB in the E_x link consumes additional energy when handling traffic from the sleeping IOB. Figure 2 highlights that power-saving strategies, particularly, E_{1-x} links are the most energy efficient, especially when more IOBs enter sleep mode. This ability to adjust the number of active IOBs based on traffic ensures significant energy savings during low-traffic times without affecting network performance.

B. Comparison Between Proposed Model and Conventional model

Additionally, a comparison was made between our proposed model and a conventional model where power consumption is assumed to be constant and independent of traffic load. Figure 3 represents the relationship between energy savings and fractions of active IOBs. The graph shows that the conventional model yields significantly higher energy savings than the proposed model. The conventional model achieves an average energy saving of 21.2%, while the proposed model achieves an average energy saving of only 9.8%. This substantial difference of approximately 11% can be attributed to the assumption of constant energy consumption during the active period in the conventional model. As a result, the conventional model overestimates the energy savings during sleep mode. This comparison demonstrates that the conventional model does not accurately predict the daily energy consumption of network elements and thus provides an overstated estimation of energy savings.

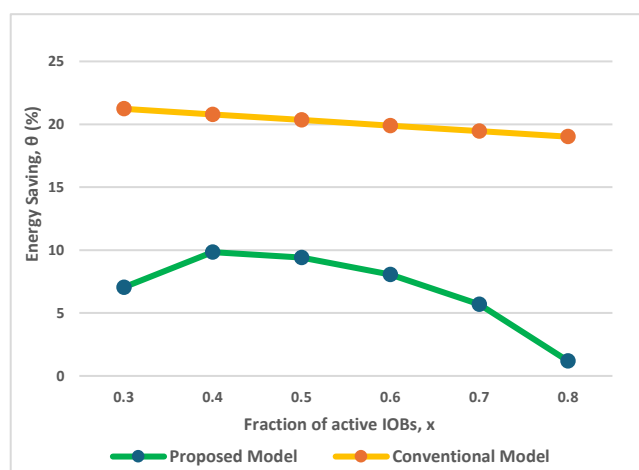


Figure 3 : Comparison of energy saving between the proposed and conventional model.

IV. CONCLUSIONS

Network user behavior was examined along with the potential for energy savings based on traffic patterns analysis. A comparison between our proposed model and the conventional model shows significant differences, indicating the higher accuracy of our approach in estimating network power consumption and energy savings. Notably, the greatest energy savings of 11% were observed when 50% of the IOBs were active, emphasizing the effectiveness of sleep modes as an energy-efficient networking tool. Additionally, we found that various power consumption components of the OLT and IOB had a significant impact on energy savings. Sleep mode proved to be more efficient when the power required to carry zero traffic was high, while the power consumption of the OLT and the power proportional to traffic were low.

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