

Deployment of Sleep and Doze Mode Technique for Energy Conservation in Optical-Wireless Access Network

H. O. Lasisi^a, M. O. Asafa^{a*}, O. O. Olawumi^a and O. R. Oyeniran^b

^aDepartment of Electrical and Electronic Engineering, Osun State University, Osogbo, Nigeria

^bDepartment of Electrical and Electronic Engineering, Osun State College of Technology, Esa-Oke, Nigeria

*Corresponding Author: mubarak.asafa@gmail.com

ARTICLE INFO

Received: October, 2021

Accepted: January, 2022

Published: January, 2022

Keywords:

Conservation

Optical-Wireless Network

Sleep mode

Doze mode

Passive Optical Network.

ABSTRACT

Strong connections are required to cater for massive traffic generated by the rapid increase in the number of internet users and the continued introduction of new bandwidth-demanding applications such as live streaming application, remote home control, cloud computing etc. Merging optical and wireless technologies is an exciting and innovative access network approach that combines the reliability and capability of optical networks with the mobility and universality of wireless networks. Energy conservation in telecommunication networks especially access networks is also getting increasing attention recently. This paper ascertained the energy saving ability of an integrated Passive Optical Network (PON) and Long Term Evolution - Advanced (LTE-A) access networks via sleep and doze mode techniques. Optimum Network Engineering Tool (OPNET) modeller software was used to create the optical-wireless access network, and the inbuilt tools were deployed to generate and drive traffic in the network. sleep and doze mode techniques were implemented on the network with simulation being performed utilizing OPNET simulation package to measure the impact of the energy-saving strategies on energy usage in the network. When the network was put into sleep mode, the energy consumption dropped from 520 Watt-Second to 20 Watt-Second. The activation of doze mode also caused a decline in energy utilization from 600 Watt-Second to 380 Watt-Second. The result revealed 96.2% energy conservation with sleep mode and 36.7% with doze mode. The study showed that by applying these energy-saving strategies to an integrated optical-wireless access network, significant energy could well be saved even in the case of excessive traffic without jeopardizing the access network's quality of service.

1. INTRODUCTION

In a Passive Optical Network (PON), passive optical splitters send data from a single transmission point to a large number of user terminals (Viavi, 2020). In this context, "passive" implies that the material and dividing elements are not powered. An Optical Line Terminal (OLT) is situated at the communication provider's Central Office (CO) while a handful of Optical Network Units (ONUs) or Optical Network Terminals (ONTs) are located at the end users' locations. PON and other optical access networks contribute

greatly to the overall energy conservation in today's networks, and are believed to benefit even more in the coming years (Tucker, 2011; Valcarengi *et al.*, 2012). However, there are several current techniques to enhance energy conservation in optical access networks work on enhancing relatively low power transceivers (physical layer approach) and sleep control mechanisms (Media Access Control (MAC) layer approach). The Institute of Electrical and Electronics Engineers (IEEE) 802.3 Ethernet in the First Mile project ratified the Ethernet PON (EPON or GEAPON) standard 802.3ah-2004 in 2004. EPON is a "short-distance" connection that employs Ethernet data packet, optical fiber, and a solitary protocol layer (Newwavedv, 2020). It also uses standard 802.3 Ethernet frame packets with 1 gigabit per second symmetric upstream and downstream rates.

EPON is an excellent option for data-centric connections along with voice, data, and video networks. It is an access network platform that integrates the benefits of low-cost Ethernet standard with low-cost optic fiber network architecture to create a low-cost access network. The downstream data transmission in an EPON is divided into segments using a Time Division Multiplexing (TDM) mechanism, with the OLT being the only device in the EPON capable of sending traffic. The OLT is the single receiver of ONU traffic in the upstream, using the Time Division Multiplexing Access (TDMA) mechanism. The PON devices function as a master/slave system, with the OLT serving as the master device that oversees a number of slave ONUs. The Multi-Point-Control Protocol (MPCP) is used by the Dynamic Bandwidth Allocation (DBA) algorithm to oversee upstream communication links (IEEE, 2013). In an EPON, an authorized ONU can connect the upstream channel and transfer signals to the OLT within the transmission time period specified by the OLT. When likened to third-generation (3G) technology, Long Term Evolution (LTE) is a fourth-generation (4G) standard for wireless network that delivers greater network speed and reliability for smartphones and other communication devices. LTE provides faster peak data transmission speeds than 3G, up to 100Mbps downstream and 30Mbps upstream at first. It has lower latency, expandable bandwidth capacity, and interoperability with GSM and UMTS technology (Dorathy and Chandrasekaran, 2018; Chen *et al.*, 2019). The subsequent development of LTE-Advanced (LTE-A) yielded peak throughput on the order of 3 Gbps to 15 Gbps; spectral efficiency has improved from 16 bps/Hz to 30 bps/Hz in Release 10 and the number of users who are simultaneously available on line has risen. (Tetcos, 2021).

Sleep and doze mode mechanisms in ONUs are two approaches for considerably lowering PON power usage (Baliga *et al.*, 2013). Most eco-friendly PON systems provide a sleep mode mechanism that assumes an ONU can exist in two states: active and sleep (Ren *et al.*, 2011). The transceiver of an ONU are operational when it is in the active mode, but when it is in the sleep state, they are turned off. As a result, an ONU cannot receive or send any traffic while it is in this condition. The moment the sleep duration ends, an ONU in sleep mode must transfer into active phase from sleep state to listen to OLT's command. Doze mode seeks to turn the transmitter off when there is no upstream traffic but maintain the receiver on all the time. It's worth noting that the time required for an ONU to turn its transceiver 'on' or 'off' has an overhead. The length of sleep intervals is determined by an algorithm used by the OLT. However, owing to the bursty pattern of traffic in access networks, forecasting optimal sleep interval lengths is extremely challenging (Zhang and Ansari, 2011; Newaz *et al.*, 2013a).

The prospect of merging wireless networks with optical fiber-based PONs in terms of energy conservation on the MAC layer remains relatively unexplored. The bulk of the research compared the energy consumption of optical and wireless access networks separately, whereas others tried to compare the energy consumption of those access networks collectively. The data on the energy consumption of the connections under consideration can be obtained using network energy modeling. Researchers have proposed Wireless-Optical Broadband Access Network (WOBAN), Hybrid Optical Wireless (HOW) Network and Fiber-Wireless (FiWi) Access Network as examples of optical-wireless integration (Chowdhury *et al.*, 2014; Maier, 2014; Shaddad *et al.*, 2014). The merging of EPON and LTE-Advanced is an example of an optical-wireless network that gained attention from scholars around 2009 (El Khadiri *et al.*, 2018). Consequently,

optical-wireless access solutions can benefit from energy performance evaluation, network architectural advancements and energy conservation provisions. Gowda *et al.* (2014), Aleksic *et al.* (2013), Ramli *et al.* (2017) and Ricciardi *et al.* (2013) worked on the evaluation of energy consumption of combined optical-wireless networks, with Gowda *et al.* (2014) offering an energy model for in-building connections instead of access networks.

Newaz *et al.*, (2013b) developed a mathematical model for calculating the energy conservation of an ONU with four levels of power. When an ONU has only two power levels, the mathematical approach can measure energy consumption (Ren *et al.*, 2011). Measuring an ONU's energy saving capabilities becomes increasingly difficult as the number of power levels grows. As a result, a simulation tool is required for EPONs with sleep mode enabled, so that not just the energy consumption of different EPON nodes can be measured, but also the QoS compliance of the traffic they serve. Optimum Network Engineering Tool (OPNET) Modeler is a robust simulation and modeling software. Some studies employ OPNET to model and analyze PON. Moradpoor *et al.*, (2011); and Zhiwen and Radcliffe, (2011) modeled EPON in OPNET in order to compare alternative DBA algorithms. Their models, on the other hand, aren't versatile enough to utilise OPNET technologies to simulate different types of traffic (such as voice, HTTP, etc). Furthermore, energy conservation in optical-wireless access networks was not a priority in the models.

In most of the literatures reviewed and to the best of our knowledge, energy consumption model for networking devices were derived solely from the figures given in the datasheets which are frequently exaggerated and there is little or no research on modeling and simulating energy conservation processes of optical-wireless access network in OPNET. As a result, a comprehensive modeling of the energy consumption of optical-wireless networking devices was conducted in this paper, taking into account the energy usage reliance on traffic volume and site factors, and the effect of energy conservation techniques on energy usage.

2. METHODOLOGY

2.1 Optical-Wireless Access Network Creation and Setup in OPNET

The OLT is located at the CO and is connected to terminal equipment (ONU) via a POS in the created Optical-Wireless Access Network. The terminal equipment consists of 16 ONUs for fixed clients (Ethernet) and LTE-A for mobile users. The OPNET modeler software's object pallet tool was used to design multiple network packet frames; 16 ONU end user nodes, an OLT node, and 16 Ethernet nodes for each ONU. With the help of an optical splitter, all of the ONU nodes from 1 to 16 are linked together. Each ONU's Ethernet nodes were pre-configured. They were installed one at a time through the node model option, and each node is made up of numerous states or process constituents that can be created using the process model feature. The layout of the created optical-wireless access network is illustrated in Figure 1.

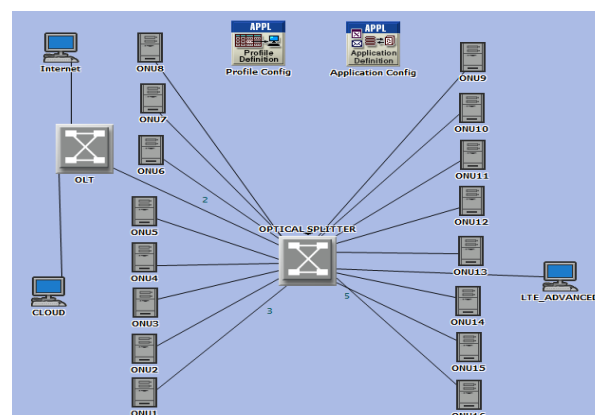


Figure 1: Designed Optical-Wireless Access Network

2.2 Optical-Wireless Access Network Configuration

Defining required applications and statistical data to be collected through the simulation, putting nodes in the simulated system, and finally specifying user profiles and applications are all steps in establishing a simulation system running application models. According to OPNET, an application model describes the characteristics of the application-generated traffic, while a user profile describes how the program is used. The joining of node equipment was the first stage in link object configuration. Layer 2 (data link layer) technology specifies connections by testing the effectiveness of the nodes that are connected by the connection. For designing and building the preferred topology, an appropriate link model was selected. In certain cases, however, it may be important to configure a link object after it has been added to a network architecture to meet particular criteria. The conceived optical-wireless access network was designed to provide network connectivity for 16 Ethernet customers employing EPON technology and a number of mobile customers utilising LTE-A technology at a data transfer rate of 2.5 gigabits per second. The media was shared using the TDMA method in the design. The medium consists mainly of a fiber optic link between the CO and a PON neighborhood. The 'Application Config', 'Profile Config', 'Name Attribute', 'Number of Rows', 'Start Time', and 'Operation Mode' were all properly pulled onto the work area and set in order to prepare for the simulation.

2.3 Mathematical Formulation for Network Energy Consumption

Given that E_{ACCESS} , E_{OLT} , E_{ONU} and $E_{LTE A}$ denote the energy used in the access network, OLT, i th ONU and LTE-A Ethernet Port, respectively. As a result, Equation 1 can be used to calculate the total energy used by the network. The actual population of ONUs in the network is represented by n in the equation. Assume that the OLT (or its constituent elements) is turned off at any time while in active state to save energy. Depicting $E_{ONU_i}(k)$ as the energy used by the i th ONU in cycle k . Equation 2 represents the total energy used by each ONU in cycle k . But, $E_{OH}(k)$ in Equation 2 is calculated using Equation 3. If $E_{tr}(k)$ denote the amount of energy consumed by one transmitter/receiver, P_{tr} and $AP(k)$ indicate the power drawn by the transceiver and the active period during one cycle k , respectively, Equation 4 can then be used to obtain $E_{tr}(k)$. An OPNET program code was used to evaluate the overall usage of energy of all nodes in the designed network.

$$E_{ACCESS} = E_{OLT} + \sum_{i=1}^n E_{ONU} + E_{LTE A} \quad (1)$$

$$E_{ONU_i}(k) = E_{OH}(k) + E_{ROLT}(k) + E_{RW}(k) + E_{RE}(k) + E_{TE}(k) + E_{TW}(k) + E_{BF}(k) \quad (2)$$

$$E_{OH} = T_{OH} \times P_{total} \quad (3)$$

$$E_{tr}(k) = P_{tr} \times AP(k) \quad (4)$$

Where:

$E_{OH}(k)$ indicates energy consumed by the ONU over the total overhead time (OH),

$E_{ROLT}(k)$ denotes energy utilised by Ethernet receptors for incoming traffic from the OLT,

$E_{RW}(k)$ denotes energy consumed by wireless receptors for traffic coming from end customers,

$E_{RE}(k)$ represents energy consumed by Ethernet receptors for traffic coming from end customers,

$E_{TE}(k)$ is the energy utilised by Ethernet transmitter,

$E_{TW}(k)$ denotes energy used by wireless transmitter,

$E_{BF}(k)$ indicates energy consumed by ONU components in active state all time,

T_{OH} denotes total overhead time,

P_{total} denotes the total power of an ONU, together with all its transceivers and active constituents.

$E_{tr}(k)$ is the amount of energy consumed by one transmitter/receiver,

P_{tr} indicates the power drawn by the transceiver during one cycle k ,

$AP(k)$ indicates the active period during one cycle k .

2.4 The Designed Network Simulation Process

Selection of simulation statistics for network objects is part of the simulation process. The energy used by the network as a result of traffic received in bytes/sec and packets/sec, as well as the energy used as a result of traffic sent in bytes/sec and packets/sec, are the simulation statistics collected in this study.

2.5 Energy-Saving Strategies: Implementation and Setup

Sleep and doze mode algorithms were configured and implemented on the access network to find the energy-saving capability of the sleep and doze mode algorithms in order to assess the energy-saving capacity of the designed optical-wireless access network.

Sleep mode

The decision to enter a sleep state for an ONU is largely influenced by the presence of traffic. Packet delay variation and packet end to end delay were the measurement indicators used to evaluate the sleep mode. At ONU, the OLT-controlled seven-mode mechanism was developed. The OLT keeps track of each ONU's arrival. The OLT instructs the ONU to go into sleep mode if the ONU has no traffic to transmit and the OLT has no traffic. The OLT sends out a message marked "Wake Up ONU" after an ONU goes into the sleeping state and traffic arrives downstream, instructing the ONU to awake and exit the sleeping state. If the ONU enters sleep state and receives any upstream traffic, it wakes up and sends a Wake Up ONU signal to the OLT, indicating the required upstream bandwidth and award time. The algorithm is determined by the sleep mode. When the OLT chooses to send the ONU into sleep state, the OLT informs the ONU of the duration of sleep calculated using Equation 5. The OLT invokes a new sleep duration every time an ONU enters the listening state to receive OLT instruction, assuming the ONU does not have traffic. With the help of an OPNET executable code, the sleep mode was applied to the designed network.

$$T_j = \begin{cases} 2^{j-1} \times T_{\min}, & \text{if } T_{\min} < T_{\max}, \\ T_{\max}, & \text{otherwise} \end{cases}, \quad (5)$$

Where: T_j is period of the j th interval of sleep, T_{\min} is minimum sleep interval length, T_{\max} is maximum sleep interval length.

Doze mode

The ONU transmitter is sometimes turned off while the ONU receiver is always on. For doze mode, the parameters used were traffic sent (bytes/sec) and traffic sent (packets/sec). The ONU disregards its upstream allocation until there is traffic to send. The downstream link, on the other hand, is fully operational, allowing for continued transfer to the client site. As part of an internal procedure to generate traffic, the ONU was woken up by a specific OLT request or a local stimulus. In the meantime, OLT sends upstream subsidies to sleeping ONUs without having to wait for responses in order to transmit traffic as soon as possible. For the designed network, a program code was developed to implement doze mode.

3. RESULTS AND DISCUSSION

3.1 Traffic Received

Figure 2 shows the flow of traffic received by customer premises equipment in the designed optical-wireless access network. It depicts the amount of traffic received in packets per second. It demonstrates how a rise in traffic flow leads to a sudden drop in speed, resulting in higher data consumption due to the increased number of packets. At every 3 minutes, the amount of traffic received decreases. This is the result of a decline in the number of connected subscribers at regular intervals.

3.2 Traffic Sent

Figure 3 depicts traffic transmitted in packets per second. The number of packets transmitted towards the OLT increases over time as shown in the graph. This has an impact on the network's energy utilization which is indicated by an increase in traffic sent with time occasioned by increase in the number of connected user and application.

3.3 Application of Sleep Mode Algorithm

Figure 4 shows the impact of the activation of sleep mode on the optical-wireless access network. The figure shows that with sleep mode, energy usage is lower than when sleep mode is not activated in the network. The maximum energy consumed is 20 Watt-Second when sleep mode is activated in the access network when compared to non-application of sleep mode when the maximum energy utilized is 520 Watt-Second. The graph shows that energy efficiency is greatly improved in the network with the application of the sleep mode algorithm.

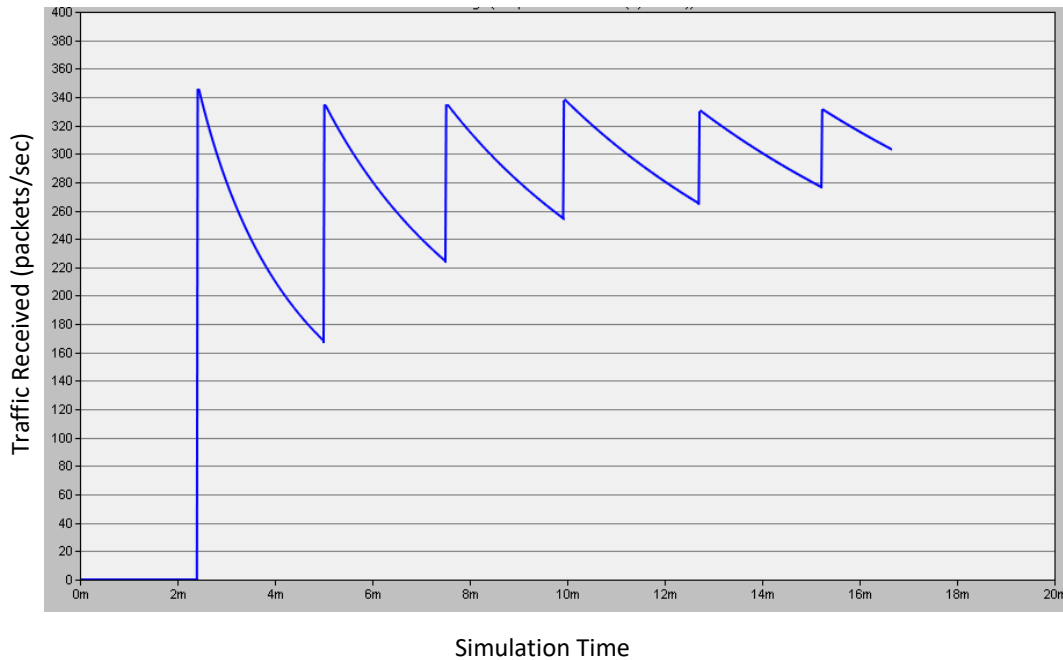


Figure 2: Traffic Received versus Simulation Time

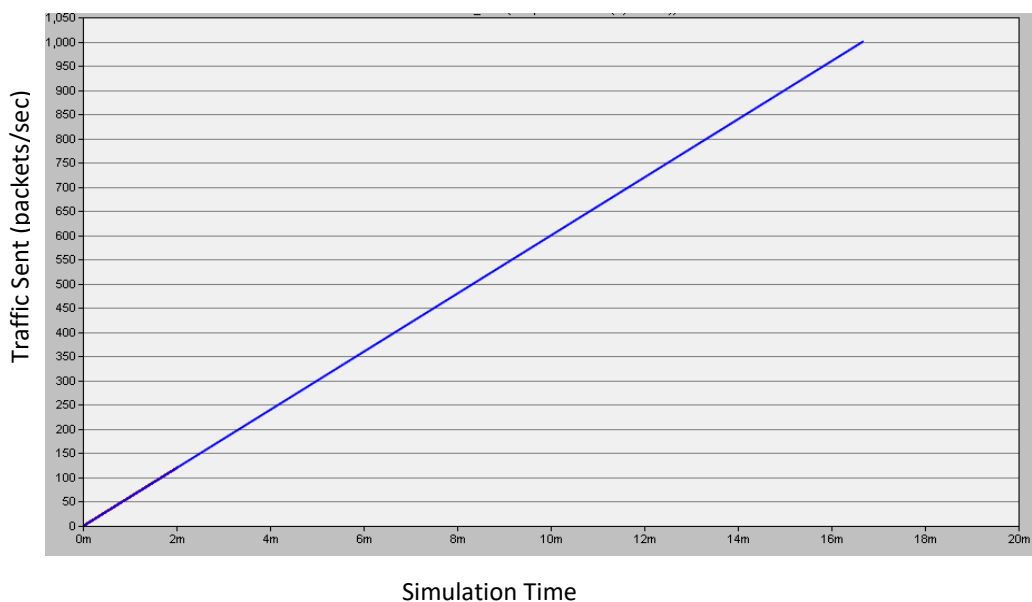


Figure 3: Traffic Sent versus Simulation Time

3.4 Application of Doze Mode Algorithm

The energy used by the ONUs and other network devices accumulated to 600 Watt-Second for transferring packets from one node to another as shown in Figure 5, but the application of doze mode was able to improve energy efficiency and reduce maximum energy utilized to 380 Watt-Second. As a result, the doze mode algorithm was able to improve energy efficiency in the network as seen from Figure 5.

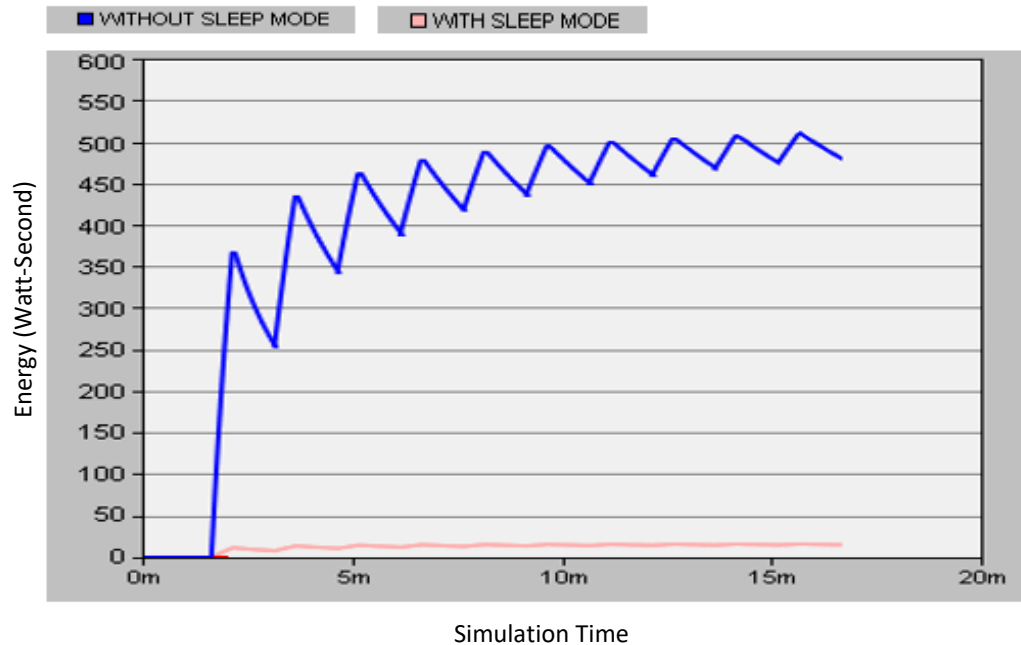


Figure 4: Energy Utilization versus Simulation Time for Sleep Mode

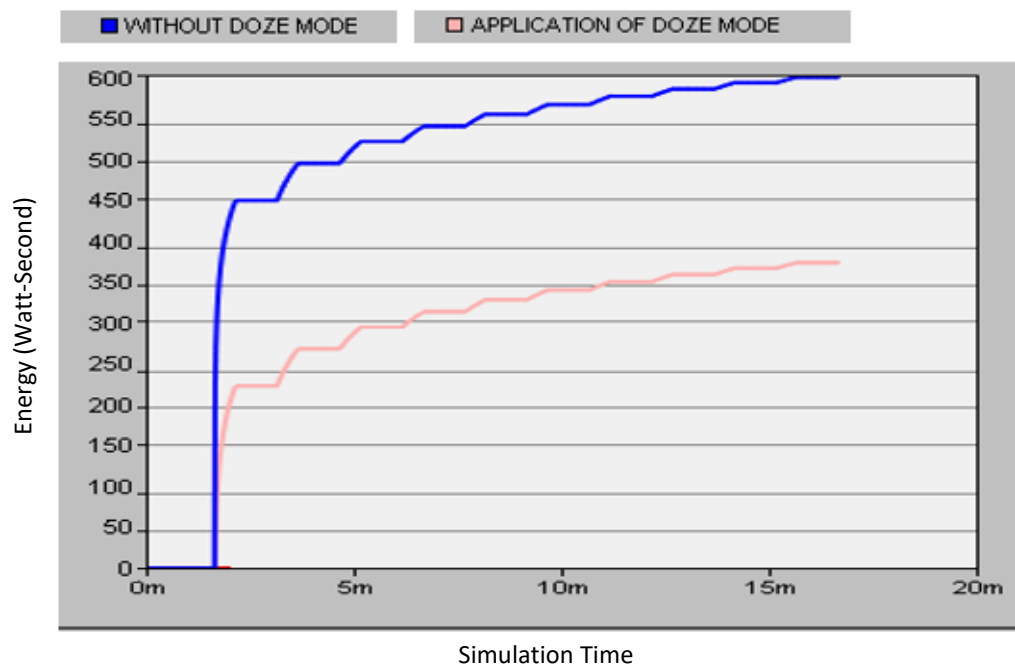


Figure 5: Energy Utilization versus Simulation Time for Doze Mode

4. CONCLUSION

This paper investigated a PON, which uses optical fiber as a transmission medium and uses passive equipment to allocate signals to and from users, and the wireless network, which employs LTE-A as the radio access technology to beam signals to mobile internet users. The two access technologies were merged to provide access subscribers with the benefits of robustness, unmetered bandwidth, mobility, and high availability. The impact of using a sleep and doze mode algorithm on the traffic in an optical-wireless access network was postulated and analyzed. The network was designed using OPNET Modeler Software in this study. OPNET modeler was used to simulate the proposed sleep and doze mode algorithms. The result revealed 96.2% energy conservation with sleep mode and 36.7% with doze mode which shows that the use of the energy-saving approaches resulted in good energy-saving qualities while still curtailing service quality impairments, even in the presence of high concentration of traffic.

References

- Aleksic, S., Deruyck, M. and Joseph, W. (2013). Energy Efficiency of Optically Backhauled LTE: A Case Study of Vienna. *International Conference on Electromagnetics in Advanced Application (ICEAA-IEEE)*. Turin, Italy, doi:10.1109/ICEAA.2013.6632263
- Baliga J., Tucker, R. S., Ayre, R., Hinton, K. and Sorin, W. V. (2009). Energy Consumption in Optical IP Networks. *Journal of Lightwave Technology*, 27: 2391-2403.
- Chen, M., Miao, Y. and Humar, I. (2019). OPNET IoT Simulation. In OPNET IoT Simulation. <https://doi.org/10.1007/978-981-32-9170-6>
- Chowdhury, R., Shami, A. and Almustafa, K. (2014). Designing of Next-Generation Hybrid Optical-Wireless Access Network. *14th IEEE International Conference on Innovations for Community Systems*, doi:10.1109/I4CS.2014.6860546
- Dorathy, I. and Chandrasekaran, M. (2018). Simulation Tools for Mobile Ad hoc Networks: A Survey. *Journal of Applied Research and Technology*, 16(5):437-445. doi:10.22201/icat.16656423.2018.16.5.739
- El Khadiri, K., Laboudiya, O., Elkamoun, N. and Hilal, R. (2018). Performance Evaluation of IPv4/IPv6 Transition Mechanisms for Real-Time Applications using OPNET Modeler. *International Journal of Advanced Computer Science and Applications*, 9(4):387-392. doi:10.14569/IJACSA.2018.090454
- Gowda, A. S., Dhaini, A. R., Kazovsky, L. G., Yang, H., Abraha, S. T. and Ngoma, A. (2014). Towards Green Optical/Wireless in-Building Networks: Radio-Over-Fiber. *Journal of Lightwave Technology*, 32(20):3545-3556. doi:10.1109/JLT.2014.2315960
- IEEE Std 1904.1-2013 (2013). IEEE Standard for Service Interoperability in Ethernet Passive Optical Networks (SIEPON), 1-834.
- Maier, M. (2014). Fiber-Wireless (FiWi) Broadband Access Networks in an Age of Convergence: Past, Present, and Future. *Advances in Optics*, pp.1-23.
- Moradpoor N., Parr, G., McClean, S. I., Scotney, B. and Sivalingam, K. M. (2011). Simulation and Performance Evaluation of Bandwidth Allocation Algorithms for Ethernet Passive Optical Networks (EPONs). OPNETWORK.
- Newaz, S. S., Cuevas, A., Lee, G. M., Crespi, N. and Choi, J. K. (2013a). Evaluating Energy Efficiency of ONUs Having Multiple Power Levels in TDM-PONs. *IEEE Communications Letters*, 17(6): 1248 - 1251.
- Newaz, S. S., Cuevas, A., Lee, G. M., Crespi, N. and Choi, J. K. (2013b). Adaptive Delay-Aware Energy Efficient TDM-PON. *Computer Networks*, 57(7): 1577-1596.

- Newwavedv, (2020). "What is EPON", Retrieved May 2020, from <http://newwavedv.com/markets/telecommunications/what-is-epon/>.
- Ramli, A., Zulkifli, N. and Idrus, S. M. (2017). Power Consumption Modeling and Analysis of Integrated Optical-Wireless Access Network. *International Journal of Electrical and Computer Engineering*, 7(6): 3475 - 3483. <https://doi.org/10.11591/ijece.v7i6.pp3475-3483>
- Ren, D., Li, H. and Ji, Y. (2011). Power Saving Mechanism and Performance Analysis for 10 Gigabit-Class Passive Optical Network Systems. *Network Infrastructure and Digital Content*, 920-924.
- Ricciardi, S., Palmieri, F., Fiore, U., Castiglione, A. and Boada, G. S. (2013). Modeling Energy Consumption in Next-Generation Wireless Access-Over-WDM Networks with Hybrid Power Sources. *Journal of Mathematical and Computer Modelling*, 58(5-6):1389-1404. doi: 10.1016/j.mcm.2012.12.04
- Shaddad, R. Q., Mohammad, A. B., Al-Gailani, S. A., Al-hetar, A. M., and Elmagzoub, M. A. (2014). A Survey on Access Technologies for Broadband Optical and Wireless Networks. *Journal of Network and Computer Application*, 459 - 472. doi:10.1016/j.jnca.2014.01.004
- Tetcos, (2021). Long Term Evolution/Long Term Evolution – Advanced, Retrieved March 2021, from <http://www.tetcos.com/lte.html>.
- Tucker, R. (2011). Green Optical Communications Part II: Energy Limitations in Networks. *IEEE Journal of Selected Topics in Quantum Electronics*, 17: 261-274.
- Valcarengi et al. (2012). Energy Efficiency in Passive Optical Networks: Where, When and How? *IEEE Network*, 26(6): 61-68.
- Viavi, (2020). PON, Retrieved April 2020, from <http://www.viavisolutions.com/en-us/passive-optical-network-pon>.
- Zhang, J. and Ansari, N. (2011). Toward Energy-Efficient 1G-EPON and 10G-EPON with Sleep-Aware MAC Control and Scheduling. *IEEE Communication Magazine*, 49 (2): 33–38.
- Zhiwen, P. and Radcliffe, P. (2011). Modeling and Simulation of Ethernet Passive Optical Network (EPON) Experiment Platform Based on OPNET Modeler. *Communication Software and Networks, IEEE 3rd International Conference*, 99-104.