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ENERGY EFFICIENCY IN OPTICAL-WIRELESS ACCESS NETWORK USING DYNAMIC BANDWIDTH ALLOCATION

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Abstract

High capacity networks are needed for enormous quantity of internet traffic, which is driven by both the exponential growth of the number of people using the internet and the ongoing introduction of new high-bandwidth requiring applications. Combining optical and wireless technologies is a new and promising access network solution. The energy efficiency of telecommunication networks is therefore attracting increasing attention today than in the past. This study is aimed at evaluating energy efficiency of optical-wireless access network which combines Passive Optical Network (PON) and Long Term Evolution - Advanced (LTE-A) networks into one. The network was designed using Optimum Network Engineering Tool (OPNET) modeler software. Traffic was generated using inbuilt tools provided in the OPNET modeler software. Dynamic Bandwidth Allocation (DBA) algorithm was applied on the network and simulation was carried out using the simulation tool provided by OPNET to evaluate the effect of the DBA algorithm on the energy consumption and efficiency in the network. The findings showed energy utilization of 430 watt-second when DBA algorithm was applied on the access network as against 700 watt-second when it was not activated. This shows a 38.6% energy conservation. It was concluded that with the application of energy saving techniques to combined optical-wireless access network, substantial energy could be conserved even in the presence of heavy traffic without compromising the quality of service of the access network.

Keywords: Energy Efficiency; Optical-Wireless Network; Dynamic Bandwidth Allocation; Passive Optical Network; Long Term Evolution-Advanced.

1.0 INTRODUCTION

Passive optical splitters transmit data from a single transmission point to many user terminals in a Passive Optical Network (PON) [1]. "Passive" in this usage means that the fiber and splitting/combining components are not powered. At the service provider's Central Office (CO), there is an Optical Line Terminal (OLT), and at the end users' locations, there are a number of Optical Network Units (ONUs) or Optical Network Terminals (ONTs).

By using a PON, the CO requires less fiber and equipment compared to point-to-point design. An Active Optical Network requires electrical power at both the service provider and subscriber end, while a PON does not. For both upstream and downstream signal transmission, PONs are utilized as a means to transfer signals concurrently [2]. British Telecommunications (BT) suggested PONs for the first time in 1987 [3]. Along with a number of other industry groups, the Institute of Electrical and Electronics Engineers (IEEE) and the International Telecommunication Union-Telecommunication Standardization Sector (ITU-T) are two of the most important standard-setting bodies in standardizing PONs.

The Ethernet PON (EPON or GEPON) standard 802.3ah-2004 was ratified in 2004 as part of the IEEE 802.3 Ethernet in the First Mile project. EPON is a "short-distance" network that uses Ethernet packets, fiber optic cables, and a single protocol layer [4]. It also employs standard 802.3 Ethernet frame packets with symmetric upstream and downstream rates of 1 gigabit per second. EPON is an excellent choice for data-centric connections as well as regular-service phone, data, and video networks.

10 Gbit/s EPON (10G-EPON) was designed and authorized as an addition to IEEE 802.3av. It provides 10/1 Gigabits per second (Gbps). As a result of the downstream wavelength plan, IEEE 802.3av with IEEE 802.3ah on the same PON may operate simultaneously at 10 Gbit/s with 1 Gbit/s, respectively. Using upstream channel, IEEE 802.3av with 1 Gbit/s 802.3ah may operate concurrently on a single channel that is shared by everyone [5].
Broadband customers benefit from the mobility and flexibility offered by wireless access networks. Wireless connectivity and broadband access are governed by a number of standards. Worldwide Interoperability for Microwave Access (WiMAX), designed for fixed and mobile access networks, is an IEEE standard. It has effective data rate of 70 Mb/s which allows it to operate within a practical range of about 5 km [6]. Although WiMAX is more developed, Wi-Fi only has a range of 100 m and a bit rate of 10 to 50 Mb/s. It's a fact that WiMAX isn't as extensively utilized as Wi-Fi because of its limitations. As low-cost deployment technologies, Wi-Fi and WiMAX don't enable video applications but are excellent for web browsing [7].

Universal Mobile Telecommunication Service / High-Speed Packet Access (UMTS/HSPA) and Global System for Mobile Communications / Enhanced Data Rates for GSM Evolution (GSM/EDGE) technologies are the foundations of Long Term Evolution (LTE) [8], [9]. Due to the use of a new radio interface and other enhancements to the core network, LTE improves the capacity and speed of wireless mobile communication. GSM/UMTS and CDMA2000 (Code Division Multiple Access) carriers may both upgrade to LTE. As a result, LTE frequencies and bands vary from one country to another. A 4G wireless service is often advertised as 4G LTE and Advance 4G, although LTE does not fulfill the technical requirements for 4G service. 3.95G is another name for LTE [10], [11].

A significant upgrade to the LTE standard, LTE-Advanced (LTE-A) is a considerable improvement to the LTE specification. LTE-A is considered a True 4G as it is capable to deliver a true 4G speed. It uses several techniques and technologies to meet higher network-performance standards. Some of them include: Peak data rate increased from 3 Gbps to 15 Gbps; Higher spectral efficiency, from 16 bps/Hz to 30 bps/Hz in Release 10 and improved number of concurrent user online [12].

Wireless-optical convergence has gained a lot of attention in the past years due to its ability to integrate optical access networks' durability and high capabilities with wireless access networks' ubiquitousness, mobility and flexibility. Some optical-wireless convergences were previously suggested by researchers; such as Fiber-Wireless (FiWi) Access Network [13], Hybrid Optical Wireless (HOW) Network [14], and Wireless-Optical Broadband Access Network (WOBAN) [15]. An example of optical-wireless network which started receiving researchers' attention around 2009 is the integration of EPON and LTE-Advanced [16]. PON segments are often built from the telecom CO's OLT all the way to the ONUs, which are near the wireless frontend. ONUs connect to wireless gateways, which then drive multiple wireless routers to serve end-users via the wireless mesh front-end [17]. The ONUs are coupled to cellular front-end (LTE-A) Base Stations (BSs), which makes end-users have access to untethered broadband service.

Dynamic Bandwidth Allocation (DBA) is a bandwidth management strategy that allows for the equitable distribution of requested bandwidth among various users of a shared telecommunication channel. DBA makes use of the fact that users frequently do not connect to the network all at once and, even when they do, do not constantly transfer data. DBA is often implemented in network protocols in a variety of ways that are established by standards created by organizations like the ITU or IEEE.

The DBA algorithm is helpful for upstream transmission since it effectively distributes bandwidth to all ONUs, which saves energy. In order to prevent packet conflicts during upstream transmission, the OLT assigns ONUs non-overlapping transmission slots based on Time Division Multiple Access (TDMA). A decent DBA must take into account bandwidth requirements and network provider's QoS [26].

Traffic containers (TCONTs) provide the basis of DBA in PONs (TCONTs). A distinct allocation ID (AllocID) is used by each T-CONT to distinguish between various traffic kinds. The amount of data that ONUs have in their queue buffer is relayed to the OLT. It then refreshes the bandwidth map (BWmap) depending on the demand frame, determines the bandwidth quota, and then allocates frames to ONUs for upstream time slot allocation [27]. Depending on its polling technique, DBA schemes for ITU PON can be divided into status reporting (SR) and non-status reporting (NSR).

The OLT uses traffic prediction to determine how much bandwidth to allocate to ONUs using NSR, therefore it is blind to the exact bandwidth requirements. By using SR polling, ONUs may keep track of queue reports for each traffic category and communicate queue sizes to OLT. Because of its superior delay performance and reduced latency to user traffic, SR is a preferred polling method [28]. A DBA scheme often has its polling and scheduling algorithms updated. While scheduling makes sure that the bandwidth allotment is dependent on T-CONT types, polling in DBA reveals the

ONU requirement.

Despite its ability to handle incorporation of recent bandwidth-consuming apps, the access network infrastructure's high energy consumption demands special attention. Access networks are widely known for enormous contribution to increase in greenhouse gases in the atmosphere. [18] claimed that energy consumption may increase by around 12% each year due to the continuous rise in wireless technology users and traffic quantities involved. As a result of rising expense of operation associated to the demand for energy with growing global climate change awareness, the use of energy efficiently is an essential element worth considering by providers of services and networks. The application of DBA Algorithm to access networks is however considered as a way of reducing the energy utilized by users of access networks.

1.1 Related Work

Several studies have been carried out on optical-wireless access network technologies to reduce the cost of providing omnipresent broadband connections for access network users. Majority of the work examined focuse on access networks' physical, Media Access Control (MAC), and network layers; with the purpose of developing and investigating low-cost technological solutions along with layer 2 and 3 algorithms and protocols. Nonetheless, because access networks are said to consume the majority of the internet's energy and hence contribute significantly to the greenhouse gas emissions, the development of energy-efficient "green" optical-wireless access networks has gotten attention among researchers [19]. However, considering energy consumption on the physical layer, the possibility of integrating wireless networks with optical fiber-based PONs remains largely untapped. Most of the studied literature compared the energy usage of optical and wireless access networks individually, whereas others dealt with the energy usage among those access networks. Therefore, energy performance appraisal, network architectural improvements, and energy conservation measures can all be applied to those specific access technologies. Just a few authors [20], [21], [22] and [18] have tried to address the task of evaluating the energy usage of integrated optical-wireless networks.

In-building optical/wireless networks using Radio-over-Frequency (RoF) technology are discussed by [20]. The study revealed that RoF networks can be more energy efficient when designed carefully with small cell sizes and when the remote units' static energy usage is more than a certain threshold. [21] proffered a model for assessing the energy efficiency of LTE radio access and backhaul networks using optical technology. They opined that while optical backhaul can provide visible energy efficiency improvements over traditional backhauling strategies, the impact of the optical technology chosen for backhaul cannot be overlooked. Furthermore, a switchover to 4G LTE with the phase-out of 2G and/or 3G networks could well reduce the power consumption of radio access network connectivity significantly.

[18] presented a detailed energy framework that combines different types of traffic in a Wireless Access-over-WDM network and accounts for the foreseen energy-aware architectures and growth rate projections. The model's low complexity and thus high scalability were demonstrated, with the hope that such an energy model will aid in the emergence of future energy-aware communication networks for attaining sustainable economic success.

[22] proposed a new template for measuring the energy usage of an integrated optical wireless access network based on a self-reliant ONU-BS layout. The model's ability to forecast the energy usage of an integrated access network, especially in small cell applications, was demonstrated. The energy usage for a wider BS range was discovered to be substantially lower. Furthermore, the difference in power consumption decreases, with the smallest difference showing a percentage of around 36%. In the meantime, the higher the wireless generation connected to the GPON backhaul, the greater the energy consumption.

[23] suggested that watchful sleep mode had the benefit of replicating both cyclic sleep mode and doze mode in a comparative research on energy conservation techniques. They came to the conclusion that the best way to optimize energy savings in PON is to apply the DBA scheme alongside sleep-assistive ONUs.

[24] examined DBA algorithms in GPON, comparing one algorithm against others using a variety of criteria. They believed that a low mean latency in the GPON algorithm, together with an effective polling and scheduling system, would improve the services provided to customers.

Based on standards, traffic characteristics, and service needs, [25] compared the DBA algorithms of EPON and GPON. When comparing the DBA of EPON and GPON, it was stated that GPON performed better, and that GPON is likely to be the technology used in future networks because to its high bandwidth, good QoS, and security. The researchers came to the conclusion that a DBA technique based on polling and scheduling should be used since it will prevent over-allocation and control throughput.

The power consumption model for the network elements in most of the reviewed literatures were derived based only on the values provided in the datasheets. These values are often oversimplified and do not represents the real consumption. Therefore, in this paper a detailed modeling of the power consumption of the network elements is provided. It also shows the application of DBA algorithm to an optical-wireless network. The power consumption dependence on the traffic load and site factors was as well considered.

2.0 METHODOLOGY

2.1 Design and Configuration of Optical-Wireless Access Network in OPNET

The designed Optical-Wireless Access Network is made up of the OLT which is situated at the CO and linked to end-user equipment (ONU) through a POS. The end-user equipment is made up of 16 ONUs to serve static (Ethernet) users and LTE-A to cater for mobile subscribers. The object pallet tool provided in the Optimum Network Engineering Tool (OPNET) modeler software was used to create various network packet frames, ONU nodes which consist of 16 end user nodes, an OLT node and 16 Ethernet nodes for each ONU. All the ONU nodes from 1 to 16, are integrated together with an optical splitter.

The Ethernet nodes was configured in each ONU and were installed individually using the node model option. Each node consists of multiple states or process components, which can be built with the process model option. Figure 1 shows the created optical-wireless access network topology.

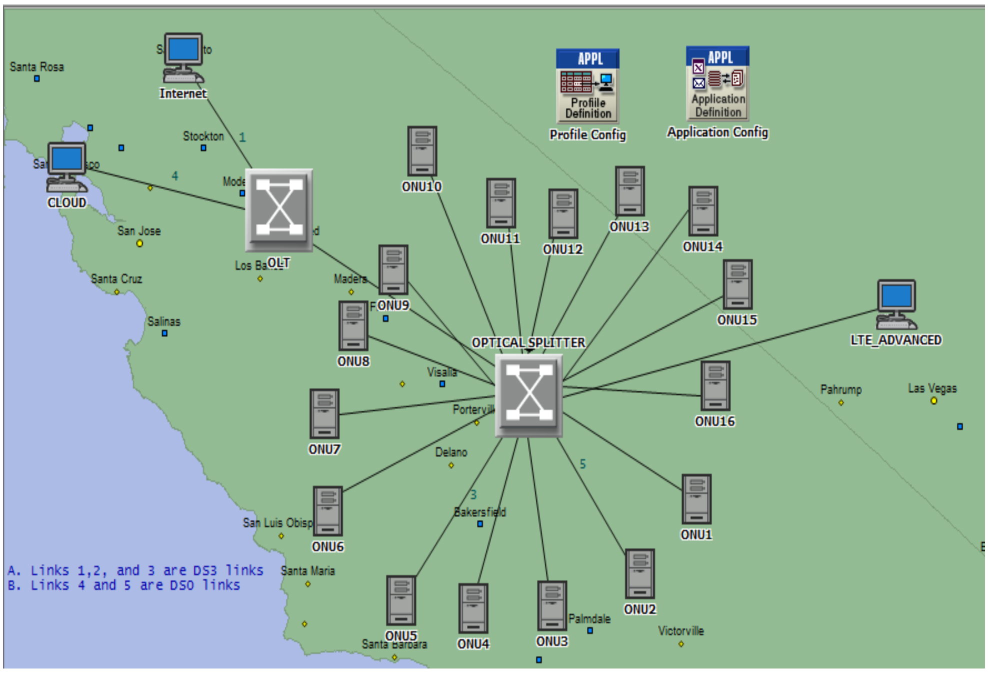

Figure 1. Designed Optical-Wireless Access Network

2.2 Configuration of the Optical-Wireless Access Network

Setting up a simulation system-running application models is a stepwise procedure that involves configuring needed applications and statistics to be gathered through the simulation, placing of nodes in the system, and defining user profiles and applications. An application model explains the features of the application generated traffic, whereas a user profile indicates the way the program is utilized, according to OPNET.

The first step in link object configuration was to join node devices. The layer 2 (data link layer) technology defines links by validating the suitability of the nodes connected through the link. A link model that is suitable was chosen for constructing the desired topology. However, in some cases, after adding a link object to a network architecture, it may be necessary to configure it to meet specific requirements.

The designed optical-wireless access network was configured to provide communication services for 16 Ethernet customers at a transmission rate of 2.5 gigabits per second using EPON technology and a number of mobile subscribers using LTE-A technology. In the design, TDMA technique was utilized for sharing the media. The medium is primarily a fiber optic connection between the CO and a neighborhood known generally as PON.

In preparation for the simulation; the 'Application Config', 'Profile Config', 'Name Attribute', 'Number of Rows', 'Start Time' and 'Operation Mode were adequately dragged onto the workspace and set.

2.3 Mathematical Formulation for Energy Consumption of the Network.

Given that E_{ACCESS}, E_{OLT}, E_{ONU} and $E_{LTE\ A.}$ represent the energy utilised by the access network, the OLT, the *ith* ONU and the LTE-A Ethernet Port respectively, the overall energy utilised by the network may therefore be formulated as indicated in Equation 1;

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

Where *n* represents the total number of ONUs in the access network.

Suppose the OLT (or any of its constituents) is switched off at any moment while in active mode for energy saving purpose. Representing $E_{ONUi}(k)$ as the energy utilised in cycle *k* by the *ith* ONU. The total energy utilised in cycle *k* by one ONU is denoted by Equation 2:

$$E_{ONUi}(k) = E_{OH}(k) + E_{R_{OLT}}(k) + E_{R_W}(k) + E_{R_E}(k) + E_{T_E}(k) + E_{T_W}(k) + E_{BF}(k) \quad (2)$$

Where $E_{OH}(k)$ is the energy consumed by ONU during the total overhead time *(OH)*, $E_{R_{OLT}}(k)$ is the energy consumed by Ethernet receptor for traffic coming from the OLT, $E_{R_W}(k)$ is the energy consumed by wireless receptors for traffic coming from end users, $E_{R_E}(k)$ is the energy consumed by Ethernet receptors for traffic coming from end users, $E_{T_E}(k)$ is the energy consumed by Ethernet transmitter, $E_{T_W}(k)$ is the energy consumed by wireless transmitter and $E_{BF}(k)$ is the energy consumed by ONU components in on state all time.

However, $E_{OH}(k)$ is obtained as in equation 3;

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

Where the total overhead time is represented by T_{OH} and P_{total} is the total power of one ONU, including all its transceivers and all other active components.

If $E_{tr}(k)$ is the energy consumed by one transmitter/receiver, P_{tr} and $AP(k)$ denote the power consumed by the transceiver and the active period during one cycle k, respectively, $E_{tr}(k)$ can then be obtained as in equation 4. The evaluation of the overall energy utilization of all nodes in the designed network was implemented with an OPNET program code.

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

2.4 Simulation Process of the Designed Network

An effective DBA algorithm is aimed towards achieving a high and effective bandwidth utilization while salso satisfying requirements like effective energy utilization, reduced packet delay and improved QoS. In this research work, the energy utilized by the network as a result of traffic received and sent in bytes/sec are the collected simulation statistics. The simulation process involves the selection of simulation statistics for the network objects. The effect of the application of DBA algorithm on the energy unitlization of the designed network are then compared to the non-application of DBA algorithm.

The inbuilt traffic generator provided by OPNET modeler software was used to model realistic traffic condition. For the traffic generation, 2.5 gigabit per second transmission rate was used with 16 Ethernet subscibers and a number of remote users. The traffic generator was used to generate 100,000 frames per user for each value of oferred load. The simulation was stopped after the first user sent the last bit of its last packet. The total simulation time was therefore determined by the ONU with the highest traffic load.

2.5 Application and Configuration of Dynamic Bandwidth Allocation

In order to evaluate the energy saving capacity of the designed optical-wireless access network, DBA algorithm was applied to the access network. To evaluate the performance of the dynamic bandwidth allocation algorithm, traffic received in bytes/sec and traffic received in packets/sec by the ONUs were used as the parameter metrics for evaluating the effect of the algorithm on the energy consumption in the network. Max-min fair for ordinary EPON networks was implemented. The allocation rules for the algorithm are:

i. The allocation of bandwidths must not be more than the buffer utilized by the ONU.
ii. Unsaturated ONUs get the same amount of bandwidth left.

With the max-min fair method, each allocation to ONU *n* was determined using the stages indicated in the flowchart in Figure 2 throughout frame *t* and grant quantity W_t^n:

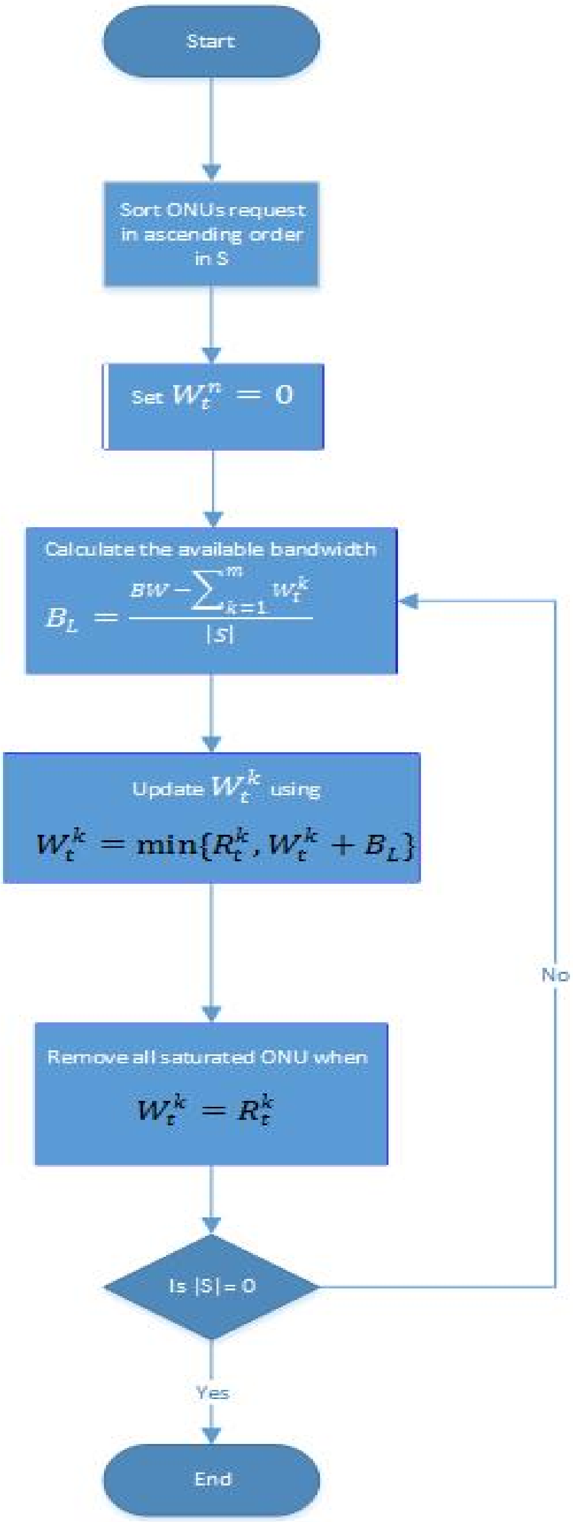

Figure 2. Flowchart for Dynamic Bandwidth Allocation Algorithm

3.0 RESULTS AND DISCUSSION

3.1 Traffic Received

Figure 3 shows the movement of traffic received by customer premises equipment (ONUs, modems, Ethernet ports etc.) for both wired and wireless users in the designed optical-wireless access network. It shows the behaviour of received traffic in the network in bytes/second and displays the movement of data in the network, indicating how bandwidth is utilized in the network. The figure shows that a minimum threshold at 0 is maintained but a fluctuation in the traffic received between the positive and negative y-axis is noticed at regular interval due to instantaneous traffic demands of connected nodes and users. When data is received, the access network provides a high capacity infrastructure for serving the data traffic demand by users in the network.

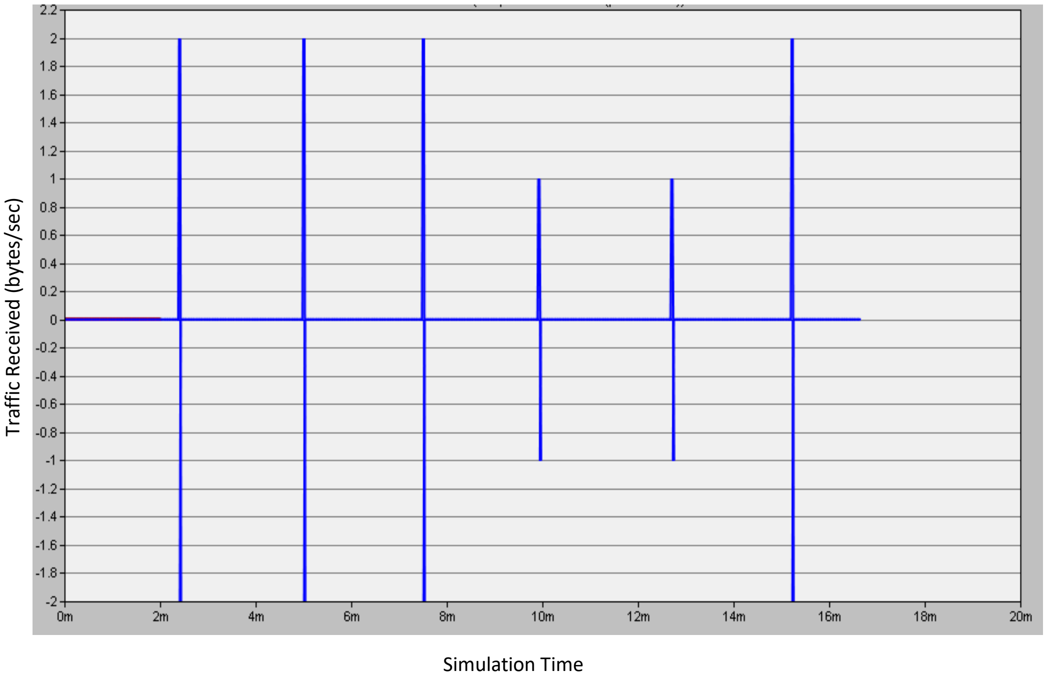

Figure 3. Traffic Received in bytes/second

3.2 Traffic Sent

The movement of the traffic sent from customer equipment which consists of both fixed and wireless subscribers in the designed optical-wireless access network is as presented in Figure 4. Therein, the figure shows the effect of traffic sent (bytes/second) towards the OLT increase with simulation time which has effect on the utilization of energy in the network. At 1.8 minutes, traffic sent is zero which indicates a reduction of energy utilized in the network. It is noticed from the figure that after 1.8 minutes, traffic sent increases by 1 byte and constant till after 0.5 minutes, this is as a result of delay in traffic movement.

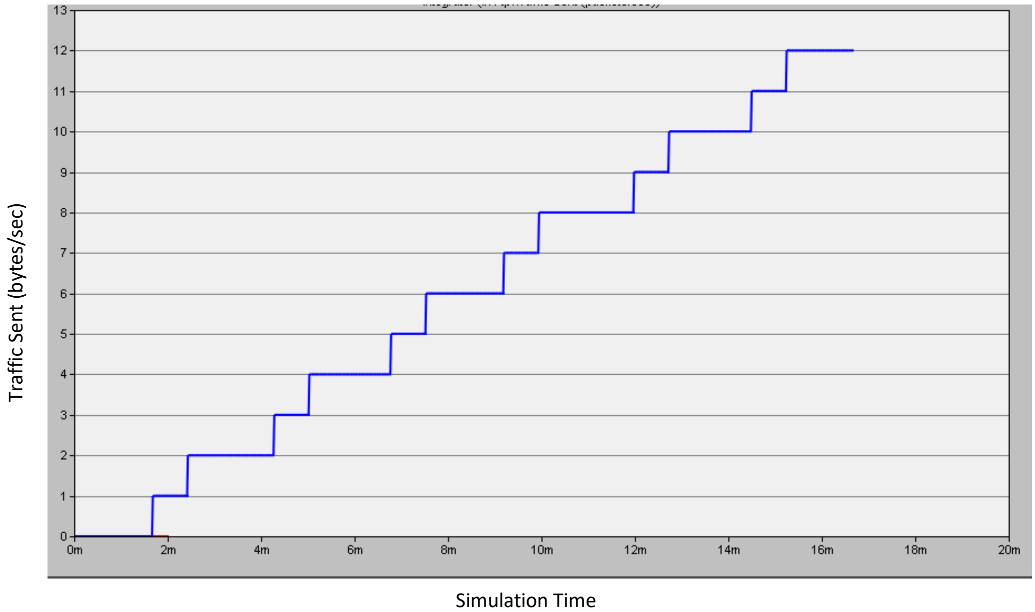

Figure 4. Traffic Sent in bytes/second

3.3 Application of Dynamic Bandwidth Allocation Algorithm

The effect of the application of DBA algorithm on energy consumption of the optical-wireless access network in the network is as presented in Figure 5. The figure indicates a consumption of 700 watt-second of energy when DBA algorithm was not configured with the designed network. However, the incorporation of DBA algorithm, caused the energy consumed to dropped to 430 watt-second. This is an increase of 38.6% in energy conserved in the system.

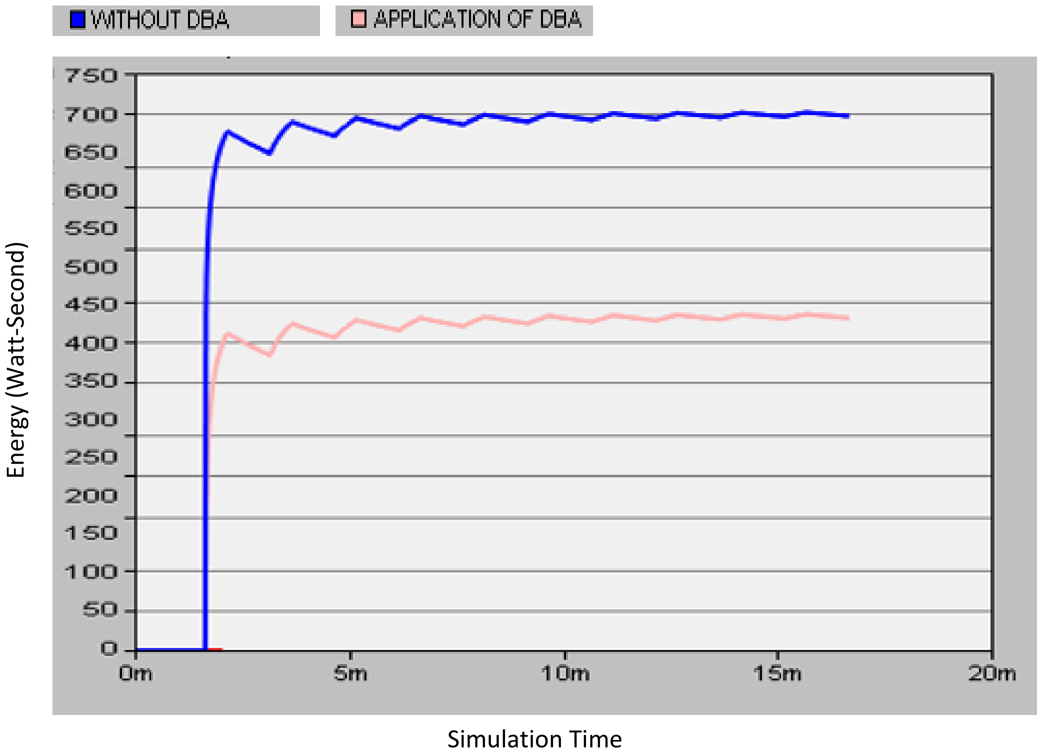

Figure 5. Energy Utilization based on Application of DBA

4.0 CONCLUSION

Energy consumption moderation in telecommunication networks is becoming a more urgent issue that needs to be sorted. This paper researched on a PON which employs optical fiber as transport medium and uses passive devices in order to distribute signals through the network, to and from the users and a wireless network which uses LTE-A as the radio access technology to distribute signals to mobile internet subscribers. The two access technologies were combined to provide the advantages of robustness, unlimited bandwidth in addition to mobility and high availability to access subscribers.
The effect of the application of DBA algorithm on a combined optical-wireless access network was proposed and investigated. OPNET Modeler Software was used to design the optical-wireless access network. Algorithm for the implementation of the DBA was proposed and simulated using OPNET modeler. The result of the simulation showed that the application of DBA algorithm led to 38.6% energy-saving while still limiting the impairments on the quality of service even in the presence of heavy traffic.

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