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Research Article

Arduino Based Energy Consumption Measurement and Monitoring in Passive Optical Network

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Abstract
This research proposes an enhanced method for monitoring of energy consumption in passive optical network (PON). The established technology will help the research community design models for the synthesis of energy-efficient protocols and algorithms for the PON network. There are several limitations to the availability of scalable and economical methods for monitoring and measuring energy consumption in a PON network for research purposes. Thus, the purpose of this work is to offer a practical/new technique for measuring and monitoring energy usage in the optical access network domain. A real-time power consumption and monitoring device with a high sampling rate of up to 10,000 voltage/current samples per second was developed. The product is used to assess the energy consumption of optical network units (ONU) for PON. The developed system based on Arduino Uno helped to create a more realistic model that can capture the relationship between varied traffic patterns and an ONU's power usage. The device's results are evaluated in a lab test with a Tektronix energy consumption meter.

Keywords: *Optical Network Unit, Power Consumption, Arduino.*

I. INTRODUCTION
The exponential growth of internet traffic has raised concerns about future power usage in the ICT sector. A study of internet energy consumption finds that the global power consumption of network devices is predicted to be more than 12% per year [1]. With the increasing demand for multimedia services such as voice over internet protocol (VOIP), video over internet protocol, and peer-to-peer communication, which entail the transfer of big files that require a lot of bandwidth, an effective internet access network is critical. An optical access network is the most energy-efficient technology for providing a high-capacity broadband access network with full bandwidth utilisation at a low bit error rate and a transmission medium with THz bandwidth. Reducing energy usage not only saves money but also promotes environmentally friendly technologies, with the goal of making green technology a fundamental driver of national economic growth. According to studies, future optical networks will require vast amounts of energy [2]. As a result, alternative network architectures will be required to deal with this exponential expansion over the next few decades. Many countries have implemented passive optical network (PON) using Fiber-to-the-Home (FTTH) technology [3].

10 Gigabit Ethernet passive optical network (10G-EPON) and (10G-PON) were standardised in 2009 and 2010 respectively [4]. This enabled service providers to boost their access network throughput using the existing optic fibre plant while also providing high bandwidth for relaying information and other network services. In this research, studies of previous research have been referred with a goal to build an optimum energy efficient module for power consumption monitoring and measurement at ONU in a PON. Optical networks are commonly utilised in backbone communication networks due to their high reliability and capacity. Increased demand for faster data rates in the access network prompted network engineers to begin developing an optical access network [5]. A PON with high efficiency, low cost, and low power consumption characteristics was developed. PON consists of an optical line terminal (OLT) located at the local exchange or central office, an optical network unit (ONU) located near the end user's premises, and a splitter that connects ONUs to the OLT. The OLT manages signal power transmission and reception in the distribution network and connects it to the backbone network. The ONU converts optical signals into electrical signals, and vice versa. Figure 1 depicts the network architecture of PON.

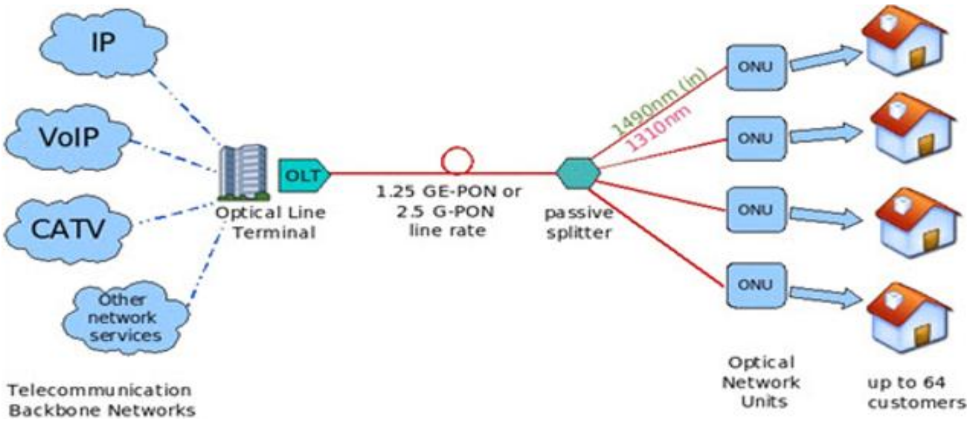

Figure 1. PON Architecture

PON is a point-to-multipoint optical distribution network (ODN) in the downstream direction from OLT to ONUs, so OLT has full bandwidth, whereas the upstream is a multipoint-to-point network in which numerous ONUs transmit data to OLT at the same time. The most commonly used standard is Gigabit Passive Optical Network (GPON), which has a maximum downstream bitrate of 2.5Gbit/s and an upstream bitrate of 1.25Gbit/s [6]. The maximum number of ONUs that may be linked to the OLT is 32 or 64, and all of the ONUs are connected to the optical splitter before connecting to the OLT via a single fibre. PON used wavelength division multiplexing (WDM), a channel separation mechanism that avoids data collisions and properly shares trunk fibre channel capacity. Each ONU operates on a different wavelength via an arrayed wave guide grating (AWG), which is also a passive device with a fixed routing matrix. The system can support several wavelength channels, each capable of supporting data rates of up to 10Gbps [7]. WDM requires a receiver array or adjustable receiver to receive many channels; nevertheless, the cost of adopting WDM is considerable due to the multiple wavelengths, which necessitate more laser sources [8].

In time division multiplexing (TDM) PON, all ONUs can operate on the same wavelength, with time slots allocated for both upstream and downstream direction between OLT and multiple ONUs, where each ONU transmits in its own transmission window, preventing data collision and ensuring proper utilisation of the PON's bandwidth [7]. TDM PON has two standards: E-PON and G-PON, which are based on IEEE 802.3ah at 1.25Gbps symmetrical and ITU-T G.984 at 2.5Gbps downstream and 1.25Gbps upstream, respectively. However, the two technologies, WDM and TDM, can function together to offer a time slot for a wavelength channel [9].

Energy efficiency in telecommunications has been rather essential in recent years due to the continual increase in energy costs and ecological problems [10]. Because the demand for internet services is increasing, the requirement for energy economy has become a significant concern when developing access networks. As a result, researchers have set out to propose and implement systems and algorithms that efficiently minimise the power consumption of network equipment. PON is an access network that provides high data rates while consuming less energy than its competitors [11]. Energy consumption measurement and evaluation has been carried out employing different approaches with a view to investigate the energy consumption behaviour of PON. One of such ways is an investigation carried-out on geographical network test bed comprising of digital subscriber line (DSL) and GPON using commercial devices at a distance of 50KM and 1 hour observation time. The results obtained show that GPON consumes a power per-user 84% lower than Asymmetric DSL2+ [12]. Figure 2 shows a comparison of power consumption between the two systems.

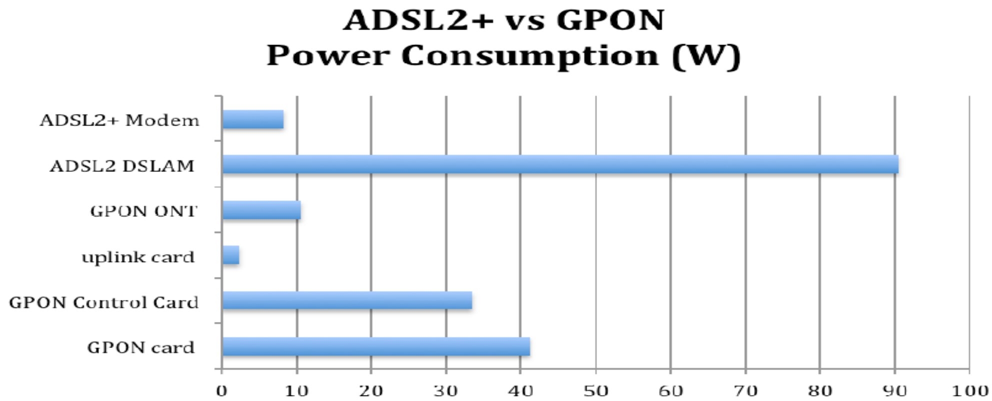

Figure 2. Power Consumption Comparison [12]

Another study evaluated energy usage on next-generation PON (NG-PON) technology, offering total energy consumption per customer while taking into account the client's premises and network operator [13]. According to their findings, TDM and orthogonal frequency division multiplexing (OFDM) PON systems consume more energy at the ONU. Whereas WDM PON energy usage is substantially higher at the OLT than at the ONU. In terms of network operator power usage, the optimal number of central offices in long reach GPON has been published [14]. Several suggestions demonstrate the potential for energy consumption reduction in customer premises by using a network enhanced residential gateway approach [15]. The power consumption of the ONU in this method can be significantly reduced 20-31% by avoiding unused Ethernet and plain old telephone service interfaces and using single-port ONUs. Using a bit interleaving protocol at the ONU in TDM PONs is presented in [16], and the concept shows a considerable reduction in energy consumption when compared to regular 10Gb/s PON. To develop an efficient algorithm to address the issue of power saving in PON, researchers require an optimal monitoring and measuring device with low power consumption that can measure quantities such as current, voltage, and power consumed by an ONU, with high resolution and a high frequency sampling rate at a low cost. This study will implement a proposed experimental method for understanding the power consumption behaviour of ONUs using a real-time energy consumption monitoring device capable of identifying high resolution and frequency sampling rates, while consuming low power and cost. The information gathered will be valuable in building a suitable algorithm for power savings in an optical access network.

II. SYSTEM DESCRIPTION

The device is intended to monitor the energy consumption of the ONU. It consists of hardware and software components based on the Arduino platform. A Python backend for configuring system running parameters including resolution sampling rate and energy consumption statistics. Arduino is an open-source quick prototyping platform built on a programmable microcontroller that can be programmed to control a variety of electronic devices. An additional shield is supplied to extend the functionality of Arduino that are directly relevant to our design, as well as an extension for networking functions utilising the Ethernet shield. Arduino uses a 10-bit analog-to-digital converter to support six input channels. The Arduino has been expanded in the design with a custom module, a voltage sensor implemented using the Hall-Effect, and a module for turning on/off the monitored device implemented using a mechanical relay. Finally, the hardware is programmed using a cross-platform integrated development environment written in Python, and the software is configured to transmit quantities such as the ONU's actual voltage, current, and average power consumption during the last observation period via the USB interface.

III. METHODOLOGY

The proposed system consists of two primary components. The hardware comprises of five stages: power supply, voltage sensor, current sensor, relay, and ONU, as seen in figure 3 below.

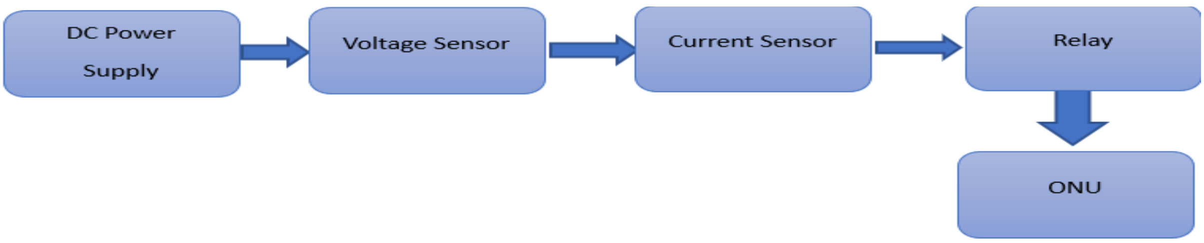

Figure 3. Block Diagram of PON Energy Consumption Monitoring System

3.2 Hardware Implementation

As demonstrated in figure 3, the current sensor ACS712 is a DC or AC current sensing device that consists of a hall-effect circuit used to measure current between -5A and 5A. The current that flows through the circuit generates a magnetic field, which is sensed and converted to proportional voltage by the hall integrated circuit (IC). If the current sensor detects no changes in the output line, its output is 2.5V with a reference current of 185mA; thus, if the output changes to 2.8V, the sensitivity is 3V/A according to the equation below.

$$Sensitivity = \frac{V_{ref} - 2.5}{I_{ref}}$$

The voltage sensor is constructed using a simple voltage divider with resistive loads R_1 and R_2. The relay is a solid-state relay that is used to turn on and off the monitored device. It can regulate loads of up to 3A 60VDC and has a control voltage range of 3V to 32VDC. Figure 4 depicts the device's schematic setup.

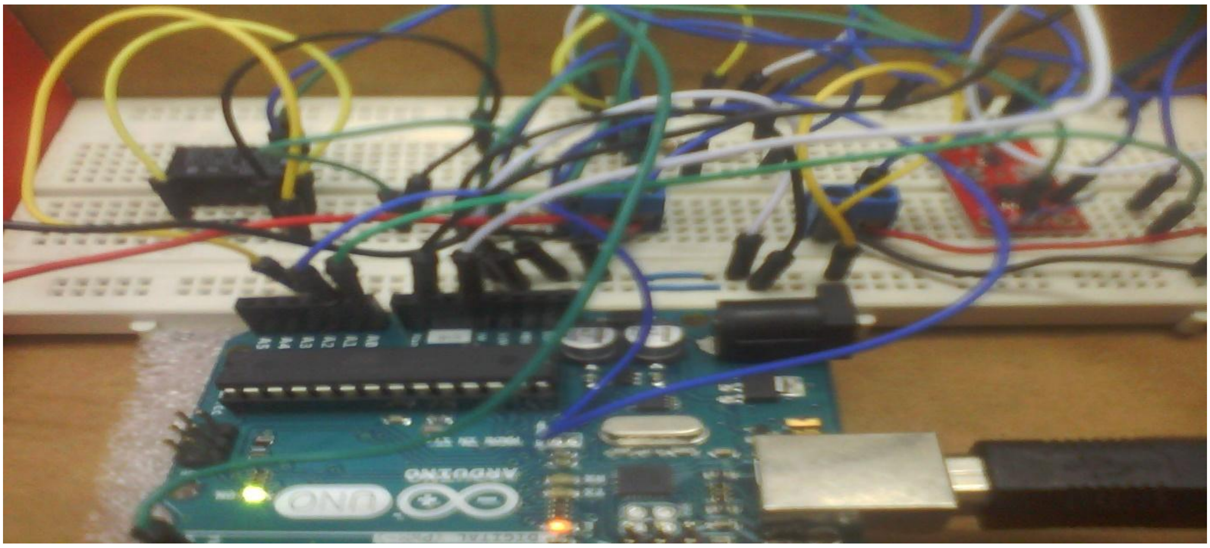

Figure 4. Complete System Setup Diagram

3.3 Software Implementation

The software was developed using the Arduino Integrated Development Environment, and the Python programming language was used to configure the device, which uses the Arduino UNO board as an interface. The Ethernet shield was used in conjunction with the Arduino board to produce high-resolution energy consumption results.

IV. RESULTS AND DISCUSSIONS

Table 4.1 shows the device specifications, whereas table 4.2 shows the power consumption of each network device.

Table 4.1 Devices Parameters

ACCESS NETWORK	TERMINAL UNIT	REMOTE NODE	CPE
PON (GPON)	Transmode DCP652	N/A	DASAN ONT H640G
PTP	CISCO 4503	N/A	TC Comm. TC3300
FTTN	Hitachi 1220	NEC AM3160	NEC VF200F6

Table 4.2 Devices Power Consumption

	PTU (KW)	PRN (W)	PCPE (W)	NTU	NRN	Bit Rate	Capacity per user
GPON	1.34	-	5.44	1024	32	2.5Gb/s	16Mb/s
PTP	0.47	N/A	4	110	N/A	1Gb/s	55Mb/s
FTTN	0.47	47	10	1792	16	50Mb/s	2Mb/s

Table 4.2 displays the access network characteristics utilised for Point-to-point (PTP) and Fibre-to-the-node (FTTN) values derived from manufacturer's data sheets. Figure 5 depicts the overall power usage per subscriber in the three-access network.

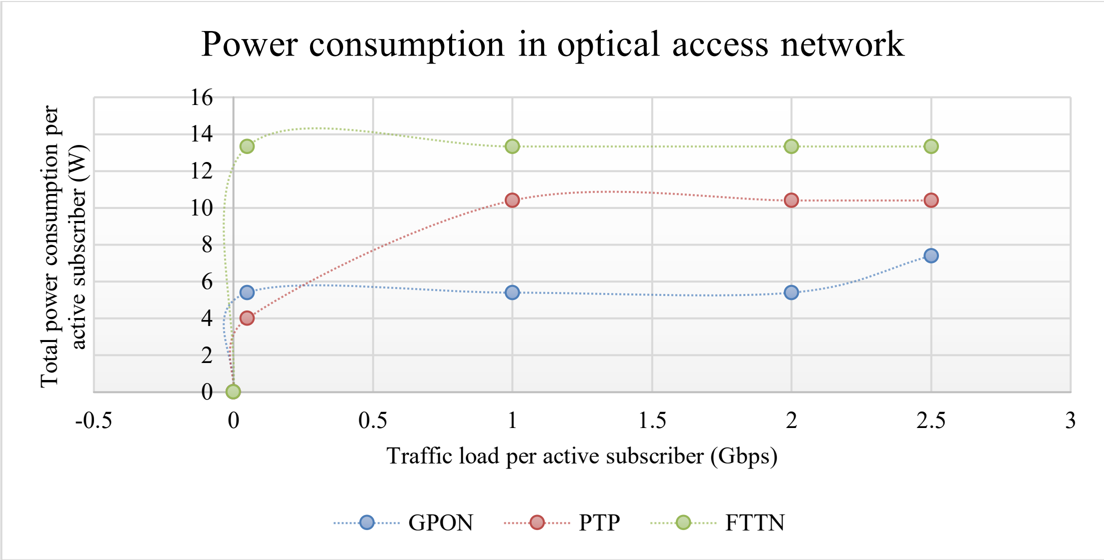

Figure 5. Energy consumption for PON, PTP, and FTTN Access Network

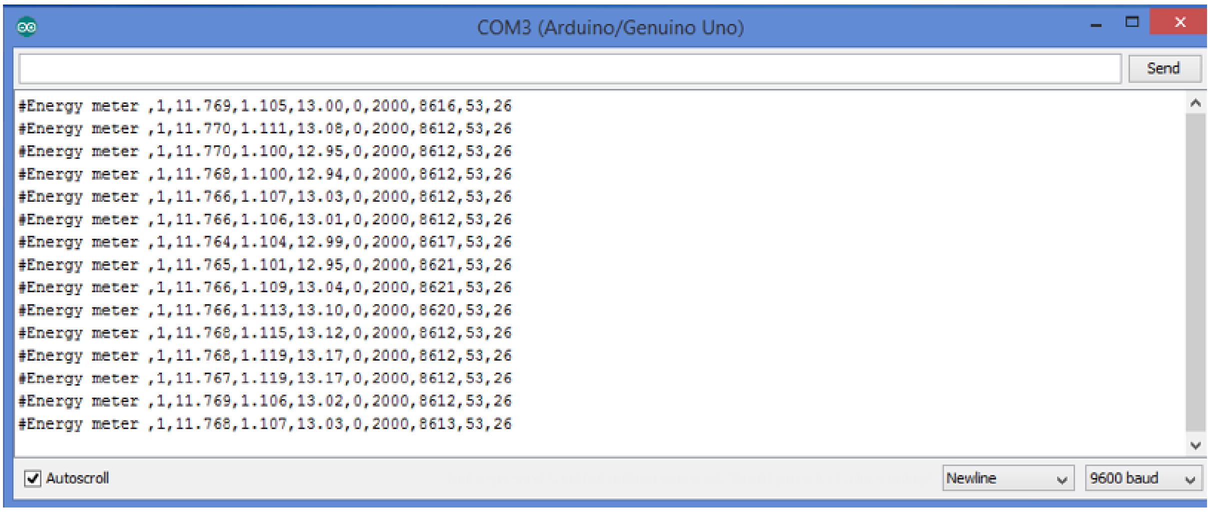

Figure 6. Screenshot of Monitored Power Consumption from the Arduino output

4.2 Results Analysis

In a PTP network, each subscriber and OLT are connected by a dedicated fibre. At the central office, an ethernet switch with 116 optical gigabit Ethernet ports connects 110 residences, while the remaining 6 serve as backhaul capacity and consume 474W. Each residence has an optical media converter that consumes 4W. For the FTTN network, a dedicated fibre is used from the OLT to the DSL access multiplexer DSLAM street cabinet, from which a very high-speed twisted pair cable is fed to the consumers. The VDSL card supported 16 users and consumed 47W, with an extra 5W consumed by the ONU to connect to an OLT. The OLT consumed 474W, while the modem at the customer's premises consumed 10W. For GPON, the OLT consumes 1.34KW and can offer access to 32 or 64 ONUs; in this investigation, we consider 32 ONUs with 1024 clients. The ONUs is connected to the OLT via a passive splitter, and each ONU consumes 5.4W. The power consumption is monitored through Arduino Uno IDE monitoring port as shown in figure 6. The GPON network with the highest access rate utilised less energy than the other two networks because the majority of network devices in PON are passive and do not require electricity.

V. CONCLUSION

The power consumption measurement was performed using an enhanced monitoring device to examine the consumption behaviour of PON technologies. The proposed system monitored and measured energy usage in an optical access network; the data acquired can be used by researchers to implement a sleep mode algorithm for the ONU.

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