

Energy Efficient Shared WDM-PON

¹S.H. Shah Newaz *, ²Khalil Laghari**, ³Gyu Myoung Lee **, ⁴Noel Crespi**, ⁵JunKyun Choi *

*Department of Electrical Engineering, KAIST, Daejeon, South Korea.

**Wireless Networks and Multimedia Services Department, Institut Telecom, Telecom SudParis, Evry, France.

¹newaz@kaist.ac.kr, ²khalil.laghari@it-sudparis.eu, ³gm.lee@it-sudparis.eu, ⁴noel.crespi@it-sudparis.eu, ⁵jkchoi59@kaist.edu

Abstract— Recent studies have unveiled that a large amount of electricity is consumed by telecom-equipments in broadband-enable countries. Therefore research effort is needed both in the industries and academia for minimizing energy consumption in telecom-equipments. This paper aims to minimize energy consumption in Shared WDM Passive Optical Network architecture. Initially, H. Song et.al and N.U. Kim et.al introduced an architecture based on WDM Passive Optical Network and broadly explained how such architectures can contribute to a greater deal in providing high data rate services and low deployment cost with broadcasting capability. In this paper, we provide policy and decision making procedure for making their proposed architecture energy efficient. Our analytical result states the significance of our solution.

Keywords— S-WDM-PON, energy saving, ONU, OLT.

I. INTRODUCTION

Due to exponential growth in internet use, the internet traffic and underlying networks are expanding very quickly. The larger the network becomes the more electrical power it consumes. And it is estimated that around 8% of total electricity is consumed for the operation of network [1]. Furthermore, the access network equipments are more responsible for energy consumption than the core network equipments although utilization of them is 15% [1]. Therefore, it is important to put research effort for minimizing energy consumption in access network equipments. In the access network part Passive optical Network (PON) has been widely deployed in countries like South Korea, China and Japan. And in the near future it would be also popular in European and American countries.

Among all the access network technologies PON is the most energy efficient solution [9]. Besides it provides high data rate which has become increasingly important factor for the bandwidth hungry content. It can be mainly classified into two categories: TDM and WDM. TDM-PON encompasses Broadband PON (BPON), Ethernet PON (EPON). TDM-PON deployment cost is comparatively much cheaper than the WDM-PON. However as the demand for high data rate services are furiously growing, WDM-PON is earning

popularity. Mainly WDM-PON has been deployed in South Korea.

In a PON network, there are two important components used: an Optical Line Terminal (OLT) and a group of Optical Network Units (ONUs). In a TDM-PON network, one passive component is used to split signal sent from the OLT to all the ONUs (downlink is broadcast). Whereas, dedicated wavelength is provided for each of the ONUs in WDM-PON architecture. Arrayed Waveguide Grating (AWG) is used in a WDM-PON network for guiding optical signals [5, 6, 7, 8].

For supporting unicast, multicast and broadcast effectively, Shared Wavelength Division Multiplexed-PON (S-WDM-PON) is proposed by some researchers [2, 4]. In S-WDM-PON architecture, an ONU requires two receivers; one of them is used for receiving dedicated optical signal, while the other one is used for receiving shared optical signal. The shared optical signal is used to transmit bursty traffic [2, 4].

This paper aims to reduce energy consumption in Shared Wavelength Division Multiplexed-PON (S-WDM-PON) which deploys a shared downstream wavelength and broadcasting arrayed waveguide grating to a Wavelength-division-multiplexed PON (WDM-PON). Although S-WDM-PON can provide high data rate service, the architecture is not energy efficient for the off-peak scenario. This is because keeping all the receivers on (i.e. active) in the ONU and the corresponding transmitters in the OLT during off-peak hours of a day (e.g. night), when traffic arrival rate is low, is an inexpedient tactic.

To state the problem statement more clearly, we would like to give an example. Let us assume there are 32 ONUs in an S-WDM-PON. Each of the ONUs has receiver for downlink dedicated data channel $CH_{C,i}$ and broadcast channel $CH_{C,B}$ (see Figure 1), then there will be total 64 receivers in total for the 32 ONUs in the user premises. It will be an energy efficient solution if we can use 32 receivers when traffic arrival rate is low (off-peak hours) regardless the service (i.e. unicast, broadcast, or multicast) and keep the rest 32 receivers turned off, so that we can save energy. The major concern would be service degradation for deciding whether both receivers will be on or not.

The main contribution of this work is to develop a control protocol for S-WDM-PON for making it energy efficient

when traffic arrival rate is low (i.e. off-peak hours). In our work, we provide decision procedure for the OLT, which is the centralized intelligence in a PON. The OLT will decide whether an ONU needs to keep both of its receivers active or just only one of them. The OLT notifies this decision by modified Multipoint Control Protocol in our solution.

Finally, Section 5 concludes this work and states future research direction.

II. SYSTEM MODEL

This section first explains an S-WDM-PON architecture. Besides, supporting unicast service in WDM-PON, broadcast and multicast service is important in PON. Therefore, one Shared Channel (SC) is deployed in S-WDM-PON. For that SC reception, each of the ONUs needs to have one receiver along with the receiver for the Dedicated Channel (DC) reception. We can observe from the Figure 1 that an ONU can receive two channels $CH_{C,i}$ (i.e. DC for ONU-i) and $CH_{C,B}$ (i.e. SC for the n number of ONUs in that S-WDM-PON domain). Whenever there is any demand of broadcasting or multicasting service (e.g. IPTV), $CH_{C,B}$ is used. While $CH_{C,i}$ is used as a dedicated channel for ONU-i in this S-WDM-PON domain. For receiving $CH_{C,i}$ and $CH_{C,B}$ in ONU-i $OR_{x,i}$ and $OR_{x,B}$ are used respectively. On the other hand, for the uplink transmission, each of the ONUs has transmitter and corresponding receiver is located inside the OLT, as shown in Figure 1.

III. PROPOSED ENERGY EFFICIENT S-WDM-PON

In this section, we explain how this proposed idea works in an S-WDM-PON for making it energy efficient. We introduce policy here for an S-WDM-PON. This policy mainly guides how this network will function at different situation. For explaining our proposal, we define some parameters here.

- Total downlink arrival rate is λ_D .
- Threshold value for deciding whether both SC and DC, or only the SC will be used $T_{threshold}$ ¹.

Then we state our policy as follows:

- When arrival rate $\lambda_D \leq T_{threshold}$, we suggest to use the SC only for supporting all kind of services (e.g. multicast, broadcast, and unicast²). As a result, each of the ONUs will use $OR_{x,B}$ rather using both receivers. On the other hand, the OLT only uses one transmitter (i.e. $OT_{x,B}$) rather using separate transmitter for each of the ONUs. Thus, by turning off $OR_{x,i}$ each of the ONUs can save significant amount of energy.
- Conversely, when $\lambda_D > T_{threshold}$ is true, in that S-WDM-PON domain, both $CH_{C,B}$ and $CH_{C,i}$ are used simultaneously. Therefore, an ONU needs to keep both $OR_{x,B}$ and $OR_{x,i}$ active. In this case, an S-WDM-PON architecture follows conventional mechanism.

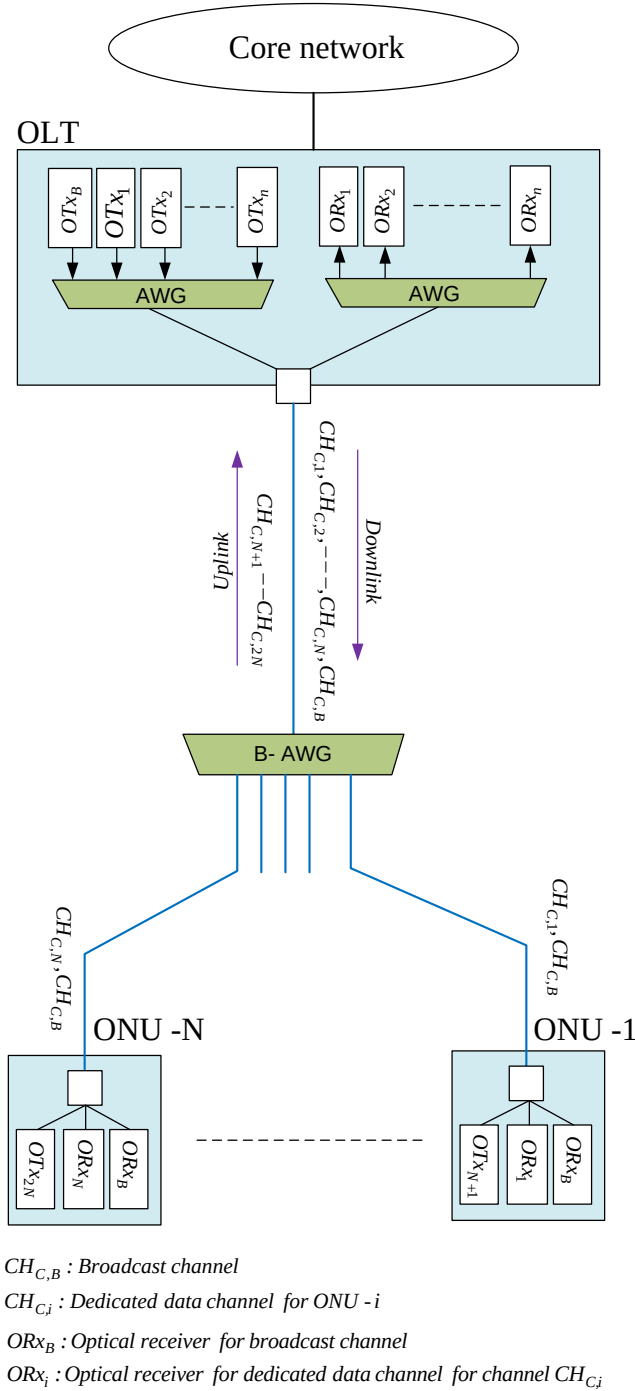


Figure 1. Generic architecture of a S-WDM-PON.

The rest of the paper is organized as follows: Section 2 states the system model, Section 3 states proposed energy efficient S-WDM-PON and Section 4 shows performance evolution.

¹ $T_{threshold}$ can be decided based on the transmission capacity of the Shared Channel (SC) in that S-WDM-PON domain.

² When broadcast channel is used for all kind of services, the S-WDM-PON behaves like a TDM-PON (e.g. EPON, BPON).

The aforementioned policy has been presented in the following Figure 2.

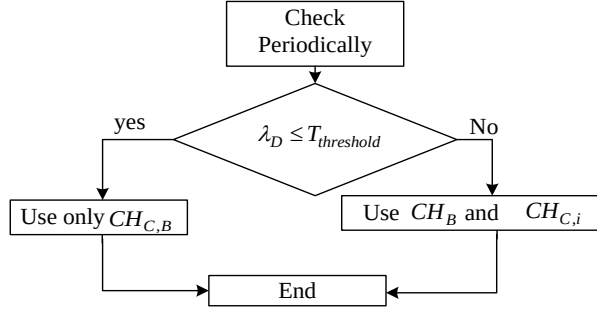


Figure 2. Decision making algorithm for Energy Efficient S-WDM-PON.

A. Protocol Description and Working Principle:

Similar to [8], we consider Multi Point Control Protocol (MPCP), which is mainly developed for OLT and ONU communication in EPON, extension for S-WDM-PON architecture. At a given time, if the $CH_{C,B}$ is supporting all the services and suddenly $\lambda_D > T_{threshold}$ becomes true, the OLT must notify the ONU which requires more downlink bandwidth. For a given time, if ONU-i requires more downlink bandwidth and consequently condition $\lambda_D > T_{threshold}$ becomes true, the OLT invokes ONU-i to turn on receiver for $CH_{C,i}$ through the SC (i.e. $CH_{C,B}$). When ONU-i receives this request, it turns on that receiver. Hence, customer does not experience any service degradation.

Similarly, when λ_D reduces (i.e. off peak hours of the day). The OLT should ask one or more ONUs to turn off the DC receiving receiver for saving energy.

IV. PERFORMANCE EVALUATION:

This section briefly describes the significance of the proposed solution for an S-WDM-PON.

It is arguably true that mainly traffic arrival rate in peak and off-peak hours cannot be the same. Here, we first show the access network traffic behaviour. To understand traffic behaviour in peak and off-peak hours, we captured 16 hours of traffic from a switch, which is analogous to an ONU, deployed in our experiment laboratory (i.e., 12 AM to 4 AM).

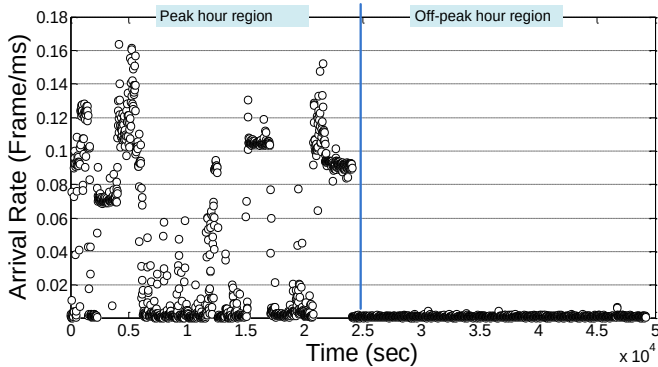


Figure 3. Arrival rate variation in peak and off-peak hours of a day (arrival rate of captured downstream traffic from 12 AM to 4 AM).

We calculate downstream traffic arrival rate at every 20 seconds and found that the arrival rate in peak and off peak hours can have significantly different trend as shown in Figure 3. From this figure, it can be realized that operating a PON architecture in same way throughout the whole day can be an expedient policy. Now we will measure the instant power consumption in an S-WDM-PON architecture having 32 ONUs.

We consider the power consumption value used in [3]. The OTx and ORx both in the OLT and an ONU consume 5 Watt each. Then using our mechanism in the off-peak hours of a day, only $CH_{C,B}$ can be used in S-WDM-PON. Therefore, at a given time for the downlink only one OTx is required in the OLT and each of the ONUs can use one ORx for that $CH_{C,B}$ channel reception turning off other ORx that is used for receiving the DC reception (e.g. ORx_i for receiving channel $CH_{C,i}$ for ONU-i). On the other hand in the peak hours, proposed solution follows conventional mechanism where both $CH_{C,B}$ and $CH_{C,i}$ works.

For the off-peak and peak hours with 32 ONU configurations, we measure instant power consumption for the S-WDM-PON architecture and present the results in following Figure 4. From this Figure, it can be observed that our proposed solution can significantly minimize energy consumption for the off-peak hours of a day. However, in the peak hours of a day both approaches work in the same way. That is in our solution both of the receivers are likely to be turned on in an ONU. Therefore, energy consumption in proposed and conventional mechanism would be same (See Figure 4 (b)).

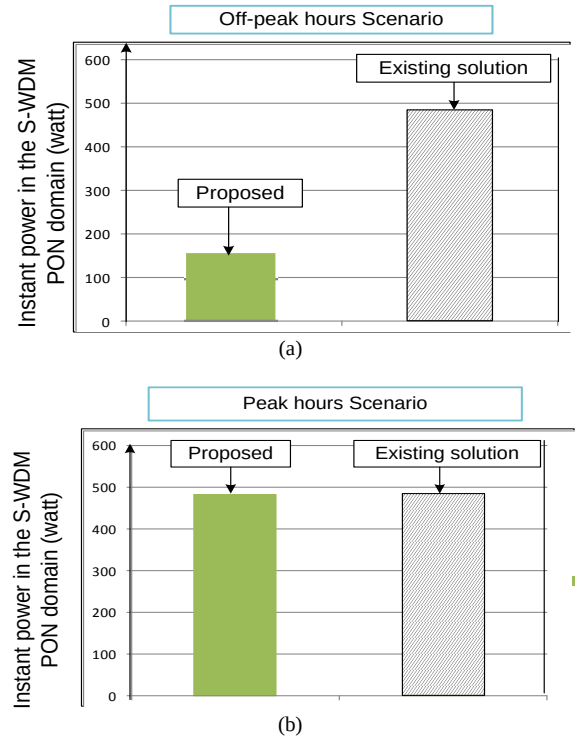


Figure 4. Performance comparison between traditional S-WDM-PON and proposed Energy Efficient S-WDM-PON; (a) Off-peak hours Scenario, (b) Peak hours Scenario.

V. CONCLUSIONS

In this paper, we present an approach for minimizing energy consumption in S-WDM-PON architecture. We have defined new rules for operating an S-WDM-PON; so that, it can save energy while meeting the bandwidth requirement of customer premises. To the best of the authors' knowledge, this solution appears as the first approach for reducing energy consumption in S-WDM-PON architecture. In the future work, we would like to provide performance results in more details.

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