Computers and Electrical Engineering 000 (2018) 1–11

Contents lists available at ScienceDirect

Computers and Electrical Engineering

journal homepage: www.elsevier.com/locate/compeleceng

Energy efficient operation for a reconfigurable and self-interleaved optical access network☆

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ARTICLE INFO

Article history:
Received 15 April 2017
Revised 14 January 2018
Accepted 15 January 2018
Available online xxx

Keywords:
Optical access network
Passive optical networks
Free spectral range
Reconfigurable
Energy efficient operation

ABSTRACT

This paper presents a resource management of an arrayed waveguide grating for the design of access network in terms of reconfigurable bandwidth allocation and energy efficient operation. Power consumption characteristics of different channel routing mechanisms are investigated for the downstream transmission. Take-up rates of the subscribers are analyzed to estimate the required optical devices at different phases of the system. Traffic mode operation is also considered to realize the power reduction and energy efficiency for different channel routing mechanisms by the optimal use of components with respect to the active users. Proposed mechanisms are discussed in details and simulation results are presented for the energy savings on network scenario. The model which exploits free spectral range wrapping, has the most promising cost efficient device utilization, power consumption of 285 W and a minimum of 45% energy saving characteristics as compared to the conventional model.

1. Introduction and objectives

Bandwidth-intensive multimedia services offered to residential homes have shown an enormous growth in the last decades. On the top of the common voice telephony, broadcast television, radio and internet communication; technology smart users are also demanding for video-based multimedia, high speed file transfer, ultra-high definition multimedia online gaming, etc. [1]. Compared to the traditional broadband connections, fiber to the home (FTTH) technologies are seen as a future proof infrastructure to support increasingly higher-speed services with unique Quality of Experience (QoE) and Quality of Service (QoS) [2]. It is widely deployed in countries like Japan, Korea, United States of America and Europe. For instance, the number of FTTH and fiber to the building (FTTB) subscribers in Europe increased by 23% over the first nine months of 2016, reaching nearly 44.3 million subscribers [2]. In order to achieve cost efficient FTTH scenarios, designers have proposed operators different versions of the passive optical network (PON) systems. Wavelength Division Multiplexing (WDM) PONs could increase the capacity for residential subscribers. On the other hand, WDM PONs tend to waste bandwidth due to the lack of flexibility. Therefore, hybrid WDM/TDM PON architectures are reported in research studies [3,4]. While WDM increases the network capacity, TDM enhances the capacity sharing and flexibility. Multiple wavelengths are generated and transmitted from the central office (CO) by applying appropriate modulation formats. TDM signaling method-

☆ Reviews processed and recommended for publication to the Editor-in-Chief by Associate Editor Dr. Z. Arnavut.

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https://doi.org/10.1016/j.compeleceng.2018.01.018
0045-7906/

ology could be used at optical networking units (ONUs) by using passive optical devices, such as Array Waveguide Gratings (AWGs) at the remote nodes (RNs) [4]. The inherit advantages of AWGs include compactness, reliability, precisely-controlled channel spacing, accurate wavelength stabilization and low loss as compared to other routing devices. The passive device also have cyclic wavelength routing and demultiplexer periodicity characteristics (self-wrapping free spectral range – FSR) [4]. In addition, FSR-multiplexing is used to increase the number of subscribers (ONUs) by exploiting the compound Latin routing and the cyclic property of AWG which actually doubles the number of ONU at minimum with the same infrastructure.

It is also a crucial research objective to design energy-efficient and cost-effective systems for next generation network architectures. Hence, it is worth investigating power consumption of access network architectures while considering the possible rise of consumers and traffic growth. It should also be noted that access networks have the highest energy consumption as compared to the other parts of the networks. The energy consumption of the existing access technologies has been considered in [5]. The main sections of energy consumption for PON systems are the ONUs and the Optical Line Terminal (OLT). While considering the bandwidth use of the end users, energy consumption could be optimized by the active controlling of the optical components at the OLT and ONUs for the unnecessary downstream/upstream data flow.

For this purpose, different energy efficiency approaches are used in several research studies. Physical component utilizations (hardware) and algorithm-based approaches can be stated as the two main categorization of these techniques [6,7]. New energy efficient optical devices with precise utilization are applied for physical approaches. On the other hand, software proposals consider the algorithms such as energy awareness [8]. It could also be stated that energy related costs have a great impact on the overall network operating costs, which is a sensitive case for operators [9]. Hence, it is a crucial objective to consider take-up rates in order to have a cost-effective network strategy. This would also prevent making the full investment at the initial stage of the deployment [5]. It is indicated in [10] that there is a 30% average take-up rate characteristic in Northern America over a decade of construction period. The cost effectiveness and power efficiency of WDM/TDM PON architectures are considered in the previous studies [11,12].

In this research work, we evaluate the energy efficiency of the reconfigurable WDM/TDM PON architectures in utilizing the characteristics of take-up rates and traffic adaptive modes. In order to reveal the reconfigurable characteristics of the proposed network, semiconductor optical amplifier (SOA) switches are used at the CO with the aim to establish the route to the central AWG by means of ON/OFF switches. This enhances the selection of the central AWG input ports. In accordance, the optical data can be transmitted to specific output-port AWG by selecting the specific input port via the well-known characteristic of AWG, Latin routing. Different channel routing mechanisms (CRMs) are proposed within the study and their power consumption characteristics are investigated. For the first part of the analysis, the take-up rates of the subscribers are considered to realize the required optical components at different phases of the system. After that, the traffic mode operation is considered for the analysis of the optimal use of components with respect to the active users.

This paper is organized as follows: the next section presents the related research works for existing energy-saving and cost-effective strategies in the literature. Section 3 introduces the proposed system architecture while considering four different CRMs. The proposed modules utilize active and dynamic routing characteristics. This is followed by the energy efficient operation discussion, including power reduction strategies and energy-efficiency in traffic adaptive mode, and analysis of the research work. Finally, in Section 5, conclusions and key findings are presented.

2. Overview of existing energy-saving and cost-effective strategies

Energy efficient and cost effective network architectures are also needed to be realized in addition to the technical performance of the network. Hence, it is an important research objective to understand the relationship between access network architecture and power consumption by observing the users' network utilization. Access parts are one of the most important power consumption units of the network architectures [6]. Different system configurations and/or device utilizations have been proposed in order to realize energy efficient characteristics for PONs. These techniques can be mainly categorized as hardware (physical) or software (resource management algorithms) approaches and recent studies are summarized in Table 1.

Different channel combine/split (CCS) modules are presented for WDM/TDM PON systems in order to achieve energy efficient network utilization [12]. Power consumption characteristics of next generation PON technologies are discussed in [13] by considering fixed and optimized split ratio strategy. In this study, the most energy efficient option is analyzed for future deployments with access bandwidths up to 1 Gb/s: XG-PON1 (with split ratio1:64) or TWDM PON (with split ratio 1:256) [13].

In accordance, maximum energy savings are achieved in ONUs by using a sleep aware dynamic bandwidth allocation (SDBA) algorithm [14] by considering the QoS requirements. The approach is experimentally evaluated by utilizing an FPGA test-bed. Sort-And-Shift (SAS) scheduling framework is studied in [15] in order to clarify the sleep time sizing. Optical switches are used in [16] at OLT of PON architectures that provide multiplexing function in order to route the downstream data to the ONUs. Switching mode is controlled by observing the traffic conditions of the system. A single transceiver is used in [17] for WDM/TDM PON system to serve for the lower capacity downstream traffic which eventually leads to energy efficient OLT. Different routing modules are proposed in [18] as an active controlling mechanism for hybrid WDM/TDM PON. As a result, minimal optical sources at the CO are utilized for an energy efficient operation which can be active or inactive. In order to control different ONUs from different OLTs with dynamic characteristics, different mechanisms are also proposed

Please cite this article as: E. Niknia et al., Energy efficient operation for a reconfigurable and self-interleaved optical access network, Computers and Electrical Engineering (2018), https://doi.org/10.1016/j.compeleceng.2018.01.018