Optics Communications 407 (2018) 69–82

Contents lists available at ScienceDirect

Optics Communications

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

Novel WRM-based architecture of hybrid PON featuring online access and full-fiber-fault protection for smart grid

Xingfeng Li, Chaoqin Gan *, Zongkang Liu, Yuqi Yan, HuBao Qiao

Key Laboratory of Specialty Fiber Optics and Optical Access Networks, School of Communication and Information Engineering, Shanghai University, Baoshan District, Shanghai, China

ARTICLE INFO

Keywords:
Smart grid
Wavelength-routing module
Online access
Full-fiber-fault protection
Dynamic bandwidth allocation

ABSTRACT

In this paper, a novel architecture of hybrid PON for smart grid is proposed by introducing a wavelength-routing module (WRM). By using conventional optical passive components, a WRM with M ports is designed. The symmetry and passivity of the WRM makes it be easily integrated and very cheap in practice. Via the WRM, two types of network based on different ONU-interconnected manner can realize online access. Depending on optical switches and interconnecting fibers, full-fiber-fault protection and dynamic bandwidth allocation are realized in these networks. With the help of amplitude modulation, DPSK modulation and RSOA technology, wavelength triple-reuse is achieved. By means of injecting signals into left and right branches in access ring simultaneously, the transmission delay is decreased. Finally, the performance analysis and simulation of the network verifies the feasibility of the proposed architecture.

1. Introduction

Electric-power communication network is an important infrastructure to support the smart grid [1]. It has high requirements for the reliability of network [2,3]. In its access part, distribution fiber protection is the key step to promote the reliability of network [4].

In general, the protection schemes of distribution fiber in PON can be divided into three categories: 1:1 protection, optical-network-unit (ONU) group protection and ring protection [5]. The earliest way to offer protection for distribution fiber is 1:1 protection [6]. It provides protection function by duplicating working fiber. Then, ONU group protection was proposed [7]. In the group protection, two adjacent ONUs are regarded as one group, and the two ONUs in a same group can implement mutual protection. Furthermore, ring protection was presented [8]. In the ring protection, all ONUs are connected to a ring structure by interconnecting fibers. In this scheme, the ONU ring is divided into two branches to provide protection for distribution fiber. Specially, to WDM-PON, clockwise mutual protection was put forward [9]. In this scheme, each ONU provides protection for next ONU along clockwise direction. To TWDM-PON, clockwise mutual protection was also proposed [10]. The protection principle of TWDM-PON is similar to that of WDM-PON. And then, all of the schemes above aim at WDM-PON and/or TWDM-PON. However, the architecture having protection function in the coexistence circumstance of WDM-PON and TWDM-PON has not been still reported.

To practical engineering application, practicability is an important factor considered. The designed electric-power communication network should not only be compatible with current electric-power communication network, but also pay more attention to the development needs in the future. To the construction of electric-power communication network, a tradeoff between the reliability and the protection cost of network should be considered. Besides, the smooth-access problem of the expanded part of network should be researched. To these problems, corresponding solution will be proposed in this paper.

2. Wavelength-Routing Module (WRM)

The WRM structure is shown in Fig. 1. It is composed of 2M circulators, M splitters and M couplers. It has M input ports and M output ports. After the downstream signals go through the splitters, they will be split into three paths by the splitters. The couplers are responsible for coupling three wavelengths signals into a fiber. WRM is a bidirectional module. The downstream signals are inputted from the upper ports and outputted from the under ports. In Fig. 1, it should be noted that the circulators marked by asterisk in top right corner are closed circulators. The distinction between closed circulator and normal circulator is that

* Corresponding author.
E-mail address: cqgan@shu.edu.cn (C. Gan).

http://dx.doi.org/10.1016/j.optcom.2017.09.001
Received 2 August 2017; Received in revised form 31 August 2017; Accepted 1 September 2017
0030-4018/

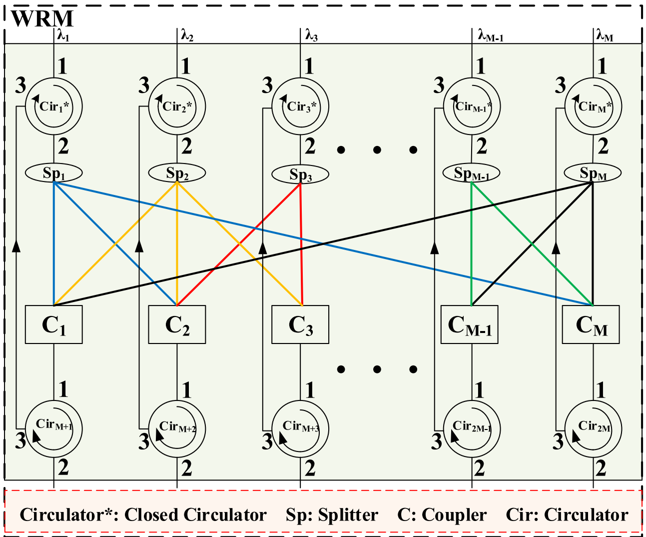

Fig. 1. The structure of WRM.

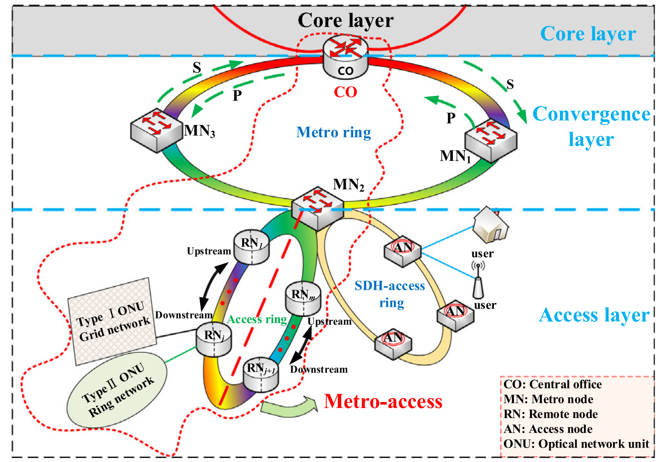

Fig. 2. Topology diagram of the proposed network architecture.

the signals can be inputted from port 3 and outputted from port 1 in closed circulator, but the signals cannot be transmitted from port 3 to port 1 in normal circulator.

Here, assume: the input wavelengths of upper ports are $\lambda_1, \lambda_2, \lambda_3 \ldots \lambda_{M-1}, \lambda_M$. The relation between input and output wavelengths of WRM's each ports is shown in Eqs. (1)–(3).

$$Input = \left[\lambda_1 \lambda_2 \lambda_3 \ldots \lambda_{M-1} \lambda_M\right] \tag{1}$$

$$F = \begin{bmatrix} 1 & 1 & 0 & \cdots & 0 & 1 \\ 1 & 1 & 1 & \cdots & 0 & 0 \\ 0 & 1 & 1 & \cdots & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & \cdots & 1 & 1 \\ 1 & 0 & 0 & \cdots & 1 & 1 \end{bmatrix}_{M\times M} \tag{2}$$

$$Output = Input \times F = \left[\lambda_M + \lambda_1 + \lambda_2, \lambda_1 + \lambda_2 + \lambda_3, \lambda_2 + \lambda_3 + \lambda_4 \ldots \lambda_{M-2} + \lambda_{M-1} + \lambda_M, \lambda_{M-1} + \lambda_M + \lambda_1\right]. \tag{3}$$

The insertion loss of each downlink of the WRM is same. It can be gotten as follows:

$$L_{WRM} = 2L_{Cir} + L_{Sp} + L_{Cpl}. \tag{4}$$

Here, L_{Cir}, L_{Sp} *and* L_{Cpl} represent the insertion loss of circulator, splitter and coupler, respectively. From the formulation (4), we can see that the insertion loss is a constant and the value of insertion loss is independent of M.

3. Network architecture

As it has been known that amount of redundant fibers are not used in electric-power communication network. They are buried when we construct the network in order to provide protection or prepare for network expansion. Here, we call them for "dormant fibers". Topology diagram of the proposed network architecture is shown in Fig. 2. From the figure, we can see that the whole network architecture is composed of three layers: core layer, convergence layer and access layer [11]. Here, we primarily focus on the convergence layer and access layer. In the figure, three rings can be seen clearly. These rings are all dual-fiber rings. The metro ring and the SDH-access ring exist in current network. They are all SDH self-healing ring. Further, they are all two fiber unidirectional path switched rings. The third ring is called access ring. It is a ring that we want to build by illumining the dormant fibers.

In the proposed architecture, both metro and access systems are consolidated into a single metro-access network. The metro-access network is our research focus. Because electric-power communication network requires low transmission delay, the access ring is divided into left and right ranches to decrease the transmission delay. In order to increase utilization efficiency of network resource and improve flexibility of network expansion, the ONUs are divided into two types according to their bandwidth requirement and coverage density. The ONU whose bandwidth requirement is small and coverage density is large is defined as Type I ONU. On the contrary, the ONU whose bandwidth requirement is large and coverage density is small is defined as Type II ONU. Furthermore, because of the reliability requirements of electric-power communication network, the Type I ONUs are formed a grid network, and the Type II ONUs are formed a ring network. By using the WRM, two types of network based on different ONU-interconnected manner can realize online access. Here, 4-port WRM is discussed as an example. It is represented as WRM-4. After the new access ring has been built, a part of services transmitted through SDH-access ring can be transferred to the access ring gradually. Then the stress of services carrying of the SDH-access ring can be decreased immensely. In addition, the comprehensive upgrade of SDH ring network to PON can be realized as the automatic aging of SDH equipment. Here, in order to simplify the analyzing process, we just illustrate one metro node (MN). Actually, operators can determine whether an MN need to be upgraded according to the practical bandwidth requirements of services. In other words, alternative upgrade to MNs can be realized.

4. Architecture configuration and operation principle

In this section, we will introduce the detailed structure of each part and elaborate the operation principle.

4.1. The structure of CO

The structure of central office (CO) is depicted in Fig. 3. In the structure, there are $n + 1$ transmitters, $n + 1$ receivers, n differential phase-shift keying (DPSK) modulators, two arrayed waveguide gratings (AWGs) and one erbium-doped fiber amplifiers (EDFA). The $n + 1$th transmitter and the $n + 1$th receiver are used to transmit and receive SDH signals, respectively. The rest of n transmitters will transmit n wavelengths. These wavelengths are used to transmit broadcast signals through using amplitude modulation. Next, these wavelengths enter into the DPSK modulators. The DPSK modulators modulate the wavelengths