

Novel WDM Access Network Featuring Self-healing Capability and Flexible Extensibility

Chen Feng, Chaoqin Gan, Ziyue Gao and Chenwei Wu

Key Laboratory of Specialty Fiber Optics and Optical Access Networks, School of Communication and Information Engineering, Shanghai University, No. 149, Yanchang Road, Zhabei District, 200072 Shanghai, China

Chaoqin Gan: cqgan@shu.edu.cn

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Abstract. A novel WDM access network is proposed in this paper. By designing the remote node and the extended node, the network has the flexible extensibility. By using ring topology, the architecture of network is constructed. It makes the network not only have the high reliability, but also can cover large access areas. By simulation, the mentioned functions are demonstrated. The simulating results show the network has good performance.

Introduction

With the exponential growth of the internet demand and high bandwidth applications, higher requirements such as larger capacity and more flexible extensibility are raised to optical access network[1]-[3]. To meet such requirements, ring-based network is considered as a good candidate solution. Owing to similar structure, ring-based network can consolidate metro and access resources into a single topology and provide larger capacity easily [4,5]. On the other hand, as the rapid growth of data traffic on network, reliability receives more and more attention. And relying on the superiority of its physical topology, ring-based network can provide fiber-fault protection easily [6]. Both dual-fiber and single-fiber ring-based schemes have been proposed to realize higher reliability [7]-[9].

In this paper, we propose a novel ring-based WDM access network not only can support fiber-fault protection, but also provide extensibility and high capacity.

Principle of Operation

The ring-based WDM access network is shown in Fig. 1. In main ring, this network contains one optical line terminal (OLT) and m remote nodes (RNs). Each RN is shared by n optical network units (ONUs), so entire network can support $m \times n$ ONUs. The main ring is divided into upper and lower branch by $RN_{m/2}$ and $RN_{m/2+1}$. In upper branch, downstream signals are transmitted clockwise, and upstream signals are transmitted anticlockwise. As opposed to upper branch, downstream and upstream signals are transmitted in anticlockwise and clockwise direction respectively in lower branch. By using extended nodes (ENs), main ring can be extended. The extended topologies can include ring, bus, tree, and so on to meet the new requirements of current network.

The structure of OLT and ONU is shown in Fig. 2. In OLT, there are $m \times n$ transmitters, one erbium-doped fiber amplifiers (EDFAs), two circulators (Cir), one wavelength selective switch (WSS), one Arrayed Waveguide Grating (AWG), one receiver array and one monitor. The WSS works as the wavelength router in the system. It decides the output port for the downstream signals. Each ONU contains one Cir, one 1×2 optical splitter, receiver, wavelength converter (WC), and one reflective semiconductor optical amplifier (RSOA).

The structure of RN is illustrated in Fig. 3. Each RN contains two dense wavelength division multiplexers (DWDMs), two couplers, two Cirs, one $2 \times N$ AWG, one wavelength block (WB) and two extended coarse wavelength division multiplexers (CWDMs).

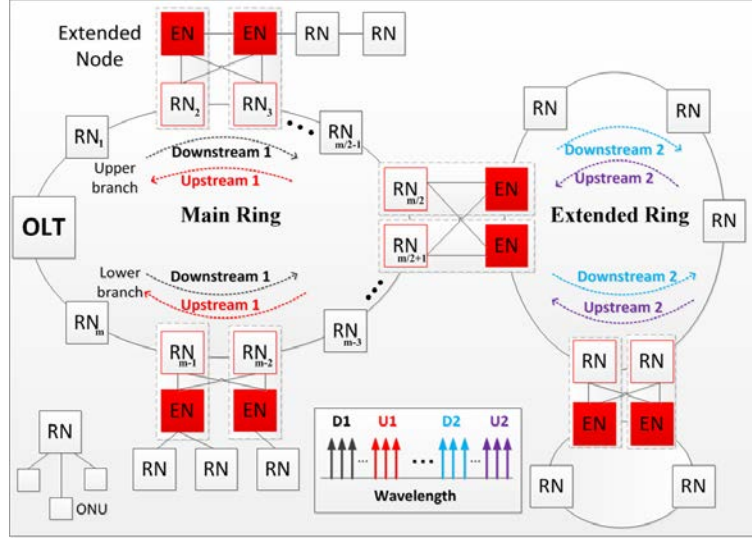


Fig.1. Schematic of network.

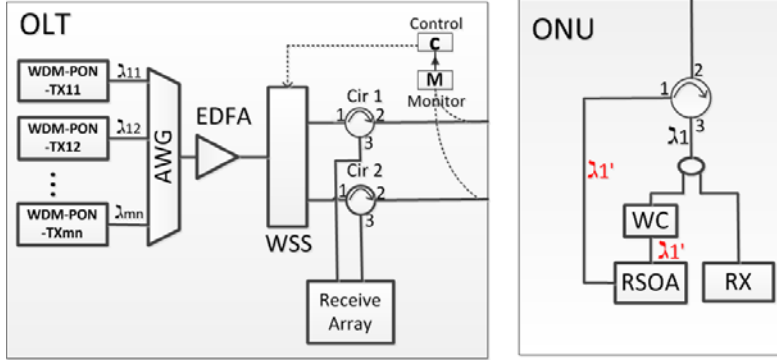


Fig.2. Proposed structures of OLT and ONU.

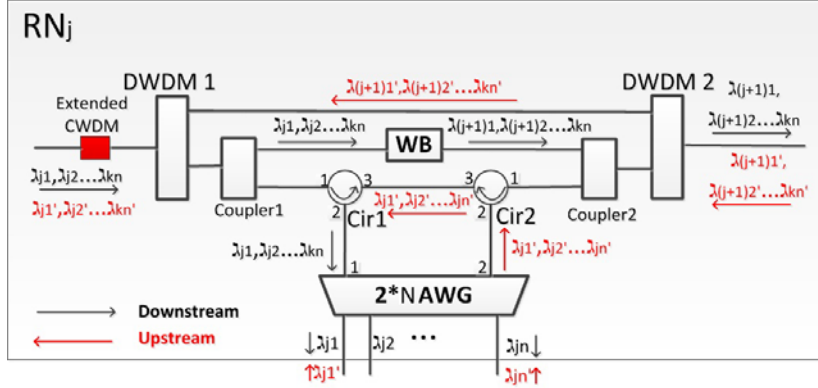


Fig.3. Schematic of the RN's configuration.

In normal mode, $m \times n$ transmitters in OLT working on wavelengths $\lambda_{11}, \lambda_{12}, \dots, \lambda_{mn}$ are used to transmit the light source of downstream signals to each ONU. Here, the wavelengths are identified by two indexed. The λ_{ij} represents the wavelength transmitted to the ONU_j connecting with RN_i. After multiplexed by AWG, these downstream signals are divided into two parts by WSS. Here, WSS works as the wavelength router in the network to control the direction of all the downstream signals. In normal mode, downstream signals $\lambda_{11} - \lambda_{m/2n}$ are routed to RN₁ by Cir₁ in upper branch, while downstream signals $\lambda_{(m+2)/21} - \lambda_{mn}$ are routed to RN_m by Cir₂ in lower branch. The M (monitor) constantly detects the optical signals from upper branch and the lower branch of the network. These signals transmitted in two branches are operated in mirror method. Taking RN_j in upper branch as an example, downstream signals $\lambda_{j1}, \lambda_{j2}, \dots, \lambda_{kn}$ (k is the last RN of upper branch in the main ring) coming from RN_{j-1} are divided into two parts by coupler₁ after passing through DWDM₁. One is sent into WB. And signals $\lambda_{j1}, \lambda_{j2}, \dots, \lambda_{jn}$ are blocked via WB to avoid further wavelength crosstalk in the later

propagation. Then Residual signals $\lambda_{(j+1)1} \lambda_{(j+1)2} \dots \lambda_{kn}$ are transmitted to next RN_{j+1} . The other are demultiplexed by $2 \times N$ AWG and sent to ONUs after passing through the Cir_1 . At ONU, downstream signals are divided into two parts by 1×2 optical splitter: one is demodulated by a receiver, while the other utilized to provide light source for upstream signals is injected into one RSOA and re-modulated. It should be noted that the proposed network is a bidirectional transmission network by employing RSOA in ONU, so Rayleigh backscattered noise can be a severe problem. To solve this problem, wavelength converter (WC) is used to shift the wavelength of signals to another wavelength band before downstream signals are re-modulated by RSOA. After being re-modulated, upstream signals $\lambda_{j1} \lambda_{j2} \dots \lambda_{kn}$ are transmitted back to RN_j over the same route. At the same time, upstream signals $\lambda_{(j+1)1} \lambda_{(j+1)2} \dots \lambda_{kn}$ coming from RN_{j+1} to RN_k are separated by $DWDM_2$ and directly routed to $DWDM_1$. Then signals $\lambda_{j1} \lambda_{j2} \dots \lambda_{jn}$ coming from the port 2 of AWG are combined with $\lambda_{(j+1)1} \lambda_{(j+1)2} \dots \lambda_{kn}$ and transmitted back to OLT.

By above working mechanism, the fiber-fault problem can be solved by appropriately setting the wavelengths for upper and lower branch RNs, respectively. In case of failure occurring in RN or fiber, the WSS in OLT will need to be adjusted appropriately. To state the principle of such adjustment, it is assumed that fiber between RN_i and RN_{i+1} fails. When the M in OLT detects the loss of the upstream wavelength signals, the C (control) module will control the WSS to reassign the wavelengths to restore the affected traffic as far as possible. Downstream signals $\lambda_{11} - \lambda_{in}$ are routed to the upper branch of the main ring and $\lambda_{(i+1)1} - \lambda_{nm}$ are routed to the lower branch. By that configuration, the transmission can be restored from the single failure.

The principle of extension in the network is demonstrated in Fig.4. When the migration is needed to extend network, two adjacent RNs in main ring will be chosen as the output interface for extension. By connecting with the extended CWDM in these two RNs, two additional ENs can realize flexible extension and mutual protection. According to the design, one RN is considered as the master RN as well as the corresponding EN. In the Fig.4, the RN_j and the EN_1 work as the master nodes. Under the normal situation, the SW_2 and SW_3 in EN_1 are triggered to port 1 (black line). At the same time, SW_2 and SW_3 in EN_2 are triggered to port 2 (black line). In this method, the EN_1 is worked as converge point of the extended ring. All the downstream and upstream signals are transmitted through EN_1 . The M of the SW_1 keeps detecting the link connectivity between the main ring and the extended ring. When the link break occurs, the C in EN_1 will first reconfigure the SW_1 to port 1 to try to recover the network from the link failure. If this configuration still does not works, the EN_2 will works as the master node of the extended ring by trigger the SW_2 and SW_3 in EN_2 to port 1. The WSS in two ENs are controlled by C and M in the same way as the WSS in OLT.

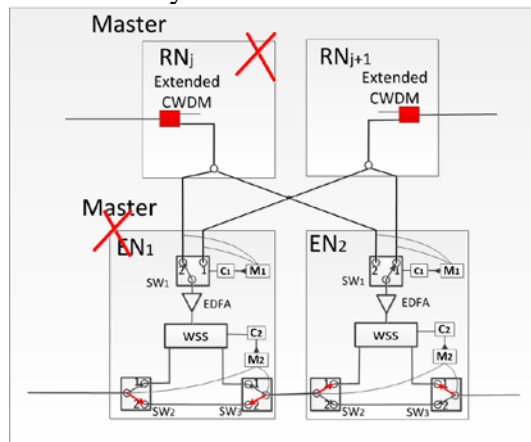


Fig.4. Schematic of the EN's configuration

In the proposed scheme, the ring-based network can be easily and flexibly extended through modularized EN. Thus both the reach distance and the number of subscribers in the network can be largely extended with the minimum migration cost. At the same time, the EN can realize the mutual

signals at 1550nm, 1550.8 nm and 1551.6 nm (around -23.2 dBm, -24.8 dBm, and -24.2dBm) in working mode. Like the simulation result of downstream signals, under protection mode, there are still big changes in transmission performances of upstream signals at 1550.8 nm and 1551.6 nm. And power penalty caused by the additional transmission distance is 2.8 dBm and 2.3 dBm, respectively. Similar to the case of downstream signals, due to the transmission distance unchanged, the minimum received powers of upstream signals at 1550 at a BER of 10^{-9} remains the same.

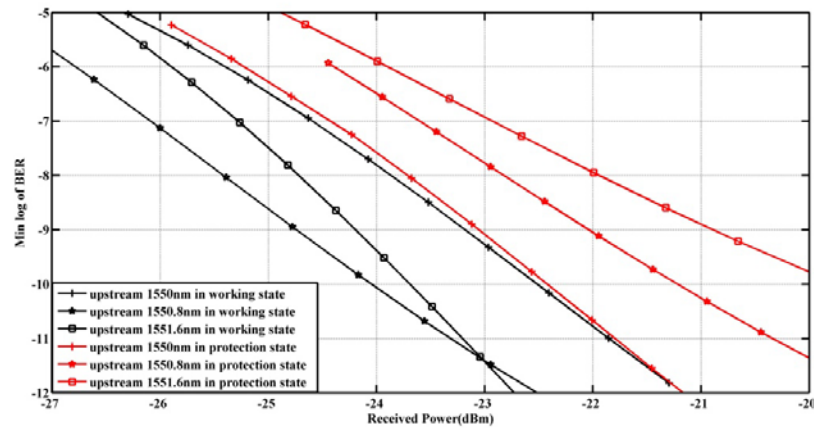


Fig.7. BER curves of the upstream signals.

Conclusion

We propose and demonstrate a ring-based WDM access network. The EN and RN is designed to make the network have the extensibility. It can flexibly configure and adjust scale of network. Through the extended CWDM and corresponding ENs, the origin network can be conveniently and modularized extended to the dual-ring architecture enlarging the scale of network. Thus both the reach distance and the number of subscribers in the network can be largely extended with the minimum migration cost. In addition, by using ring-based topology, the network has protection mode. The affected traffic can be restored against fiber faults occurring in both the feeder fiber and the extended nodes by using the proposed protection mode. These make the network have high reliability. All of the above indicate the network has great resilience. Finally, we realize and demonstrate the mentioned functions of the network by the simulation. Simulation results show the network has good transmission performance of downstream and upstream signals.

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