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Reliable architecture for high-capacity fiber-radio systems

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Abstract

In this paper, we present a reliable architecture for high-capacity fiber-radio system and demonstrate its feasibility. The main trunk of the proposed architecture is a star network with branches comprising a series of concatenated ring subnets. The conventional drawback, the lack of reliability, of star networks is overcome by the ring subnets with a self-healing function based on optical switches. To compensate the extra loss of the system, we adopt compact erbium-doped waveguide amplifiers to construct our proposed architecture. The architecture can provide highly reliable, flexible, and robust performance for fiber-radio systems.

Keywords: Fiber-radio system; Wavelength-division multiplexing; Erbium-doped waveguide amplifiers

1. Introduction

The architecture of future fiber-radio systems should provide large capacity, high reliability, and excellent flexibility. Wavelength-division multiplexing (WDM) is a powerful and cost-effective technique to increase the network capacity, reconfigurability, and best use of the huge bandwidth provided in fiber. However, conventional WDM fiber-radio systems with star or tree architectures, whose connectivity between optical line terminal (OLT) and optical network units (ONUs) is obtained using an optical multiplexer [1,2], do not provide self-healing functions to provide sufficient quality of service (QoS). Compared with the ring architectures [3,4], the star or tree architectures are more vulnerable to single point failures because of its topology and the lack of an alternative redundant path. Nevertheless, the star or tree architectures can offer less propagation delays.

Recently, WDM networks based on bidirectional add-drop multiplexers and star-bus-ring architectures have been proposed [5]. However, the optical network unit (ONU) in the ring subnet is relatively difficult to be with high data rates, large bandwidth, and self-healing functions. In this paper, we proposed a reliable architecture for high-capacity fiber-radio systems. Such a reliable architecture consists of a star network on the upper level and a series of concatenated ring subnets on the lower level. The design idea is to use the star subnet as a high-capacity infrastructure for the network and the ring subnet as a cost-effective way to serve the optical network units. The ring subnets, with self-healing capabilities, overcome the weakness in reliability in the star network. The self-healing function can be performed at ONUs by using optical switches to reconfigure the data traffic if any failure occurs in ring subnets. Recently, erbium doped waveguide amplifiers (EDWAs) are very attractive to be used in metro and access networks because of their compactness and excellent compatibility with optical fibers [6]. Therefore, we use EDWAs in our proposed system to compensate the extra losses. The experimental setup employs a multi-carrier RF signal (with each channel having a data rate of 100 Mb/s) operating at 5.2-, 5.5-, and 5.8-GHz, which locate in an operation band for next generation wireless system. Experimental results show that this architecture

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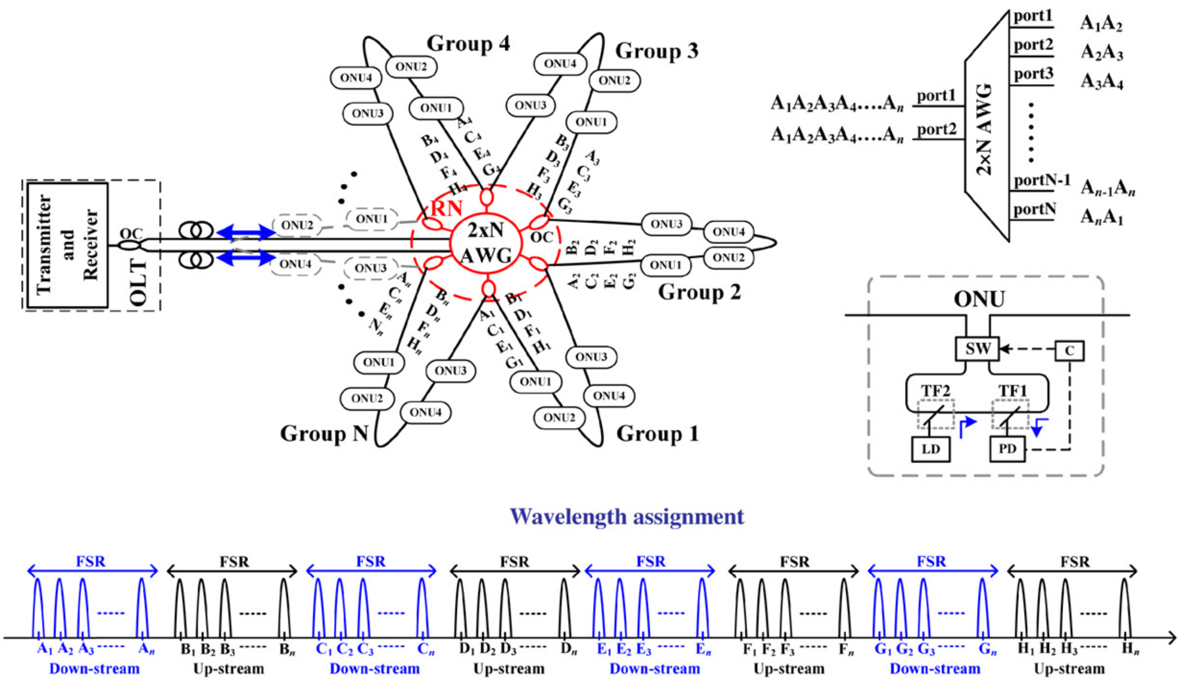

Fig. 1. Proposed star-ring-bus architecture (OLT: optical line terminal, RN: remote node, ONU: optical network unit, AWG: array-waveguide grating, OC: optical coupler, TF: thin film filter, C: controller, SW: optical switch).

can provide excellent reliability, high capacity, and flexibility for future fiber-radio systems. Furthermore, our proposed architecture should be applicable to any access network employing subcarrier multiplexing technology. There has not been any demonstration for subcarrier multiplexing and radio over fiber access networks with this architecture yet.

2. Architecture description

Figure 1 shows the schematic diagram of our proposed reliable architecture for WDM fiber-radio systems. A remote node (RN) comprises a $2 \times N$ array-waveguide grating (AWG) and N 1×2 optical couplers (OC) connecting to the ONUs. Two fibers from the OLT are connected to the two successive input ports of the $2 \times N$ AWG, which correspond to two adjacent passband channels next to each other. As a result, each output port of AWG will carry signals with wavelengths A_i from one fiber input and A_{i+1} from the other fiber input to the AWG. The ONUs are assigned in a ring subnet and are serially connected to the output port of the AWG through a 1×2 optical coupler. In each ring subnet, four ONUs are employed here as an example. Because the four ONUs are connecting to the same port of the AWG, we use the spectral periodicity property inherent in the AWG to assign the upstream and downstream wavelengths for ONUs. For example, for each ONU, we assign two specific wavelengths separated by a distinct free-spectral range (FSR) of the AWG for the downstream and upstream signals, respectively. Therefore, each ring subnet needs to use eight FSR wavelengths of the AWG for four ONUs. The wavelength assignment of each ONU is shown in the inset of Fig. 1. The downstream wavelengths (A_i, C_i, E_i, G_i) and the upstream wavelengths (B_i, D_i, F_i, H_i) in the ith group are separated each other by one FSR of the AWG. Therefore, we can route all eight wavelength channels via one port of AWG at the same time. The ONU in the ring subnet is a bidirectional device, which comprises a 2×2 optical switch, two thin film filters (TF), a photodiode (PD), and a laser diode (LD), as shown in the inset of Fig. 1. By controlling the 2×2 switch, each ONU has a self-healing function to reconfigure the ring subnet. Figure 2 schematically shows a situation when the fiber link fails between ONU3 and ONU4. When the 2×2 switch of ONU3 is in the bar state, we lose E_i signal. Nevertheless, the 2×2 switch of ONU3 can be switched into cross state to reconfigure the E_i signal. Hence achieve the self-healing function. The drawback of this architecture for fiber-radio systems is that the optical switches and coupler in the network introduce extra losses. In order to compensate the losses, we adopt EDWAs in the OLT. The proposed architecture can result in a highly reliable fiber-radio system for large radio terminals.

3. Experimental setup and results

To test the feasibility of the proposed system, an experimental setup is shown in Fig. 3. A 300 MHz RF signal is mixed with a local oscillator at 5.5 GHz to generate three RF carriers, spaced by 300 MHz. A 100 Mb/s non-return-to-zero (NRZ) pseudo-random binary sequence (PRBS) data with $2^{31} - 1$ pattern length from a pattern generator mixed with the three RF carriers provides the three radio signals with binary data. Figure 4a shows the electrical RF spectrum of our 3-channel RF data signal. Then a DFB laser is externally modulated by this 3-carrier RF electrical data signal. The modulated optical spectrum of our optical signal at point B is shown in Fig. 4b. The resulting optical RF carrier is then passed through two AWGs, an EDWA, 12.5 km of single mode fiber, fiber couplers, and two thin film filters to simulate this WDM fiber-radio system.

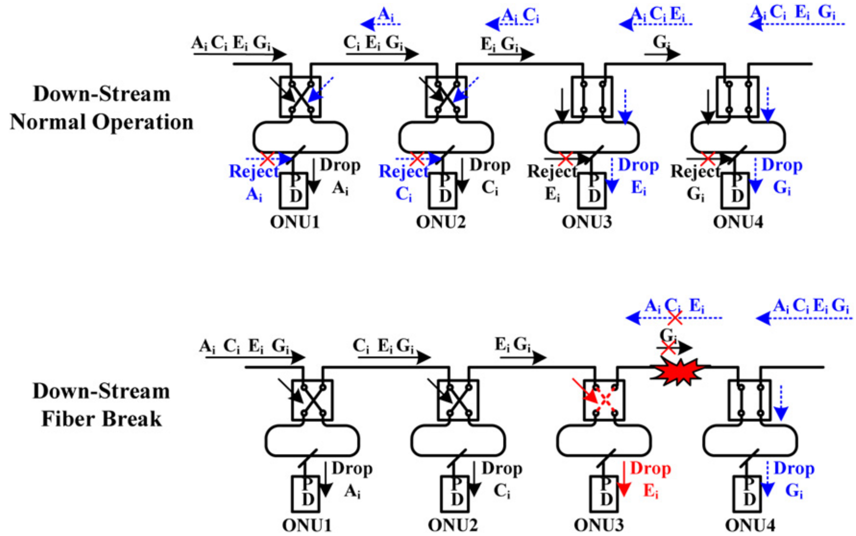

Fig. 2. Schematic situation when fiber link fail between the ONU3 and ONU4.

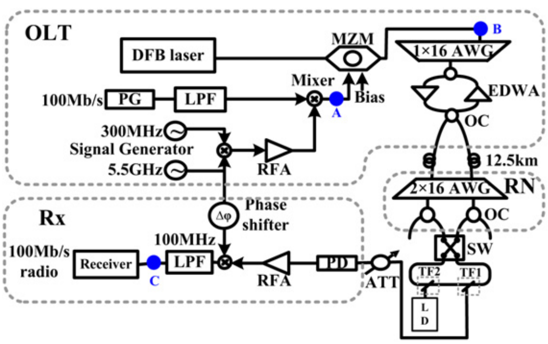

Fig. 3. Experimental setup (PG: pattern generator, LPF: low pass filter, RFA: RF amplifier, EDWA: erbium-doped waveguide amplifier, OC: optical coupler, ATT: optical attenuator, MZM: Mach–Zehnder modulator).

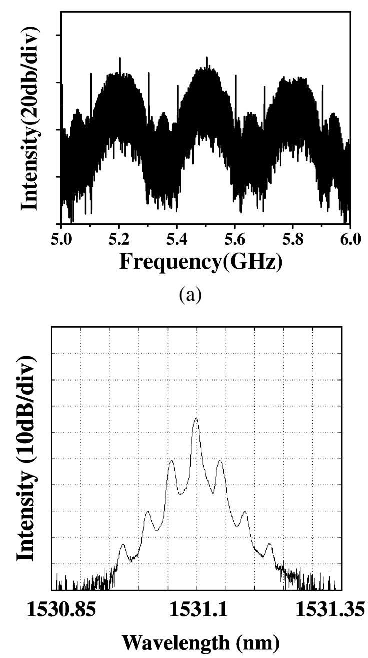

Fig. 4. (a) RF spectrum at point A. (b) Measured optical spectrum at point B.

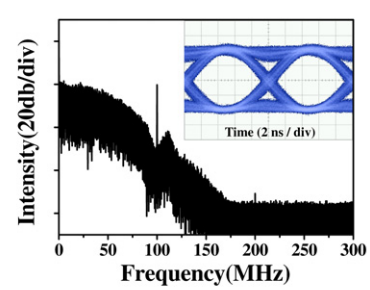

Fig. 5. Recovered 100 Mb/s signal and eye diagram at point C.

The central wavelength of thin film filter TF1 and TF2 are 1531.1 and 1569.6 nm, respectively. The EDWA is manufactured by Teem Photonics via a two-step ion-exchange process, and has a saturated output power of about 10 dB m. The received 3-carrier RF data signal is electrically amplified and down converted using an electric mixer. A variable phase shifter is used to adjust the carrier phase for down conversion. Figure 5 shows the eye diagram and RF spectrum of the recovered 100 Mb/s signal at the point C. Figure 6 shows the measured bit error rate curves for back-to-back and after 12.5 km transmission. The power penalty is below 0.7 dB. This demonstrates the feasibility of the proposed architecture. Furthermore, when the fiber link fails between the ONU and the RN, the ONU can still connect to the OLT by controlling the optical switch to select an alternative path (shown in Fig. 2). In our experiment, the power penalties would be the same when the optical switch is either in bar or cross state.

4. Discussion

Due to the self-healing functions in each ring subnet, our architecture provides a higher reliability which is very important in distributed and access networks. For the ring architecture demonstrated in [4], the reliability is worse than ours since there is only one single-ring protection for the network. The star or tree architectures in [1] exhibited poor reliability because they

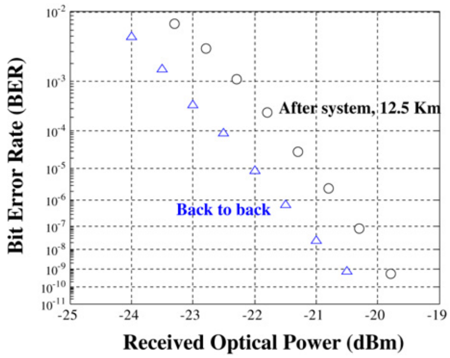

Fig. 6. Measured bit error rate curves.

do not even equip with any self-healing function. However, the reliability does not come without cost. In contrast with the star or tree architectures, our proposed star-ring architecture experienced more optical loss which increases the required power budget. Usually a higher reliability means a higher cost because more devices would be needed to guarantee better protection. Therefore, there exists a trade-off between the reliability and the operation/deployment cost. For those services requiring higher reliability, our architecture is with much more attraction and could be a better choice.

Although the optical switches in ONUs can provide the self-healing function to implement a robust system, they also increase power losses as well as switching crosstalks. The cascadability of the optical switches will limit the scale of our proposed architecture. In our experiment, the insertion loss of the optical switch and thin film filter are about 0.7 and 0.6 dB, respectively. The crosstalk of the optical switch is below −60 dB. To estimate the network scale, we assume that the single channel power to the ring subnet is −4 dB m and the fiber chromatic dispersion in the ring subnet is negligible. The worst case is that there is a breakpoint occurred immediately at the either input of the ring subnet. To guarantee that each ONU in the ring subnet can be operated with normal function, the received optical power at the last ONU must remain above the required receiving sensitivity of the optical receiver. Therefore, the ring subnet would support up to five ONUs in our experimental setup. Moreover, for shorter transmission distances where the fiber nonlinearities and fiber loss are not critical, the transmitted power can be further increased and more ONUs can be in service in our proposed star-ring architecture.

5. Conclusions

We have proposed a reliable architecture with self-healing functions for high-capacity WDM fiber-radio systems. The proposed fiber-radio system provides the self-healing function by employing reconfigurable bidirectional ONUs and a $2 \times N$ AWG. Furthermore, we set up a 3-carrier RF signal to demonstrate the feasibility of our proposed fiber-radio systems. The experimental results reveal that the proposed star-ring-bus architecture is a promising architecture for future high-capacity fiber-radio systems.

Acknowledgments

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