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A NOVEL ARCHITECTURE FOR DENSE WAVELENGTH-DIVISION MULTIPLEXING / SUBCARRIER MULTIPLEXING NETWORKS

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ABSTRACT: *We propose and demonstrate a new survivable dense wavelength-division multiplexing / subcarrier multiplexing (DWDM / SCM) network based on the star–bus–ring architecture (SBRA). This architecture ensures an OBI-free optical network, and can serve tremendous subscribers. In addition, remote nodes and bidirectional wavelength add / drop multiplexers (B–WADMs) are designed by using simple optical switches to reconfigure the network under link failure. We further set up an experimental network to demonstrate the feasibility of the proposed architecture.* © 2001 John Wiley & Sons, Inc. Microwave Opt Technol Lett 32: 51–56, 2002.

Key words: *dense wavelength-division multiplexing / subcarrier multiplexing (DWDM / SCM); star–bus–ring architecture (SBRA); optical beat interference (OBI); bidirectional wavelength add / drop multiplexing (B–WADM); cascade add / drop transceiver (CAT)*
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I. INTRODUCTION

Owing to the inherent flexibility in simultaneously carrying analog and digital messages, as well as the capability to finely use the available modulation bandwidth of laser sources, the subcarrier multiplexing (SCM) based on a passive optical network (PON) is a promising approach for future subscriber networks to accommodate advanced broadband services. A critical limitation imposed on the SCM network is the optical beat interference (OBI) problem, which would limit the number of subscribers served by the network [1–3]. The authors of this paper had proposed a modified star–ring architecture (MSRA) by adopting a cascade add/drop transceiver (CAT) structure in the lower level rings to offer an OBI-free SCM network [4]. However, the MSRA could not provide abundant bandwidth to serve the dramatic rise in the applications of high-speed multimedia, video on demand (VOD), and future advanced services. Therefore, a new broadband architecture is desirable.

The DWDM/SCM network is currently being developed to transmit video as well as advanced Internet applications to serve users needing a large channel capacity [5]. Here, we propose a novel DWDM/SCM network, which employs a properly designed three-level star–bus–ring architecture (SBRA) having a star subnet on the upper level, several bus subnets on the middle level, along with many ring subnets on the lower level. The star subnet establishes a high-capacity infrastructure for the network, whereas the bus subnets offer broadband channels for multiwavelength signals to and from the lower level ring subnets. In the ring subnets, we adopt the cascade add/drop transceiver (CAT) structure at each optical network unit (ONU) to overcome the OBI problem. The use of DWDM/SCM technology combined with all-optical wavelength add/drop multiplexing (WADM) is able to accommodate future growth in broadband subscriber networks [6].

Since the network accommodates a large number of subscribers, any service outage due to link failure will translate into tremendous loss for service providers. Therefore, the design of a self-healing function to recover from failure in real time is very important [7]. In this paper, we propose a simple surviving scheme based on two protected stages in the SBRA. Consequently, the SBRA is a reliable broadband network architecture.

II. THE DWDM / SCM STAR–BUS–RING ARCHITECTURE

Figure 1 shows the configuration of the SBRA based on a DWDM/SCM network. A star subnet on the upper level connects many remote nodes (RNs) to a central office (CO) using two fibers for each link. This provides a high-capacity optical path between the CO and each RN. A dual-fiber bus connects two neighboring RNs. Many ring subnets are attached to the bus via bidirectional wavelength add/drop multiplexers (B–WADM), with each ring subnet serving a number of ONUs.

In the star subnet, we design two distinct wavelength groups $\{\lambda_{A1}, \lambda_{A2}, \ldots, \lambda_{An}\}$ and $\{\lambda_{B1}, \lambda_{B2}, \ldots, \lambda_{Bn}\}$ in the alternate links. Each group consists of many ITU-T standard wavelength signals, being used in both upstream and downstream directions. This arrangement will ease the network reconfiguration under link failure. The function of the RN is to properly transfer multiwavelength signals between the CO

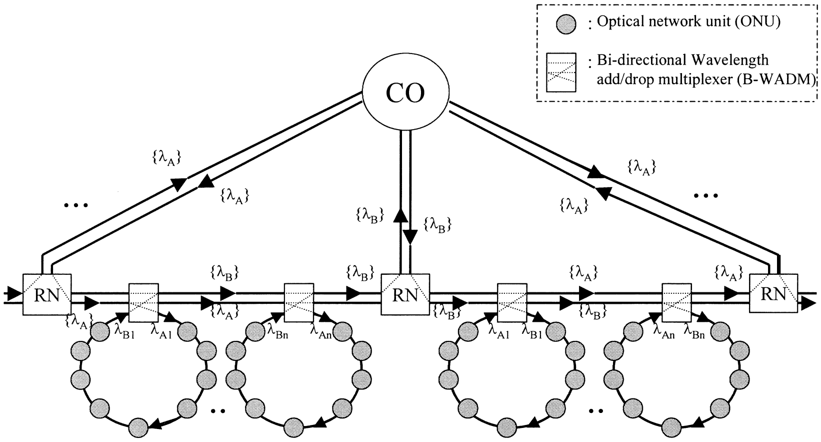

Figure 1 DWDM/SCM star–bus–ring architecture

and the corresponding fiber bus. Downstream signals are delivered from the CO to the fiber bus via the RN, and upstream signals from the fiber bus are forwarded to the CO through the RN as well. The RN can perform a self-healing function if link failure occurs in the star or bus subnet.

The two fibers in the fiber bus carry downstream and upstream multiwavelength signals, respectively. Downstream signals are dropped to the lower level ring subnets via B–WADM. Each B–WADM drops a specific wavelength signal (e.g., λ_{A1}) from the downstream wavelength group (e.g., $\{\lambda_A\}$). This downstream wavelength signal contains many SCM signals to serve those ONUs belonging to the ring subnet of interest. A special cascade add/drop transceiver (CAT) is employed at each ONU to drop the desired downstream SCM signal and to add the local upstream SCM signal as well. The use of a CAT structure can eliminate the OBI problem, and compensate the branch loss at each ONU. The last ONU in the ring subnet transmits the upstream signal with a specific wavelength (e.g., λ_{B1}) in the other wavelength group $\{\lambda_B\}$, being carried by another fiber of the fiber bus. The fiber bus gathers all upstream wavelength signals coming from the attached ring subnets, and then forwards them to the CO via the corresponding RN.

A. The Bidirectional WADM (B–WADM). In order to ensure excellent reliability, a B–WADM making use of simple optical components is designed to alter the signal flow if the corresponding fiber bus is cut. We employ the multilayer dielectric interference filter to implement the B–WADM due to its bidirectional property. This filter can be designed to add or drop a specific wavelength signal within a group of multiwavelength signals.

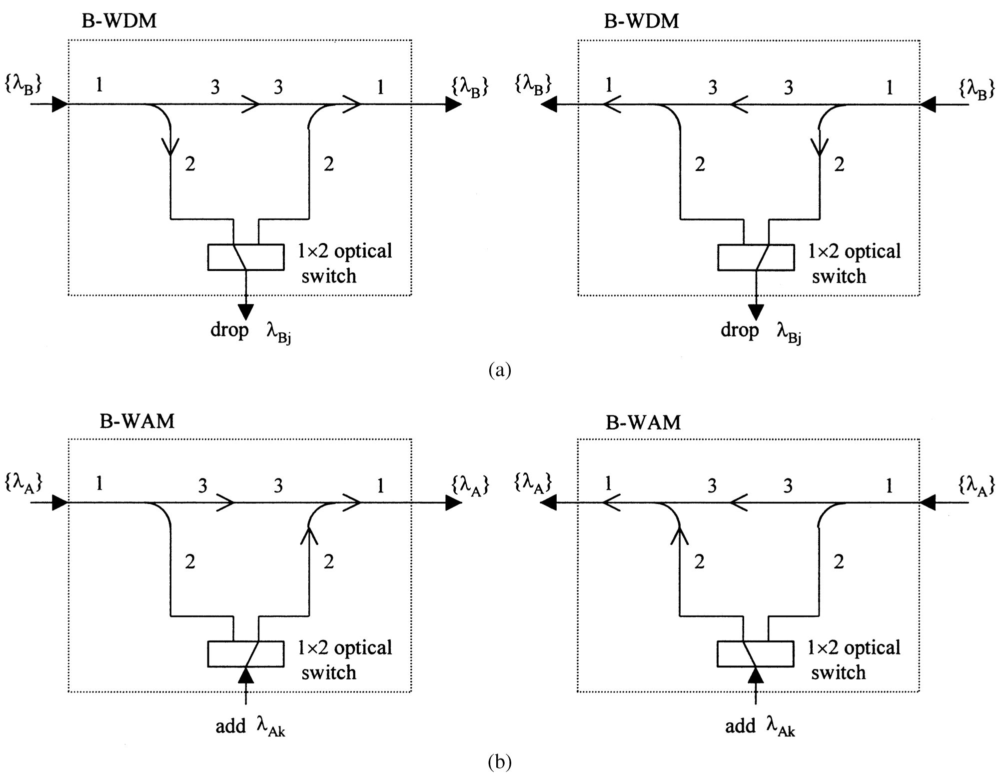

Figure 2 Configurations of (a) bidirectional wavelength drop multiplexing (B–WDM), (b) bidirectional wavelength add multiplexing (B–WAM)

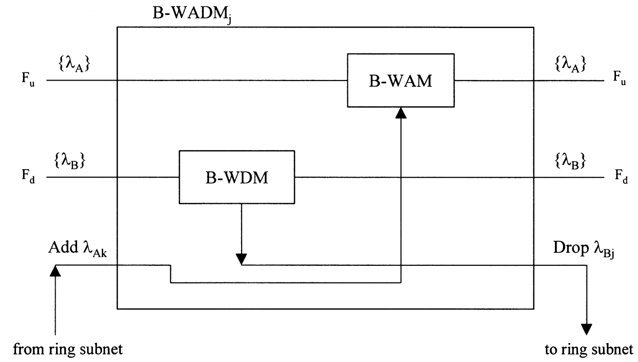

Figure 3 Block diagram of bidirectional wavelength add/drop multiplexing (B−WADM)

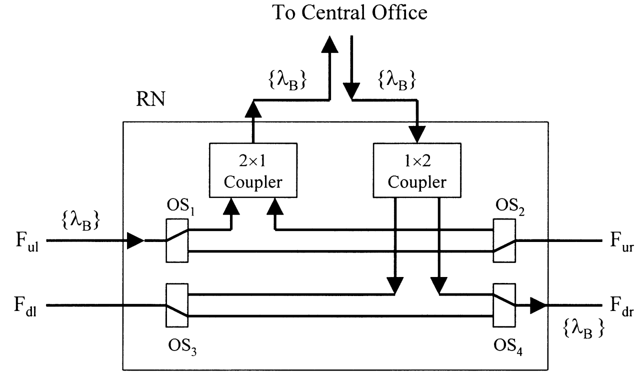

Figure 4 Configuration of remote node (RN) under normal condition

Figure 2(a) demonstrates a bidirectional wavelength drop multiplexing (B−WDM) via a 2×1 optical switch (OS). It can drop a specific wavelength λ_{Bj} from a group of wavelengths $\{\lambda_B\}$ in both directions. Figure 2(b) demonstrates a bidirectional wavelength add multiplexing (B−WAM), which can add a specific wavelength λ_{Ak} within a group of wavelengths $\{\lambda_A\}$. Finally, we design the B−WADM to be used in the SBRA, as shown in Figure 3. It is composed of a B−WAM and a B−WDM, which can add/drop a specific wavelength signal in the dual-fiber bus in both directions by controlling the states of optical switches. As will be clear later, the B−WADM will alter signal flow in the fiber bus if link failure occurs.

B. The Remote Node (RN). Figure 4 shows the configuration of an RN under normal conditions. Each RN contains four 1×2 optical switches and two 1×2 couplers. Refer to Figure 1 to better understand the signal flow. The switch states are arranged such that downstream wavelength signals coming from the CO are forwarded through a 1×2 coupler, and then sent to a fiber in the fiber bus (F_{dr}) located on the right of the RN. On the other hand, upstream wavelength signals coming from the bus located on the left of the RN (F_{ul}) are directed to a 1×2 coupler, and then sent to the star link. The switch states of the RN can be modified to redirect signal flow in case a fiber cut occurs in the star or bus subnets.

C. The Cascade Add / Drop Transceiver (CAT) Structure. As shown in Figure 5, a ring subnet drops a specific wavelength signal (e.g., λ_{Aj}) from the downstream wavelength group, and we adopt the cascade add/drop transceiver (CAT) structure at each ONU. The CAT consists of a *p-i-n* detector, an electrical add/drop module, and a laser transmitter. In the first ONU (ONU_1), the downstream SCM signal coming from the CO is first converted to electrical by the *p-i-n* module. This signal is forwarded to an add/drop module in which the upstream signal (S_1) is added and the message destined to the ONU_1 (C_1) is dropped. A Fabry−Perot (FP) laser trans-

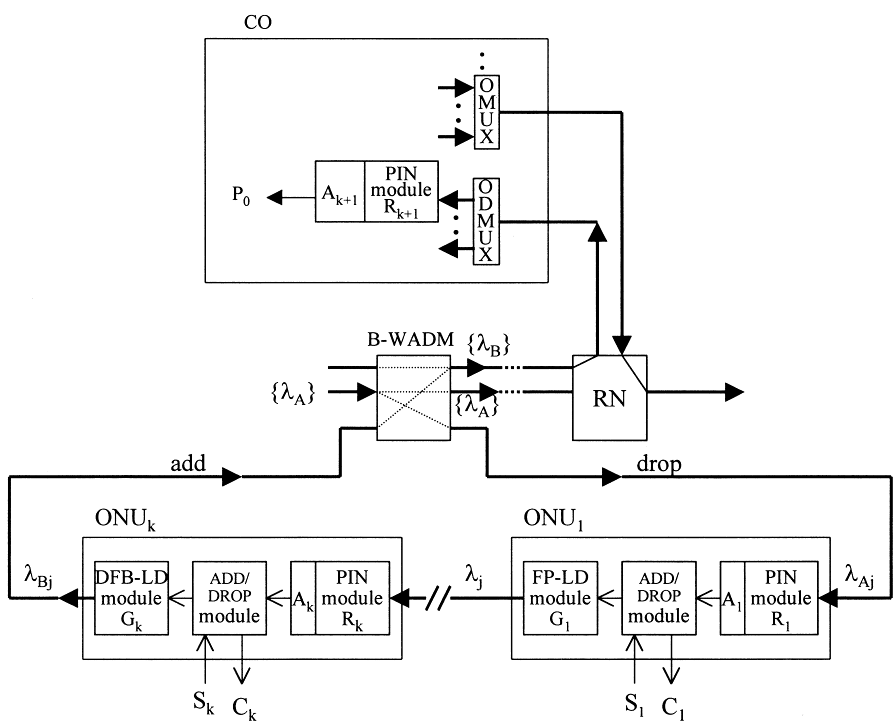

Figure 5 Cascade add/drop transceiver (CAT) structure

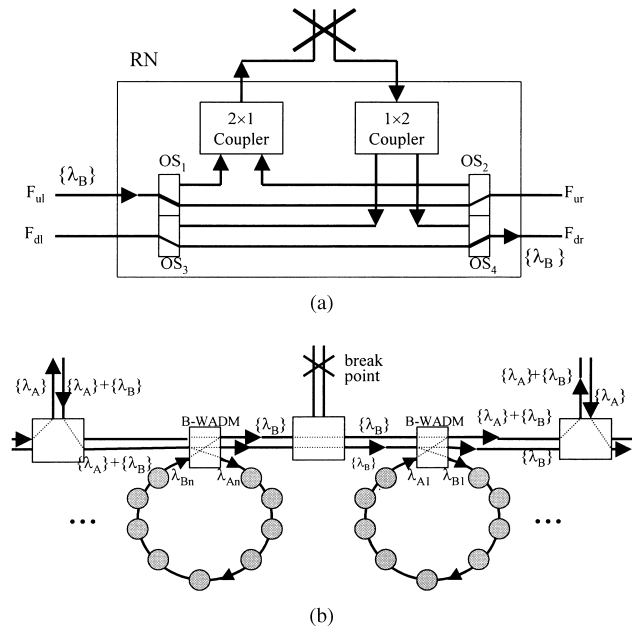

Figure 6 (a) Reconfiguration of RN under link failure in the star. (b) Virtual connection of RN and the configuration of B–WADM under link failure in the star

mits the output of the add/drop module, which contains the downstream signal from the CO and the upstream signal of the ONU_1, to the next ONU. The same operation is performed in the following ONUs in a cascade manner. Finally, the last ONU (ONU_k) converts the upstream signals into a specific wavelength signal (λ_{Bj}), and forwards it to the B–WADM. Thus, all downstream signals are received by destined ONUs, and all upstream signals can be transferred to the B–WADM and then to the CO via the corresponding RN. Only an ITU-T standard DFB laser transmitter should be used in the last ONU.

D. Self-Healing Functions. The SBRA can offer survivable functions under link failure by reconfiguring the RN and the B–WADM. If a fiber cut occurs in a star link, the switch states of the corresponding RN are modified as shown in Figure 6(a); thereby, the virtual configuration of the network is as shown in Figure 6(b). In this case, traffic originally supported by the failed link (e.g., up/downstream wavelengths $\{\lambda_B\}$) is managed by two neighboring RNs. Note that the assignment of distinct wavelength groups for alternate links in the star subnet eases reconfiguration without affecting the signal flow in the bus and ring subnets. If a fiber cut occurs in the bus subnet, we can modify signal flow by reconfiguring the corresponding B–WADM and RNs as shown in Figure 7. In this case, up/downstream signals in the ring subnets are redirected to avoid the breakpoint, and the switch states of RNs are rearranged such that up/downstream signals are adequately transferred between the CO and those ring subnets.

III. EXPERIMENTAL SETUP AND RESULTS

To demonstrate the feasibility of the SBRA, we set up an experimental network as shown in Figure 8. In the downstream direction, four ITU-T standard DFB lasers (λ_1, λ_2, λ_3, λ_4) with center wavelengths of 1547.72, 1549.32, 1550.92, and 1552.52 nm are directly modulated with subcar-

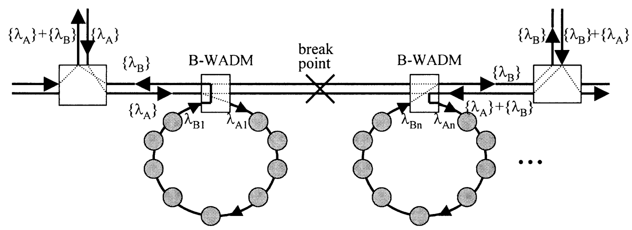

Figure 7 Reconfiguration of RN and B–WADM under bus link failure

rier multiplexed signals covering the 550–1000 MHz band. These four optical signals are multiplexed by a DWDM multiplexer, and sent to the RN through a 2.2 km single-mode fiber. The four signals are forwarded to a dual-fiber bus via the RN, and the 1549.32 nm (λ_2) as well as the 1550.92 nm (λ_3) signals are dropped by B–WADM to two ring subnets, respectively. There are four ONUs in each ring subnet, which can receive desired downstream signals and transmit upstream signals as well.

In the upstream direction, the signals generated at the ring subnet are linked to the CO via B–WADM and the RN. Two ITU-T standard DFB lasers with center wavelengths of 1554.12 nm (λ_5) and 1558.92 nm (λ_8) are used in the last ONU of two ring subnets, respectively. Low-cost 1.5 μm FP lasers are used in the other ONUs, being directly modulated by several 3 Mbit/s FSK subcarrier signals. The upstream FSK subcarrier channel spacing is 6 MHz, ranging from 80 to 500 MHz. The 3 Mbit/s data signal can be converted into an FSK signal through a VCO module, and then directly modulates the laser. In this work, the upstream subcarrier channels were chosen from 94 to 136 MHz, and the 106 MHz channel (ONU3) was monitored. In the downstream direction, the subcarrier channels were chosen from 550 to 562 MHz, and the 556 MHz subcarrier channel was monitored. The total optical loss through the 2.2 km single-mode fiber is 0.43 dB at 1549.32 nm. The end-to-end optical loss of the system of the downstream 1549.32 nm signal is 6.53 dB, and it is 7.33 dB for the upstream 1554.12 nm signal.

Figure 9 shows the measured BER of the 556 MHz downstream channel versus the received optical power at the

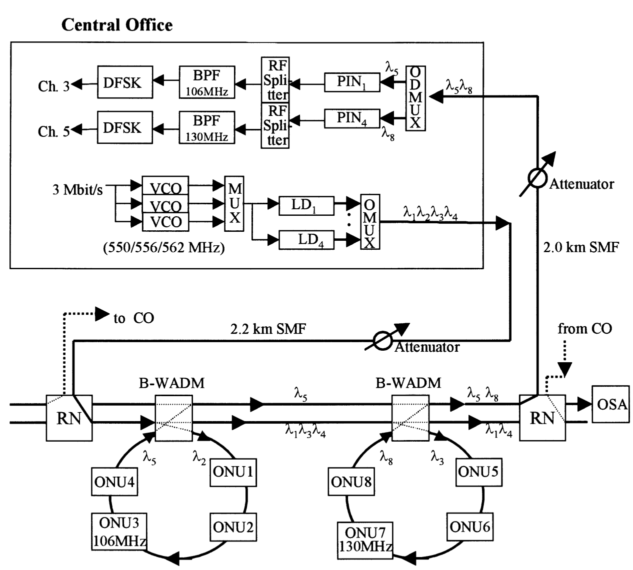

Figure 8 Experimental setup

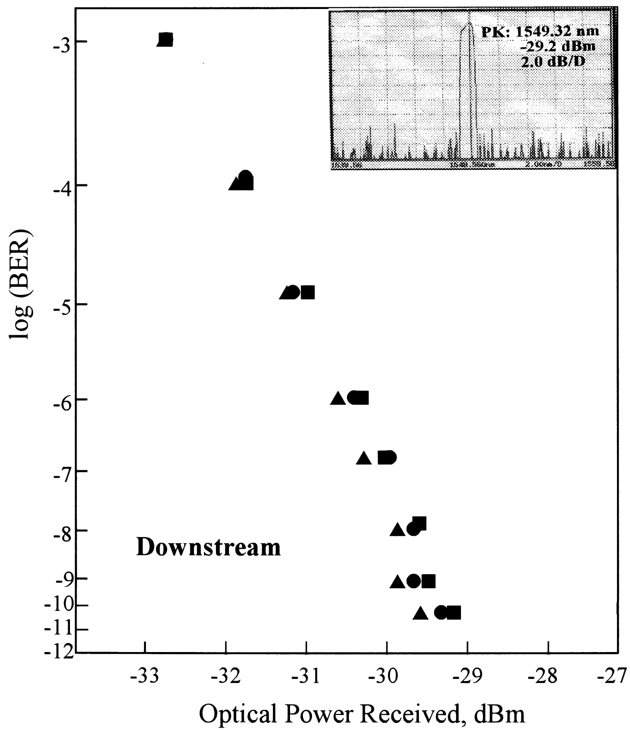

Figure 9 Measured BER curves for downstream transmission at ONU1. ▲ with the 556 MHz SCM channel only, • with two adjacent downstream SCM channels, ■ with eight upstream SCM channels and two adjacent downstream SCM channels

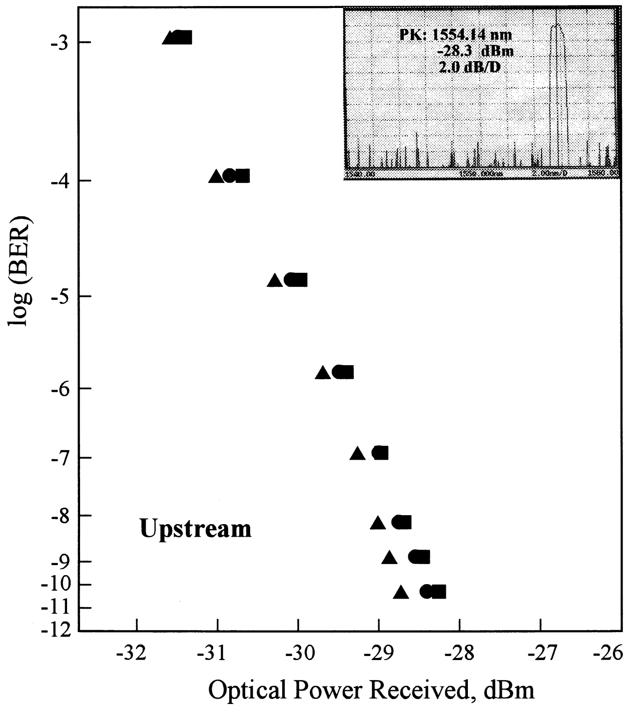

Figure 10 Measured BER curves for upstream transmission at CO. ▲ with the 106 MHz SCM channel only, • with seven adjacent upstream SCM channels, ■ with three downstream SCM channels and seven adjacent upstream SCM channels

output of the *p-i-n* module in ONU1. It is monitored under three conditions: 1) transmit the 556 MHz channel only, 2) add two adjacent downstream SCM channels, and 3) add two adjacent downstream SCM channels and eight upstream SCM channels. For the 1549.32 nm DFB laser at the CO, the transmitted optical power is -0.2 dBm, and a BER of 10^{-9} is obtained at a received optical power of -29.9 dBm in case 1. There is a 0.4 dB power penalty due to the eight upstream channels in case 3. Thus, the downstream channel optical power margin is 22.77 dB $(-0.2 - 6.53 - 0.4 + 29.9)$ in case 3.

In Figure 10, the 106 MHz upstream channel is monitored under the following three cases: 1) transmit the 106 MHz SCM channel only, 2) add seven adjacent upstream SCM channels, and 3) add three downstream SCM channels and seven adjacent upstream SCM channels. For the 1554.12 nm DFB laser in ONU4, the transmitted optical power is -0.2 dBm, and a BER of 10^{-9} is obtained at a received optical power of -28.7 dBm in case 1. There is a 0.5 dB power penalty with three downstream SCM channels and seven adjacent SCM channels in case 3. Thus, the optical power margin is 20.67 dB $(-0.2 - 7.33 - 0.5 + 28.7)$ in case 3.

IV. DISCUSSION

In the SBRA, two distinct wavelength groups are repeatedly used in alternate links of the upper level star subnet for up/downstream transmission. Each wavelength signal in the group can carry many SCM signals to serve a ring subnet. If there are N wavelengths in each group, each link of the star subnet can support N ring subnets. Thus, each star link can support a total of $N \cdot k$ nodes, where k is the number of ONUs in a ring subnet. As there is no limit on the number of links in the star subnet, the network capacity of the SBRA is virtually unlimited.

While bandwidth is the salient advantage of star networks, the inherent weakness in reliability should be adequately addressed. In the SBRA, we design two distinct wavelength groups in alternate star links cooperating with RNs with self-healing functions to overcome the weakness of the star subnet. We further design B−WADM to manage fiber cut occurrences in the bus subnet. In practice, some signaling schemes should be included in order to recover failures promptly, but are omitted in this paper.

From our CAT structure, the RIN is a critical factor concerned with the maximum number of ONUs in the ring subnet. However, the RIN is indeed not the only critical parameter in the system if the number of active ONUs is large. In this scenario, the nonlinear distortion induced by laser clipping should be taken into consideration [8]. Moreover, laser modulation bandwidth is also a dominant factor for the maximum number of ONUs. In this study, we use commercial FP laser diodes with a modulating bandwidth of about 1 GHz in each ONU. Thus, the downstream signal frequency bandwidth is chosen from 550 MHz to 1.0 GHz, and the upstream signal frequency bandwidth ranges from 80 to 500 MHz, respectively. If 6 MHz is assigned to each subcarrier, more than 70 subcarrier channels are available both in the upstream and downstream directions according to our simulated results.

V. CONCLUSIONS

We have proposed and demonstrated a feasible and flexible architecture for DWDM/SCM passive optical networks with very high capacity and excellent reliability. The SBRA is a three-level network having a star subnet on the upper level to offer virtually unlimited bandwidth, bus subnets on the middle level to transfer multiwavelength signals, and ring subnets on the lower level to link a number of ONUs. We adopt a CAT structure in the ring subnet to eliminate the OBI problem and compensate branch loss. The SBRA demonstrates to be a good combination of those three popular network topologies, being able to support tremendous broadband users. Self-healing functions are designed to overcome fiber cuts in the star and bus subnets to ensure good network reliability. We have further set up an experimental network to demonstrate the feasibility of SBRA. From the results, we believe that the proposed SBRA is a promising architecture for future high-capacity broadband subscriber networks.

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OPEN-HEXAGON TILTED PATCH ANTENNA FOR TERRESTRIAL DIGITAL TV RECEPTION

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ABSTRACT: *Some specific situations for digital TV reception need vertically polarized transmission, and so, vertically polarized antennas. This letter presents a new open-hexagon suspended tilted patch antenna. This element provides medium gain and directivity in a compact format and small size. The proposed antenna is an open-hexagonal patch, tilted 45° relative to the ground plane. The radiation pattern is end fire, and the polarization is orthogonal to the ground plane. This design has been analyzed, built, and measured, showing good performance for the intended use.* © 2001 John Wiley & Sons, Inc. Microwave Opt Technol Lett 32: 56–60, 2002.

Key words: *digital terrestrial television; patch antenna; antenna design; antenna radiation pattern*
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INTRODUCTION

Digital television broadcasting has several advantages if compared to analog technology, such as baseband efficiency, flexibility, and RF performance. Therefore, all broadcasts will eventually fall to the digital wave.

A major catalyst of the digital era is the Digital Video Broadcasting (DVB) project [1, 2]. It is a collaborative project that began in Europe, but now involves a large number of organizations from around the world. Not only has DVB scaled technical heights in digital television systems development, but it has also taught us much about working together to achieve standardization. The DVB has three different specifications: the DVB-T (terrestrial), the DVB-C (cable), and the DVB-S (satellite).

Both analogical and digital terrestrial TV broadcasting signals are usually transmitted in horizontal polarization. Nevertheless, some broadcast transmitting stations use vertical polarization in order to avoid local critical situations such as interference or high attenuation.

A typical case is that found in shadowed areas with no visibility to the transmitting station. A nonexpensive solution is the installation of a retransmitter located in a line-of-sight place, with its receiving horizontally polarized antenna pointed to the transmitter, and its transmitting vertically polarized antenna pointed to the possible subscribers of the service. In this way, a pseudomicrocell is performed.

Another special situation where a vertically polarized antenna is often used is the domestic gap filler. Such a system, which can be defined as an indoor retransmitter, avoids cabling a house or a building. In this case, it is used as a base station for a wireless indoor network. The basis is the use of a typical antenna (horizontally polarized) for outdoor reception, and the installation of a vertically polarized antenna indoors, to provide the signal distribution.

For both situations, the microcell and the domestic gap filler, the proposed hexagonal antenna is intended for use.