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A Modified Optical Add-Drop Multiplexer with Improved Transmission Performance

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Summary

The near-term potential benefits of optical networking will be realized by deployment of reconfigurable optical add-drop multiplexers (OADMs). We propose some modifications on a previously reported all-fiber OADM. These modifications aim to enhance the optical spectral efficiency, modularity and spectral response of the original OADM. Simulations of the OADM and its modified version indicate significant improvements in the transmission performance achieved by the modified OADM, allowing more nodes to be cascaded without the need for intermediate electronic 3R regeneration.

Key words:

Optical add-drop multiplexers, WDM rings, Transparency

1.Introduction

Future optical transport networks are expected to provide a format-independent (transparent) aggregation, routing and management of signals with distinct center frequencies (wavelengths). This transparent optical networking enables the increased utilization of fiber capacity using wavelength division multiplexing (WDM) and provides improves flexibility of service provision by the network operator [1]. Consequently, the "client" layers, such as, IP, ATM or Gigabit Ethernet are placed directly above the newly established optical layer instead of the ubiquitous SDH (or SONET in North America) layer [2, Chapt. 2].

The imminent upgrade of SDH/SONET point-to-point links or rings to corresponding WDM links or rings is to be brought about by the deployment of optical add-drop multiplexers (OADMs) [3], [4]. These optical devices selectively add or drop distinct wavelength tributaries to/from an aggregate WDM stream, at different points along a fiber link (see Figure 1). The add or drop instructions for the OADM can be relayed automatically from a remote location, typically the central-office.

A variety of OADM implementations have been reported [3]. These are based on technologies as diverse as planar lightwave circuits, micromechanical systems or bulk-optics. The inevitable increase in demand for extra bandwidth is usually accommodated by the activation of new wavelength channels. In practice, more components are needed in the OADM to support the new channels, with each added component contributing to the increase in the OADM-induced impairment of the signal. This has raised interest in OADM architectures that maintain the same levels of transmission performance regardless of such throughput increases. From that point view, fiber-based devices have been identified as one of the most promising components for implementing OADMs [3], by virtue of their low loss, polarization independence, ease of coupling, wide operating bandwidths, robustness and high stability. Furthermore, they offer the potential for volume production due to their simple and inexpensive fabrication and packaging requirements

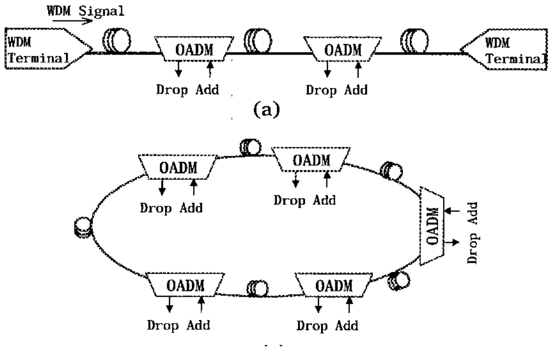

Figure 1 Using OADMs for WDM (a) links and (b) rings.

In this paper, we propose a modified all-fiber, reconfigurable OADM suitable for future optical transport networks. Modifications are carried out on a previously reported all-fiber OADM [5] with the aim of improving its spectral characteristics, modularity and optical spectral efficiency. The transmission performance of the modified OADM is analyzed and comparisons are made with the previously reported OADM. Simulation results indicate a significant improvement in the OADM cascadability performance over the latter case.

2. All-Fiber OADM Architecture

The OADM considered here is based on fiber Bragg gratings (FBGs) that reflect a channel centered at the Bragg wavelength λ_R of the FBG which is determined by

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the grating (fiber core index variation) period Λ_g [6]. The λ_R of these FBGs can be made tunable by varying Λ_g using external forces (stress, strain or bending), magnetic fields or temperature changes [10]. The signals reflected by an FBG are usually dropped off using a three-port optical circulator (OC), which is essentially a passive and non-reciprocal optical device.

In practice, a fixed OADM is permanently configured to add/drop a small fraction of the total tributary channels in the WDM aggregate signal. This fixed OADM can be implemented using fixed apodized FBGs (with low sidelobes) for isolating the channel to be dropped, and, 2 OCs for dropping and adding channels, as shown in Figure 2a. However, in order to add/drop a larger number of channels at a particular location it might be necessary to cascade several OADM modules. A reconfigurable OADM can be implemented using the same arrangement, the only difference being that the FBGs are made tunable (see Figure 2b). Kim *et al* [5] use FBGs that are tuned by stretching the gratings using peizo-electric transducers (PZT) at a rate of 2.4 nm per 100 V. Due to survivability requirements it is preferable that WDM rings are deployed as 2- or 4-fiber shared protection rings (SPRINGs) [2, Chapt. 8]. This means that OADMs used for SPRINGs will need 2 input/output fiber ports. Indeed, this can be viewed as a 2×2 optical cross-connect element that is obtainable from basic single input/output OADMs [7].

Another data-driven approach used to minimize the number of concatenation points is to select large units, such as syllables or words. While this approach allows for excellent voice quality, it results in a large non-scaleable system, and it does not generalize well to new acoustic contexts.

3. Proposed Modifications

We previously proposed the modifications described here, for optical cross-connect nodes that employ FBGs [8]. These modifications are implemented as follows:

Spectral Response: The presence of non-ideal filtering modules in a cascade of OADMs encountered on a signal's path induce performance degrading effects such as intrusive crosstalk and noise components as well as narrowing of the filtering bandwidth. To improve the spectral performance, a fiber Fabry-Perot (FFP) filtering stage is added at the output of the drop OC as shown in Figure 3. This eliminates the out-of-band noise and crosstalk from the dropped signal(s). Moreover, FFPs could sharpen the precision of channel selectivity to the MHz regime. The FFP considered here is of a double-cavity Vernier-tunable ultraselective design with transmission peaks that can be set by adjusting the free spectral range (FSR) of the two filtering stages [9]. This provides crosstalk isolation that is an order of magnitude higher than single-cavity FFP filters and adds more flexible wavelength tunability to the ON-OFF tunability provided by the FBGs. This dual tuning arrangement enables the OADM to drop any arbitrary set of channels from an ITU (International Telecommunications Union) recommended frequency grid.

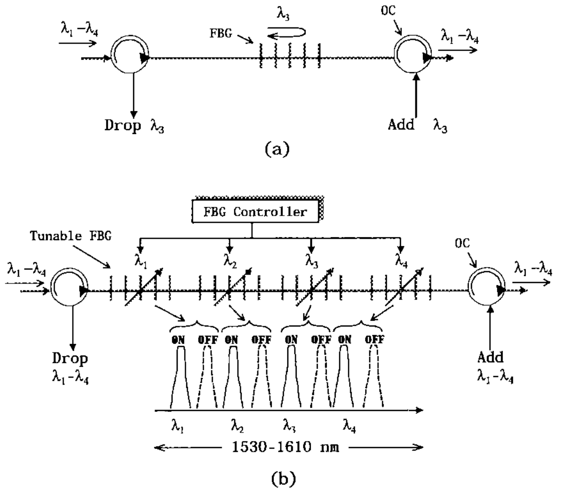

Figure 2 Using FBG for implementing (a) fixed and (b) fully reconifgurable OADMs in 4-channel systems.

Optical Bandwidth Utilization: The utilization of the optical transmission bandwidth by an N-channel system with a Δf channel spacing, can be quantified the optical spectral efficiency $\eta = NB_r/\Delta f$ (bit/s/Hz), where B_r is the common line rate. Due to possible crosstalk interference, frequency drift of optical sources and imperfect receiver or filter tuning, there is a lower bound Δf. Another factor that is likely to limit the minimum spacing is possibility of fortuitous reflections by the FBGs. To illustrate this final point further, consider an FBG with Bragg wavelengths λ_k and $\lambda_k \pm \Delta\lambda_{R,k}$ in its ON and OFF states respectively. It is obvious that $\Delta\lambda$ (Δf in wavelength units) has to be large enough so as to avoid any overlap between the reflection spectrum of an OFF FBG and the co-propagating adjacent channel $\lambda_{k+1} = \lambda_k \pm \Delta\lambda$ as this could cause fortuitous reflections. A rather straightforward solution to this problem, would be to ensure that $\lambda_k \pm \Delta\lambda_{R,k}$ lies outside the 1530-1610 nm transmission window used by amplified WDM systems [1]. Therefore $\Delta\lambda_{R,k}$ should be at least 80 nm, thus eliminating any possibility of overlap with the co-propagating channels. This level of Bragg wavelength shift is currently unattainable using FBGs written on silica fibers [10]. However, FBGs that have been written on plastic or polymer fibers producing polymer Bragg gratings (PBGs) promise longer shifts of their Bragg wavelengths. Strain-tuned polymethylmethacrylate (PMMA) cladded fiber PBGs have demonstrated the wavelength shifts greater than 80nm [11]. This is attributed to the fact that polymer fibers possess strain recovery flexibility that is significantly higher than silica fibers. Other potential advantages of using PBGs is their low cost, tolerance to adverse environmental conditions and back-compatibility with standard FBG fabrication procedures.

Efficient Modularity: The increase in OADM size further accentuates the OADM-induced impairments on the signals they handle [3]. Furthermore, there is a expected deterioration in node dependability (availability performance and its influencing factors) and increased running costs that limit the potential returns on the investment of the added components [12]. Additional concerns for the OADM considered here, is the increase in number of (F)PBGs on the signal's path. The leads to the gradual narrowing of the filter bandwidth and the successive dispersion of pass-through channels due to the out-of-band dispersion properties of FBGs which more severe than standard singlemode fibers [13]. Optical (or wavelength) granularity has been proposed to reduce the rate at which optical nodes grow with channel count [14]. The essence of this technique is that the demands between each node pair are pre-assigned G adjacent wavelength slots thus enabling them to be routed as group instead of individual wavelength channels. As a result, each (F)PBG's reflection band is made to simultaneously reflects G channel tributaries. This implies that only $\lceil N/G \rceil$ ($\lceil \bullet \rceil$ is a ceiling function that rounds towards $+\infty$) tunable PBGs are needed in each OADM—instead of the N FBGs used in [5]—as shown in Figure 3.

4. Performance Comparison

Modeling of the transmission performance of original and modified OADMs is carried out using VPItransmissionMaker™, a wavelength-domain optical simulator running on a Windows™ NT platform [15]. A 4-channel WDM system using the intensity modulated-direct detection (IM/DD) scheme is assumed, the bit rate per channel set at 2.5 Gbit/s (2^{23}-1 PRBS, NRZ). The channels are spaced at 100 GHz and range from 192.95 to 193.25 THz (corresponding to f_1—f_4). The simulation configuration is based on an optical circulating loop consisting of the OADM under test and a total loop length of 35 km (SMF and DCF of 30 and 5.33 km respectively) as illustrated in Figure 4. Others parameters for the components of Figure 4 are listed in Table 1.

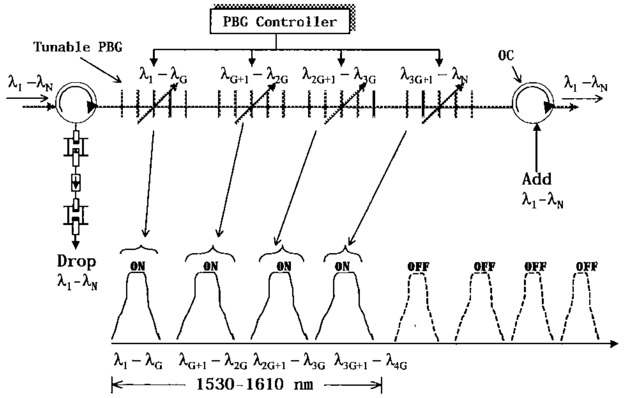

Figure 2 The modified OADM for N-channel systems.

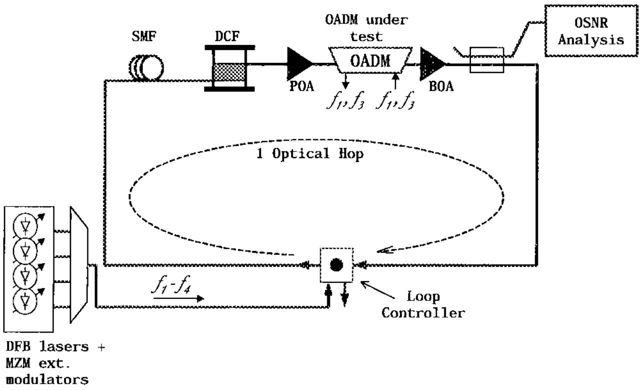

Figure 4 Block diagram of simulation setup to determine transmission performance of cascaded OADMs

The optical signal to noise ratio (OSNR) performance of f_1 for up to 30 loop cycles (30 cascaded OADMs and 1050 km of fiber) is shown in Figure 4. If the signal quality acceptance level is set at OSNR 20 dB to maintain a bit error rate (BER) of $<10^{-12}$, over 30 and 20 OADMs can be traversed—without electronic 3R regeneration—for systems using the original and modified OADM respectively (see Figure 5).

Table 1 Simulation parameters for different components

Parameter	*Value*
DFB [power, linewidth]	[0dBm, 12MHz]
MZM extinction ratio	30 dB
FBG [loss, reflectivity]	[0.1 dB, 99%]
PBG [loss, reflectivity]	[1.0 dB, 90%]
OC [loss, isolation]	[1, 40] dB
Loss [SMF, DCF]	[0.2, 06] dB/km
Dispersion[SMF, DCF]	[16, -90] ps/nm.km
POA [gain, noise figure]	[9.2, 6] dB
BOA [gain, noise figure]	[variable, 4] dB

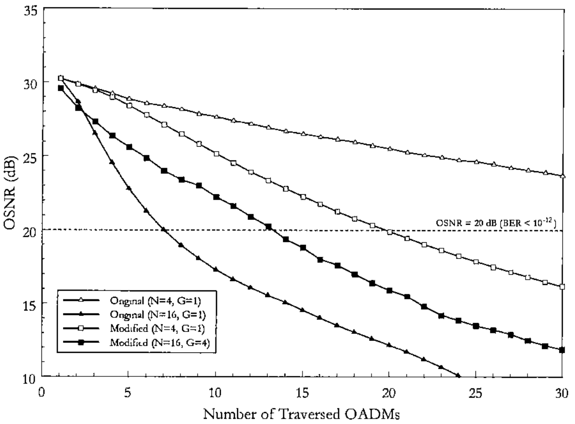

Figure 5 The simulated OSNR for up to 30 traversed original and modified OADMs.

However, if the number of channels for each demand is quadrupled, only 7 OADMs are traversable, since the number of FBGs on the signal's path is also quadrupled as quadrupled as illustrated in Figure 5. Now, considering a case where the modified OADM is used and assuming that *G*= 4, the number of traversable OADMs is now 13. This can be explained by the fact that the number of PBGs on the signal's path remains the same and the main difference is that wideband PBGs are used instead to simultaneously reflect 4 channels.

5. Conclusions

Modifications for FBG-based OADMs have been proposed. Simulations of two separate systems using the original and modified OADMs were carried. It is noted that the original OADMs offer a better performance when the channel count is low. However, for high channel counts, the modified OADMs offer less penalties, thus relatively more OADMs could be traversed without the need for electronic 3R regeneration.

Better results are expected with improvement in the performance (e.g., loss, spectral response, reflectivity etc.) of the PBGs used in the modified OADM. Moreover, the use of PBGs should enable the OADMs to exploit the wide bandwidths that are to opened up by the use of novel fiber designs and expanded optical amplification windows [1].

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