TRANSMISSION PERFORMANCE EVALUATION OF OPTICAL ADD DROP MULTIPLEXERS (OADMs) in OPTICAL TELECOMMUNICATION RING NETWORKS

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Abstract. In the present paper, optical add drop multiplexers (OADMs) for Ultra Wide Wavelength division multiplexing (UW-WDM) in optical telecommunication ring networks have been modeled and parametrically investigated over wide range of the affecting parameters. Moreover, we have analyzed the flexible configuration changes as well as higher capacity and maximum possible transmission bit rates. Also in the same way, we have developed OADMs, which are capable of dealing with one to several channels arbitrarily selected. Finally, the performance characteristics of the OADMs are taken as the major interest in optical access ring networks to handle maximum distributed transmission bit rates per optical channel for the maximum supported users.

Keywords: Access optical networks, OADMs, Semiconductor Optical amplifier (SOA), SMF, and Ring network.

Introduction

The optical add-drop multiplexer is one of the key components for dense wavelength division multiplexing (DWDM) and ultra wide wavelength division multiplexing (UW-WDM) optical networks. The OADM is used for selectively dropping and inserting optical signals into a transparent DWDM network. Several wavelength OADMs have been proposed based on arrayed wave-guide gratings (AWG), Fabry-Perot filters, combination of dielectric thin film MUX and DEMUX [1] and Bragg gratings written in Mach-Zhender interferometers. We have proposed a more simple, cost effective, flexible, easily upgrade and transparent configuration, using a fiber Bragg grating (FBG), an optical circulator, a power combiner and a mechanical – optical switch. The introduction of optical add drop multiplexers into optical networks allows traffic to be inserted, removed and, most importantly, bypassed. Additionally, functions such as protection, drop/continue, loop-back and wavelength reuse of the optical channels can be supported by the OADM [2]. Wavelength reuse means that the dropped channel does not pass through to the next OADM. Instead a new channel of the same wavelength can be added. Drop and continue means that the channel is both dropped at the node but also allowed to pass through to the next OADM. Depending on, which network the OADM should be used in, different requirements are set,
based on cost, capacity, redundancy and flexibility. OADMs can be realized in various technologies [3]. From a transmission point of view OADMs can be classified into notching and demultiplexing. The DMUX based solution separates all the incoming wavelengths and then combines them again after dropping and adding wavelengths. The crosstalk component at the OADM output port originates from poor suppression of the drop channel (assumed wavelength reuse), which leads to interferometer crosstalk. Similar to the optical time multiplexing (OTM), the OADM can be divided into a single port with static wavelength assignment, a single port with dynamic wavelength assignment and a multi port with static and dynamic wavelength assignment. The single port with static wavelength assignment is mainly used in hubbed structures, where the OADMs are connected to a central hub, e.g. in the metropolitan network [4]. In order to utilize network resources in a more efficient way, the OADMs with dynamic wavelength assignment are preferred when traffic variations are comparable to network capacity. The multi port OADMs can be utilized when the network is characterized by a uniform traffic distribution and high capacity.

Recently, optical networks have been introduced commonly to satisfy the rapid increase of traffic demands. In addition to the high capacity characteristics of optical fibers, WDM technologies provide more bandwidth per fiber, and are used in core backbone networks, metropolitan area networks (MANs), and regional area networks. In the MANs and regional networks [5], wavelength routing capability in WDM networks is also investigated as well as the effective use of the high capacity. In the wide area networks (WANs) and MANs to connect buildings and offices for business use, the wavelength routing capability should be used more effectively than others. The design procedures for the wavelength-routed networks have been investigated. The design issues include how many wavelengths are required to connect nodes to satisfy the traffic demands with low blocking probability, and to minimize the required node system scale [6].

In the present work, the transmission performance evolution characteristics of the OADMs are investigated and parametrically analyzed over wide range of the affecting parameters for UW-WDM in telecommunication ring optical networks to handle the maximum transmission bit rates and higher capacity for the maximum number of the supported subscribers.
Simplified UW-WDM Passive Optical Network Architecture Model

The enormous growth in the demand of bandwidth is pushing the utilization of fiber infrastructures to their limits. To fulfill this requirement the constant technology evolution is substituting the actual signal wavelength systems connected in a point to point technology by dense wavelength division multiplexing (DWDM) systems, creating the foundations for the optical transport network (OTN). The objective is the deployment of a optical network layer with the same flexibility because it is more economical and allows a better performance in the bandwidth utilization. Optical add drop multiplexers are the simplest elements to introduce wavelength management capabilities by enabling the selective add and drop of optical channels. UW-WDM networks with a static OADMs may provide a reliable, cost effective and scalable network, since the static OADMs are based on low loss, low cost passive devices and does not need any power supply [7]. As shown in Fig. 1, multiplexer is combined all optical signals from laser diodes in to a light beam and is directed to single mode fiber (SMF) link and then to be amplified through semiconductor optical amplifier (SOA). OADMs play an important role to increase or decrease the channels capacity and then directed to the demultiplexer which divides the light beam in to different optical channels adjustable at different specific wavelengths and then directed to optical network units (ONUs) and finally directed to the minimum or maximum number of supported users depend on the process of add or drop multiplexing.
Simplified Optical Add Drop Multiplexers (OADMs) Module

Fig. 2. Simplified Architecture of OADMs with SMF Link Carrying N Wavelengths.

Figure 2 shows the basic schematic view of the OADMs with a single input/output fiber link that carries N different wavelength channels. At the input fiber the incoming optical signal comprising a total of N wavelength $\lambda_1$, $\lambda_2$, ………., $\lambda_N$ is preamplified by means of an optical amplifier. A good choice for an optical amplifier is the so-called semiconductor optical amplifier (SOA). A single SOA is able to amplify multiple UW-WDM wavelength channels simultaneously. After optical preamplification the UW-WDM wavelength signal is portioned into N separate wavelengths by using a 1 x N demultiplexer (DEMUX). In general, some bypass wavelengths $\lambda_{bypass}$ remain in the optical domain and are thus able to optically bypass the local node. The remaining wavelengths $\lambda_{drop}$ are dropped by means of optical to electrical conversion (OE) for electronic processing and/or storing at the local node. In doing so, the dropped wavelengths become available. The local node may use each of these freed wavelengths to insert local traffic on the available added wavelengths $\lambda_{add}$. Note that the dropped wavelengths $\lambda_{drop}$ and added wavelengths $\lambda_{add}$ operate at the same optical frequency but carry different traffic (locally dropped or added traffic respectively). Subsequently, all N wavelengths are combined onto a common outgoing fiber by using an N x 1 wavelength multiplexer. The composite optical UW-WDM combined signal may be amplified by using another optical amplifier at the output fiber (e.g., OSA).

Model and Equations Analysis

Optical add drop multiplexers (OADMs) are used to provide flexibility and scalability to optical networks. OADMs allow customers to optimize the use of existing fiber by adding or dropping channels on a per-site basis, thereby maximizing fiber bandwidth. OADMs can be deployed into a UW-WDM system or network for added signal grooming flexibility. OADMs allow you to add or drop channels from a fiber that is wavelength division multiplexed. OADMs are installed in a multi-wavelength fiber span, and allow a specific wavelength on the fiber to be demultiplexed (dropped) and remultiplexed (added) while enabling all other wavelengths to pass. Crosstalk is a
major problem, the crosstalk arises from mixing of a received signal wave on the photodetector, originating an interference beat noise locally at the receiver. In the case of these OADM configuration a heterodyne crosstalk is induced between the drop signal and the leakage of the remaining input signals at different wavelengths. In-band crosstalk added to wavelength channels at any node should be reduced in order to allow cascadability of nodes which is an important requirement in optical transport networks based on ring and mesh topologies. The in-band crosstalk is usually caused by a non-ideal isolation of the switches and the wavelength filters (MUX and DeMUX). The impact of crosstalk is quantified by the power penalty parameter, which is commonly defined as the additional optical power required at the receiver in order to maintain a given bit error rate (BER). The optical received power can be calculated by the following equation [8] as:

\[ P_{\text{received}} = -10 \log(1 - \text{crosstalk}) , \]  

(1)

Another type of crosstalk is the homodyne crosstalk induced between the add signal and the leakage of the drop signal at the same wavelength. The received optical power can be expressed in another form in terms of crosstalk and signal to noise ratio (SNR) as follows:

\[ P_{\text{received}} = -10 \log(1 - (\text{SNR})^2 \cdot \text{crosstalk}) , \]  

(2)

The bit error rate (BER) essentially specifies the average probability of incorrect bit identification. In general. The higher the received SNR, the lower the BER probability will be. For most PIN receivers, the noise is generally thermally limited, which independent of signal current. The bit error rate (BER) is related to the signal to noise ratio (SNR) as follows [8]:

\[ \text{BER} = \frac{1}{2} \left[ 1 - \text{erf} \left( \frac{\text{SNR}}{2 \sqrt{2}} \right) \right] , \]  

(3)

Where erf represents the error function. For SNRs \( \geq 16 \) (\( \approx 12 \) dB), the BER can be approximately by:

\[ \text{BER} \approx \frac{2}{\pi \cdot \text{SNR}} \exp \left( -\frac{\text{SNR}}{8} \right) . \]  

(4)

In active optical networks, the number of users which can be supported will be limited by split loss of insertion loss (crosstalk) of add-drop multiplexing. While UW-WDM will be providing large bandwidth, to use effectively the network need to support large number of users. This can be done by placing the optical amplifiers appropriately. In computation, one of the most thing is the loss model. If the transmitted power (\( P_T \)) and semiconductor optical amplifiers (OSAs) are not there between central office (CO) and receivers for which BER is computed, the loss in dB between transmitter and receiver, assuming that the receiver is in \( i^{th} \) group starting from CO is given by [9]:

\[ \text{loss} = \text{loss between CO and } i^{th} \text{ group} . \]  


\[ \text{Loss}_{\text{TR}} = L_W + i \alpha L + (i-1)L_m + L_d + 10 \log_{10} n \]  

Where \( L_W \) is the insertion loss of the wavelength multiplexer at CO, \( \alpha \) is fiber attenuation per unit length, \( L \) is the length of the fiber between two consecutive OADMs, \( L_m \) is the insertion loss of the OADMs, \( L_d \) is the insertion loss for drop signal in OADM, and \( n \) is the number of supported users in the system group. The loss between transmitter at CO and first OSA is used to find the input power to OSA. If the first OSA is placed before \( i^{th} \) group, the loss between transmitter and first OSA is [9]:

\[ \text{Loss}_{\text{OSA}} = L_W + i \alpha L + (i-1)L_m \]  

If the two consecutive amplifiers are placed before \( i^{th} \) and \( j^{th} \) OADM respectively, then the loss (in dB) between them is given by the following expression [9]:

\[ \text{Loss}_{\text{OSA+OADM}} = (j-1)L_m + (j-i)\alpha L \]  

Further loss in dB between a receiver in \( l^{th} \) branch and nearest amplifier (which is before \( t^{th} \) OADM) is given by the following equation [9]:

\[ \text{Loss}_{\text{OADM+R}} = (t-1)L_m + L_d + (t-t)\alpha L + 10 \log_{10} n \ , (at \ t = b) \]  

Here \( b \) is the total number of nodes or point links in the passive optical network system.

Fig. 3. Simplified Architecture of 2-Port OADM.  
Fig. 4. Simplified OADM in Optical Ring Network.

By using MATLAB curve fitting program, we can fit the relationship between the optical received power and BER for the added and dropped signal at different lengths of the fiber cable as follows [7]:
BER = 0.0035 - 0.0754 P_{received} + 1.072 P_{received}^2 - 0.976 P_{received}^3 \quad \text{(For added signal)}, \quad (9)

BER = 0.136 + 0.763 P_{received} - 4.098 P_{received}^2 - 1.584 P_{received}^3 \quad \text{(For dropped signal)}, \quad (10)

As shown in Fig. 3, the block diagram of OADMs of 2-port, which introduced two types of restoration mechanism to be implemented in ring/mesh optical networks by means of linear/multiplex protection and ring protection as shown in Fig. 4. In the same by means of MATLAB curve fitting program, the result of the relationship between maximum number of nodes, b, and the total number of channels, N_{Ch} for two and four ports of OADMs as follows [10]:

\[
\text{Number of nodes}(b) = 3.09 - 7.253 N_{Ch} + 5.9 N_{Ch}^2 - 0.086 N_{Ch}^3 \quad \text{(For 2-port OADM).} \quad (11)
\]

\[
\text{Number of nodes}(b) = 1.18 + 5.86 N_{Ch} - 9.74 N_{Ch}^2 - 1.063 N_{Ch}^3 \quad \text{(For 4-port OADM).} \quad (12)
\]

According to modified Shannon theorem, the maximum bit rate per optical channel for supported number of users, or the maximum capacity of the channel for maximum subscribers is given by [11]:

\[
\text{Channel capacity}(C) = BW_{sig} \cdot \log_2 (1 + \text{SNR}) \quad \text{Gbit/sec} \quad (13)
\]

Where SNR in the above equation in the absolute (not in dB), therefore, the expressed (SNR)_{dB} as:

\[
\text{SNR}_{dB} = 10 \cdot \log_{10} \text{SNR}. \quad (14)
\]

Simulation Results and Discussions

The optical add-drop multiplexer (OADM) is one of the key components for UW-WDM in passive optical ring networks. The OADM is used for selectively dropping and inserting signals into a transparent UW-WDM. Therefore, in the present study, we have investigated and analyzed the evolution of the performance characteristics of the OADMs, moreover OADMs are taken as the major interest in optical networks to handle transmission bit rates and maximum transmission distances for the supported users at the assumed set of parameters as shown in Table 1.

Table 1: Proposed parameters in the designed ring optical network model.

<table>
<thead>
<tr>
<th>Operating parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmitted power, P_T</td>
<td>50 mWatt–200 mWatt</td>
</tr>
<tr>
<td>Desired bit error rate, BER</td>
<td>10^{-9}</td>
</tr>
<tr>
<td>Losses in SMF</td>
<td>0.2 dB/km</td>
</tr>
<tr>
<td>Insertion loss for dropping signal</td>
<td>0.5 dB/km</td>
</tr>
<tr>
<td>Parameter</td>
<td>Value</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td>------------------------------</td>
</tr>
<tr>
<td>OADM, $L_d$</td>
<td>0.7 dB/km</td>
</tr>
<tr>
<td>Insertion loss for passing signal in OADM, $L_m$</td>
<td></td>
</tr>
<tr>
<td>Operating signal wavelength range, $\lambda_s$</td>
<td>1.45 $\mu$m–1.65 $\mu$m</td>
</tr>
<tr>
<td>Number of users per each node, $n$</td>
<td>32</td>
</tr>
<tr>
<td>Number of channels range, $N_{ch}$</td>
<td>600–2400</td>
</tr>
<tr>
<td>OSA gain range</td>
<td>20 dB–40 dB</td>
</tr>
<tr>
<td>OSA optical power range</td>
<td>0.05 mWatt–1 mWatt</td>
</tr>
<tr>
<td>Optical signal bandwidth range, $BW_{sig}$</td>
<td>6.8 MHz–8 MHz</td>
</tr>
<tr>
<td>Optical received power, $P_{received}$</td>
<td>1.5 mWatt–3.5 mWatt</td>
</tr>
<tr>
<td>Number of nodes range, $b$</td>
<td>20–120</td>
</tr>
</tbody>
</table>

Based on the proposed parameters as shown in Table 1, and the results of the set of the series of the figs. (5-17), the following facts are assured as follows:
Fig. 5. Variations of the bit error rate with the optical received power for drop multiplexing technique at the assumed set of parameters.

Fig. 6. Variations of the bit error rate with the optical received power for add multiplexing technique at the assumed set of parameters.

Fig. 7. Variations of the signal to noise ratio with the optical received power for drop multiplexing technique at the assumed set of parameters.
Fig. 8. Variations of the signal to noise ratio with the optical received power for add multiplexing technique at the assumed set of parameters.

Fig. 9. Variations of the bit error rate with the optical received power for 80 km fiber cable length at the assumed set of parameters.

Fig. 10. Variations of the bit error rate with the optical received power for 20 km fiber cable length at the assumed set of parameters.
Fig. 11. Variations of the optical received power with the optical transmitted power for different fiber cable lengths at the assumed set of parameters.

Fig. 12. Variations of the optical received power with the optical transmitted power for different fiber cable lengths at the assumed set of parameters.

Fig. 13. Variations of the maximum number of nodes in the network with the number of channels at the assumed set of parameters.
Fig. 14. Variations of the number of supported users in the network with the number of channels at the assumed set of parameters.

Fig. 15. Variations of the number of supported users in the network with the number of channels at the assumed set of parameters.

Fig. 16. Variations of maximum bit rate/channel with the signal to noise ratio for optical add multiplexing at the assumed set of parameters.
i) As shown in Figs. (5, 6), as the optical received power increases, the bit error rate (BER) decreases in the both cases of add and drop multiplexing. But in the case of drop multiplexing presents a higher BER than the add multiplexing case. Moreover, with the signal crosstalk, the BER presents higher values than the signal without crosstalk.

ii) Figs. (7, 8) have indicated that as the received optical power increases, the signal to noise ratio (SNR) also increases in the both cases of add and drop multiplexing. But in the case of drop multiplexing presents a lower SNR than the add multiplexing technique. Moreover, with the signal crosstalk, the SNR presents lower values than the signal without crosstalk.

iii) As shown in Figs. (9, 10), as the optical received power increases, the BER decreases in the both cases of added and dropped signals. But in the case with 80 km fiber cable length presents higher BER than in the case of 20 km fiber cable length for both cases of added and dropped signals.

iv) Figs. (11, 12) have demonstrated that as the optical transmitted power increases, the optical received power also increases at the same fiber cable length. While as the fiber cable length increases, the optical received power decreases at the same optical transmitted power. But with the optical semiconductor amplifiers (SOAs) presents higher transmission distance for optical signals.

v) Fig. (13) has indicated that as the number of channels increases, the maximum number of nodes in the network decreases for both 2-port and 4-port OADMs. But with 2-port OADM presents the maximum number of nodes than 4-port OADM.

vi) As shown in Figs. (14, 15), as the number of channels increase, the number of supported users are also increase in the both cases of 2-port and 4-port OADMs. But with presence of OSA in the network system help us to increase number of supported users to approximately ≈ 1000 users.
vii) Figs. (16, 17) have assured that as the SNR increases, the maximum bit rate/channel increases at the same optical signal bandwidth for both cases of OAM, and ODM techniques. In the same way, as the optical signal bandwidth increases, the maximum bit rate/channel also increases at the same SNR for both cases of OAM, and ODM techniques. But in the case of the presence of OAM technique presents higher bit rate/channel than the ODM technique.

Conclusions
In a summary, we have demonstrated that the OADMs are the simplest elements to introduce wavelength management capabilities by enabling the selective add and drop of optical channels. We have concluded that the increased optical received power, the lower BER, the higher SNR for both the cases of add and drop signals. Also, we have demonstrated that the increased fiber cable length, the higher BER for both add and drop signals. Moreover, the presence of OSA and OADM (2 or 4-ports) presents long transmission distances up to 80 km with the increased optical received power and the increased number of supported users up to approximately ≈ 1000 users. Moreover as well as we have assured that in the presence of OAM or ODM techniques, the maximum distributed transmission bit rates per channel per supported users is approximately between (6-10 Gbit/sec).

References


