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Optical Add Drop Multiplexers with UW-DWDM Technique in Metro Optical Access Communication Networks

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Abstract—**In the present paper, optical add drop multiplexers (OADMs) with ultra wide dense wavelength division (UW-DWDM) multiplexing technique in metro optical communication 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 transmission bit rates for the maximum supported users.**

***Index Terms*—Access Optical Networks, OADMs, Optical Amplifier (OA), SMF, UW-DWDM and Metro Access Network**

I. 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. The proposed 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 adds 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.

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 [2]. 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 [3]. 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 [4].

Future optical data transmission will change from todays point to point connections towards transparent meshed optical networks. At the same time the increasing bandwidth demand will require much higher transfer capacities per fiber than current ones. It is still an open issue whether the increase of capacity will be accomplished by a higher number of wavelengths per fiber or by higher bit rates per wavelength or most probably a combination of both. 160 Gb/s optical time domain multiplexing (OTDM) is a promising candidate for cost effective optical networks. For data rates of 80, 160 Gb/s or more per wavelength OTDM has to be applied since electronic processing is not possible yet for such high data rates. However, the flexibility of transparent optical networks which will be implemented for the wavelength multiplexing technology (WDM) within the next years should be conserved when introducing OTDM in addition to the WDM technology [5].

This implies the need of additional optical elements in the network: time domain add-drop multiplexers (TD-ADMs). In an OTDM add-drop node a low-bit rate single data channel has to be separated (drop function) from an incoming high-bit rate data stream. Simultaneously, the remaining data channels have to be left undisturbed (through function) and the time slots of the dropped channels have to be depleted sufficiently [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.

II. 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 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 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 link and then to be amplified through semiconductor optical amplifier. 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 [6].

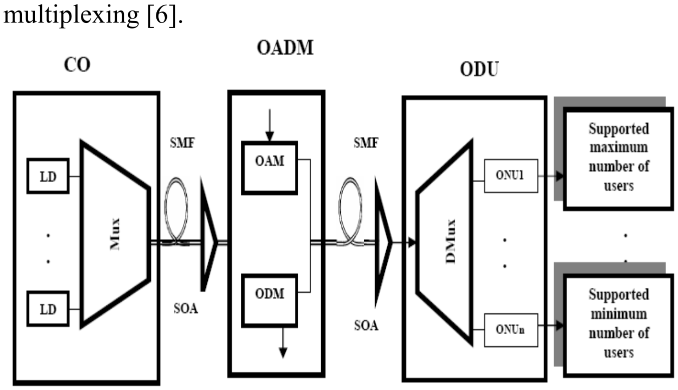


Fig. 1. UW-WDM passive optical network architecture model

A. Optical Add Drop Multiplexers

The main function of an optical multiplexer is to couple two or more wavelengths into the same fiber.

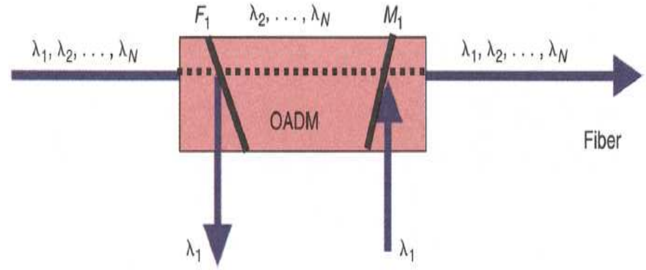


Fig. 2. The optical add-drop multiplexer is a DWDM function

If a demultiplexer is placed and properly aligned back-to-back with a multiplexer, it is clear that in the area between them, two individual wavelengths exist. This presents an opportunity for an enhanced function, one in which individual wavelengths could be removed and also inserted. Such a function would be called an optical wavelength drop and add demultiplexer/multiplexer-and for brevity, optical add-drop multiplexer. OADM is still evolving, and although these components are relatively small, in the future, integration will playa key role in producing compact, monolithic, and cost-effective devices [6].

B. Main Function of OADMs

The OADM selectively removes (drops) a wavelength from a multiplicity of wavelengths in a fiber, and thus from traffic on the particular channel. It then adds in the same direction of data flow the same wavelength, but with different data content. The model of an OADM, for wavelength λ_1, is schematically shown in Fig. 2, where F_1 signifies a filter selecting wavelength λ_1 while passing through all other wavelengths, and M_1 signifies a multiplexer that multiplexes all wavelengths [6].

A better view of OADM function is shown in Fig.3. This function is especially used in WDM ring systems as well as in long-haul with drop-add features. OADMs are classified as fixed-wavelength and as dynamically wavelength selectable OADMs. In fixed-wavelength OADM, the wavelength has been selected and remains the same until human intervention changes it. In dynamically selectable wavelength OADM, the wavelengths between the optical demultiplexer/multiplexer

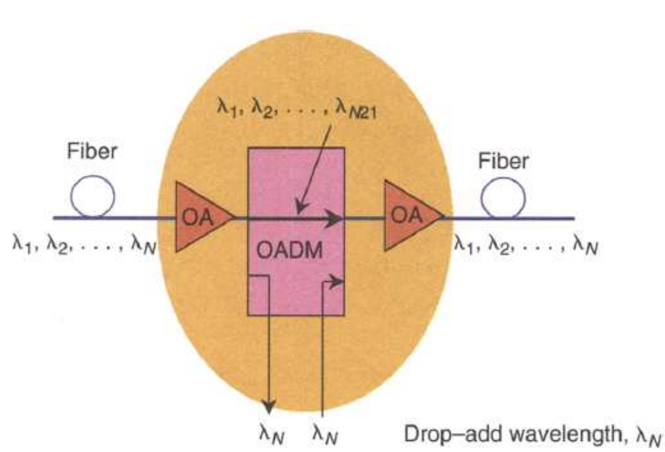


Fig. 3. The main function of optical add-drop multiplexer

may be dynamically directed from the outputs of the demultiplexer to any of the inputs of the multiplexer [7].

III. DEVICE MODELING ANALYSIS

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 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. By using MATLAB curve fitting program, the fitting the relationship between the optical received power and bit error rate (BER) for the added and dropped signal at operating wavelength λ=1.55 μm) can be expressed as [7]:

$$BER = 0.0001\, x P_R^2 - 0.1077\, x P_R^1 + 0.4969\, x 10^{-9} , \quad (1)$$

The received power from each channel, P_R can be expressed as a function of transmitted power per channel, P_T and fiber loss (α) in dB/km, and transmission distance in km as:

$$P_R = P_T\, x 10^{(-\alpha L/10)} , \quad (2)$$

Moreover the optical signal to noise ratio (OSNR) of the system after amplification can be:

$$OSNR = \frac{\lambda_s P_T}{2h\ c\ B.W_{sig.}} , \quad (3)$$

Where h is the Planck's constant (6.02 $x10^{-34}$ J.sec), c is the speed of light ($3x10^8$ m/sec), λ_s is the operating signal wavelength in μm, $B.W_{sig.}$ is the signal bandwidth. The refractive-index of silica-doped fiber link based on empirical equation is given by [9]:

$$n = \sqrt{1 + \frac{A_1\lambda^2}{\lambda^2 - A_2^2} + \frac{A_3\lambda^2}{\lambda^2 - A_4^2} + \frac{A_5\lambda^2}{\lambda^2 - A_6^2}} , \quad (4)$$

The coefficients of empirical equation is cast as in Ref. [3]. These coefficients are a function of T, T_0, and x. Where T is the ambient temperature in ºC, T_o is considered as room temperature (25 ºC), and x is the ratio of germanium dopant added to silica fiber to improve its optical performance characteristics within the range of $0.0 \le x \le 0.3$. Then the first and second differentiation of Eq. (4) w. r. t operating wavelength λ yields as in Ref. [3]. The total pulse broadening for optical system is the square root of the sum of the squares of the transmitter rise time, receiver rise time, delay due to chromatic dispersion, and total pulse broadening due to polarization mode dispersion . That is given by [10]:

$$\tau_{sys} = \sqrt{\tau_{tr}^2 + \tau_{cd}^2 + \tau_{PMD}^2 + \tau_{rc}^2} , \quad (5)$$

Where τ_{tr} is the transmitter rise time or pulse broadening, τ_{rc} is the receiver rise time which is given by the following equation in case of using none return to zero (NRZ) code:

$$\tau_{rc} = \frac{0.7}{B_r} , \quad (6)$$

Where B_r , is the receiver bandwidth. τ_{cd} is the delay due to chromatic dispersion, which is given by the following equation:

$$\tau_{cd} = \tau_{mat} + \tau_{wg} , \quad (7)$$

For the step index single mode fiber waveguide dispersion, τ_{wg} is relatively small, so in this case the delay due to the chromatic dispersion equals the delay due to the material dispersion $\tau_{mat.}$ Which is given by the following [11]:

$$\tau_{mat.} = L\, \Delta\lambda\, |D_{mat}| , \quad (8)$$

Where Δλ is the spectral line width of the optical source in nm, and D_{mat} is the absolute value for material dispersion coefficient Which is given by:

$$D_{mat.} = -\left(\frac{\lambda_s}{c}\right) \cdot \left(\frac{d^2 n}{d\lambda^2}\right) , \quad (9)$$

The total pulse broadening due to polarization mode dispersion (PMD) τ_{PMD}, can be expressed as [12, 13]:

$$\tau_{PMD} = D_{PMD}\sqrt{L} , \quad p\sec/\sqrt{km} \quad (12)$$

Where D_{PMD} is Polarization mode dispersion parameter, and L is the transmission distance.

The maximum transmit power per channel, as a function of fiber link length can be expressed as [14]:

$$P_T = \frac{4\times 10^4}{N_{ch}(N_{ch}-1)\,\Delta\lambda_s\, L} , \quad (13)$$

Where N_{ch} be the number of transmitted channels, and $\Delta\lambda_s$ be the channel spacing in nm. For single mode fiber, the transmitted signal bandwidth can be determined as [15]:

$$B.W_{sig.} = \frac{0.7}{\tau_{sys}} , \quad (14)$$

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 [16]:

$$B_{Sh} = B.W_{sig.} \log_2(1 + OSNR), \quad (15)$$

Where OSNR in the above equation in the absolute, therefore, the expressed $(OSNR)_{dB}$ as follows:

$$OSNR_{dB} = 10.\log_{10} OSNR , \quad (16)$$

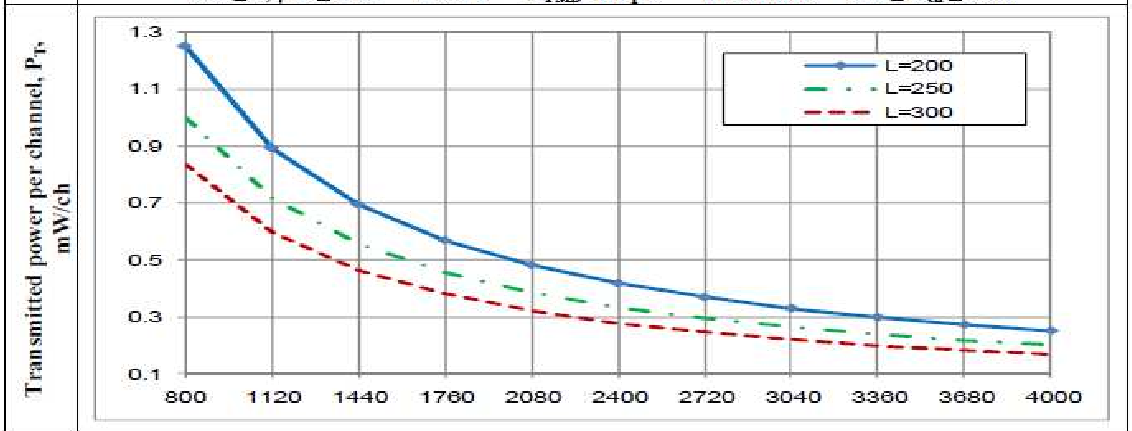
As well as the Shannon transmission bit rate distance product can be determined by [17]:

$$P_{Sh} = B_{Sh}\ L , \quad (17)$$

IV. SIMULATION RESULTS AND DISCUSSIONS

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.

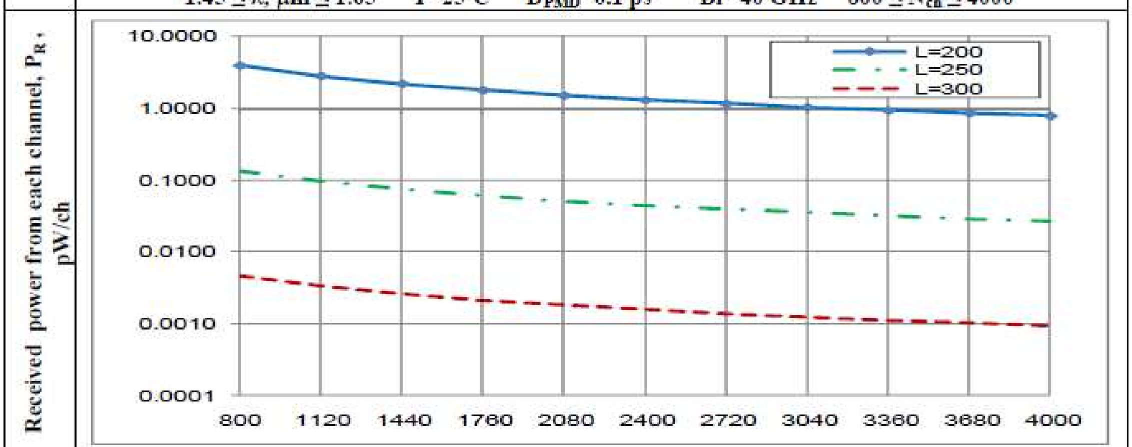
$1.45 \leq \lambda$, µm ≤ 1.65 T=25°C D_{PMD}=0.1 ps Br=40 GHz $800 \leq N_{ch} \leq 4000$



Number of transmitted channels, N_{ch}

Fig. 4. Variation of number of transmitted channels, N_{ch}, against variations of transmitted power per channel , P_T, mW/ch.

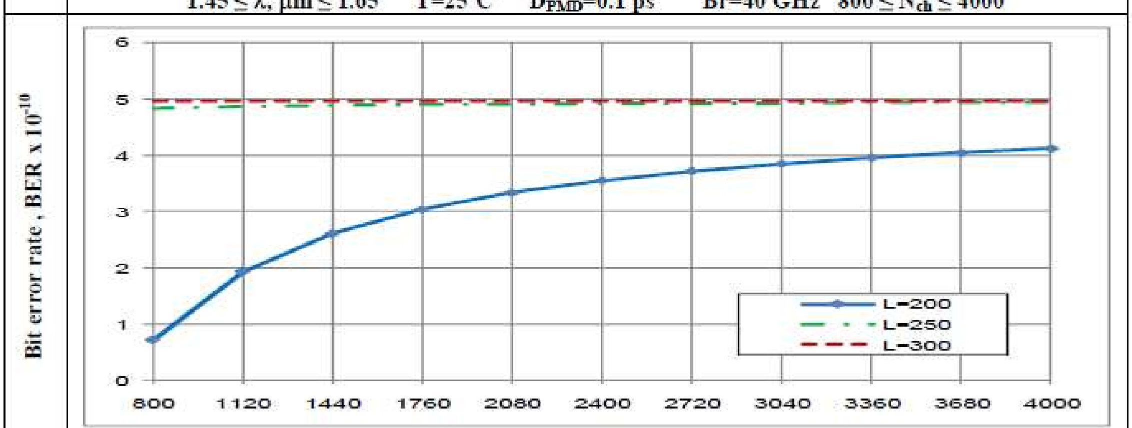
$1.45 \leq \lambda$, µm ≤ 1.65 T=25°C D_{PMD}=0.1 ps Br=40 GHz $800 \leq N_{ch} \leq 4000$



Number of transmitted channels, N_{ch}

Fig. 5. Variation of number of transmitted channels, N_{ch}, against variations of received power from each channel, P_R, pW/ch.

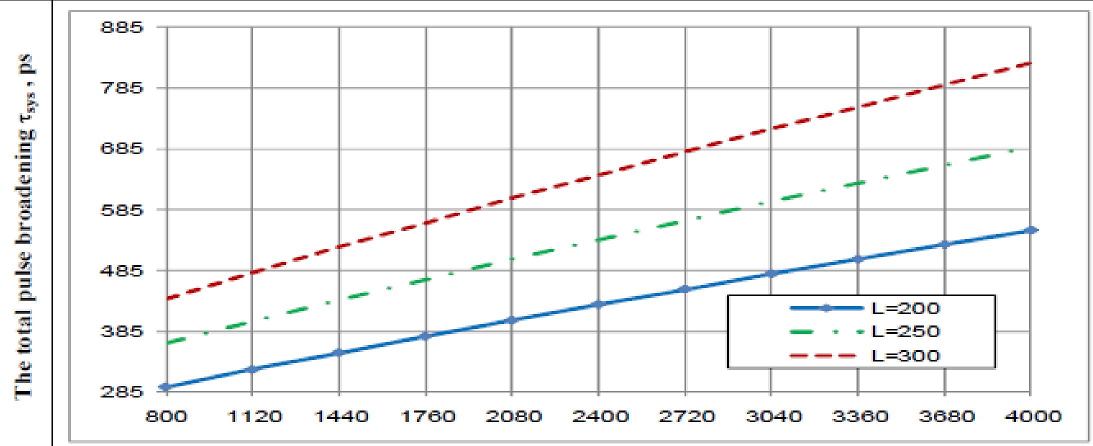
$1.45 \leq \lambda$, µm ≤ 1.65 T=25°C D_{PMD}=0.1 ps Br=40 GHz $800 \leq N_{ch} \leq 4000$



Number of transmitted channels, N_{ch}

Fig. 6. Variation of number of transmitted channels, N_{ch}, against variations of bit error rate , BER.

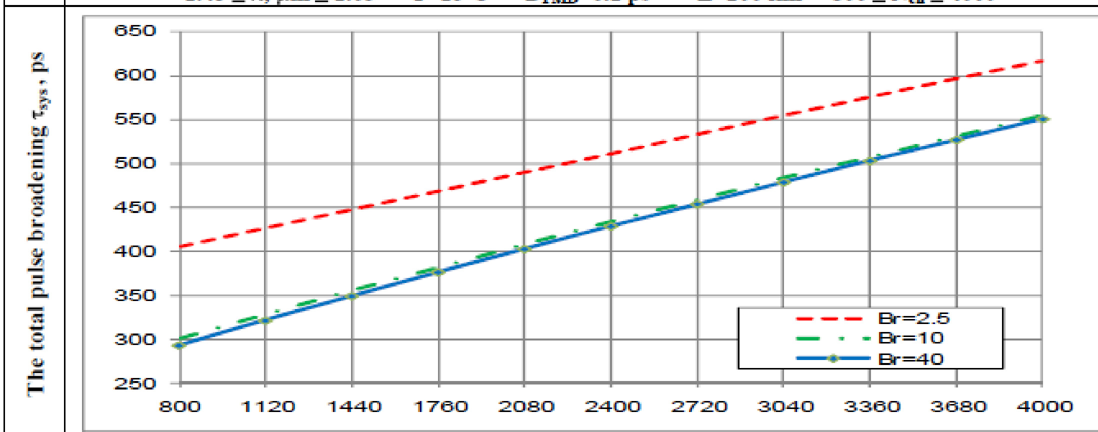
$1.45 \le \lambda, \mu m \le 1.65$ T=25°C D_{PMD}=0.1 ps Br=40 GHz $800 \le N_{ch} \le 4000$



Number of transmitted channels, N_{ch}

Fig. 7. Variation of number of transmitted channels, N_{ch}, against variations of the total pulse broadening τ_{sys} , ps.

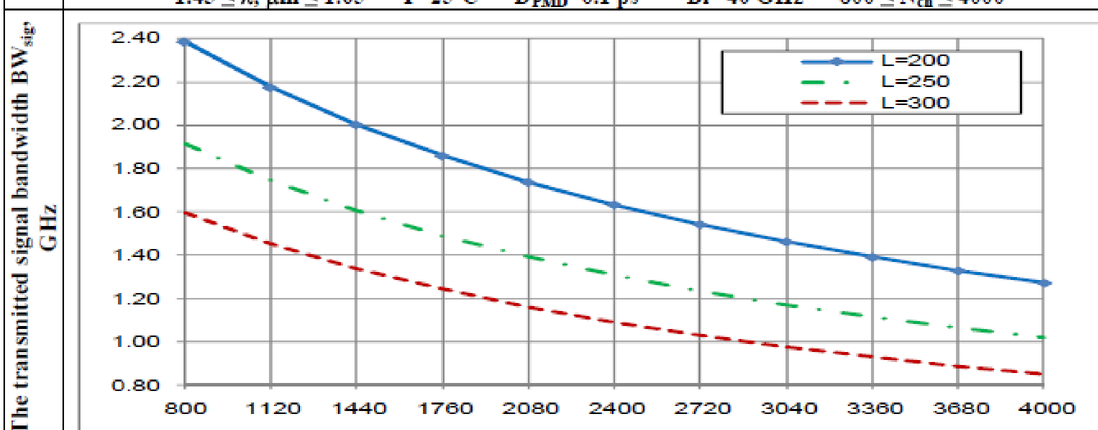
$1.45 \le \lambda, \mu m \le 1.65$ T=25°C D_{PMD}=0.1 ps L=200 km $800 \le N_{ch} \le 4000$



Number of transmitted channels, N_{ch}

Fig. 8. Variation of number of transmitted channels, N_{ch}, against variations of the total pulse broadening τ_{sys} , ps .

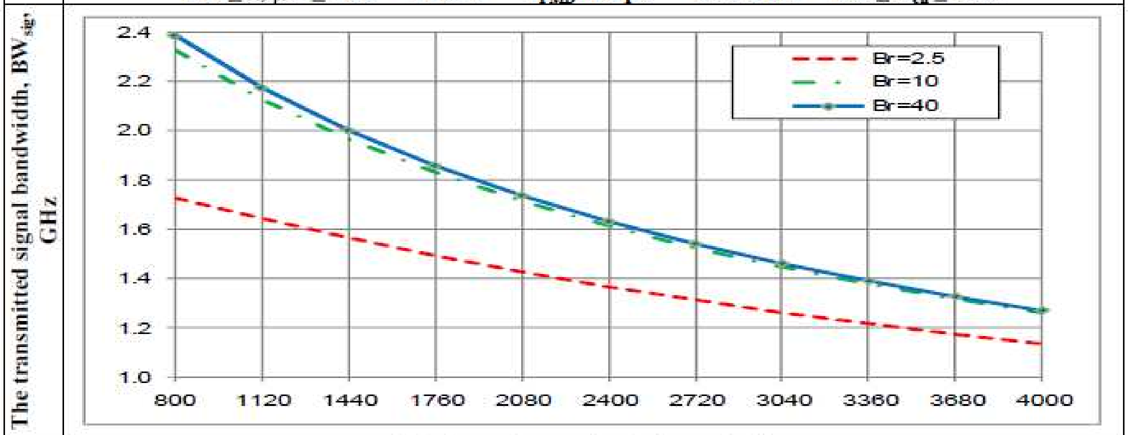
$1.45 \le \lambda, \mu m \le 1.65$ T=25°C D_{PMD}=0.1 ps Br=40 GHz $800 \le N_{ch} \le 4000$



Number of transmitted channels, N_{ch}

Fig. 9. Variation of number of transmitted channels, N_{ch}, against variations of the transmitted signal bandwidth, BW_{sig} , GHz .

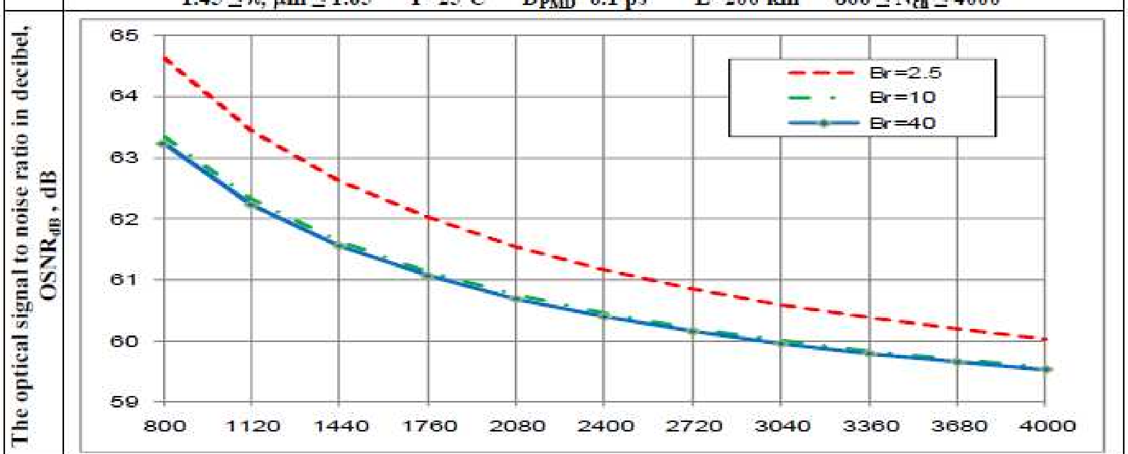
$1.45 \leq \lambda$, $\mu m \leq 1.65$ $T=25°C$ $D_{PMD}=0.1$ ps $L=200$ km $800 \leq N_{ch} \leq 4000$



Number of transmitted channels, N_{ch}

Fig. 10. Variation of number of transmitted channels, N_{ch}, against variations of the transmitted signal bandwidth, BW_{sig}, GHz .

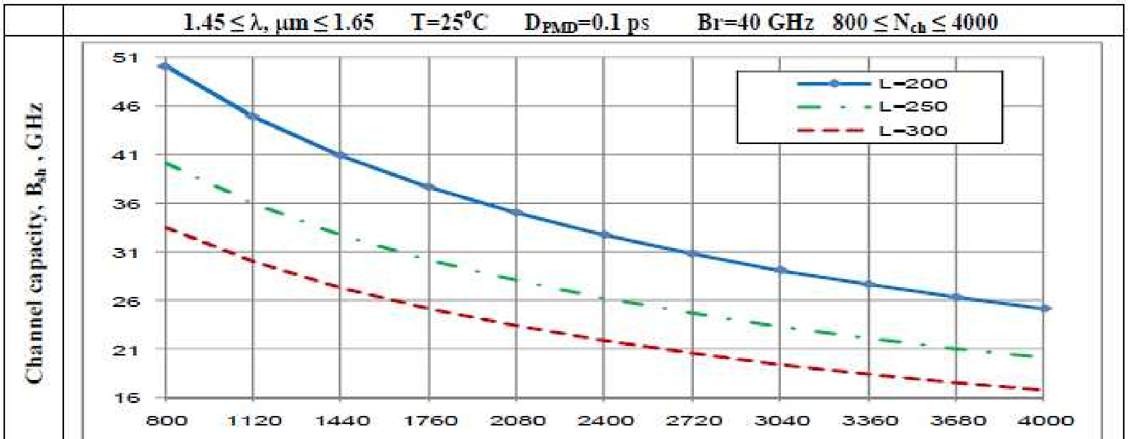
$1.45 \leq \lambda$, $\mu m \leq 1.65$ $T=25°C$ $D_{PMD}=0.1$ ps $L=200$ km $800 \leq N_{ch} \leq 4000$



Number of transmitted channels, N_{ch}

Fig. 11. Variation of number of transmitted channels, N_{ch}, against variations of the optical signal to noise ratio in decibel, $OSNR_{dB}$, dB .

$1.45 \leq \lambda$, $\mu m \leq 1.65$ $T=25°C$ $D_{PMD}=0.1$ ps $Br=40$ GHz $800 \leq N_{ch} \leq 4000$



Number of transmitted channels, N_{ch}

Fig. 12. Variation of number of transmitted channels, N_{ch}, against variations of channel capacity, B_{sh}, GHz .

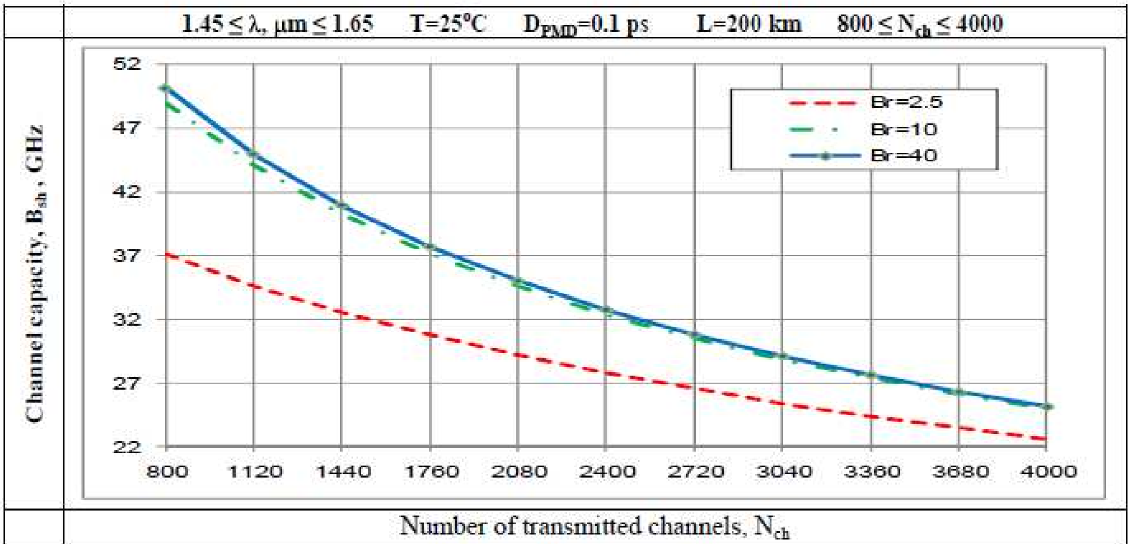


Fig. 13. Variation of number of transmitted channels, N_{ch}, against variations of channel capacity, B_{sh} , GHz .

Table 1: Proposed Parameters in the Designed Metro Optical Network Model

Operating parameters	Value and unit
Polarization mode dispersion parameter, D_{PMD}	(0.1) psec/ $\sqrt{km}$
Transmission distance,(fiber link length) L	200-300 km
Operating signal wavelength range, λ_s	$1.45 \le \lambda_s$, µm ≤ 1.65
Number of channels range, N_{ch}	$800 \le N_{ch} \le 4000$
Ambient temperature, T	T=25 °C
Room temperature, T_o	T_o=25 ºC
Spectral linewidth of optical source, $\Delta\lambda$	0.1 nm
Transmitter pulse broadening, τ_t	25 psec
Fiber loss, α at λ= 1.55 µm	0.275 dB/km
Receiver Bandwidth , Br	2.5-40 GHz

Based on the proposed parameters as shown in Table 1, and the results of the set of the series of the figs. (4-14), the following facts are assured as follows:

A) Variations of the transmitted power per channel, P_T, mW/ch

Variations of the transmitted power per channel are investigated against variations of the controlling set of parameters as displayed in Fig. 4. This figure clarifies the following results:

i. As the number of transmitted channels increases, this leads to decrease the transmitted power per channel.
ii. For certain number of transmitted channels, the transmitted power per channel decreases with increasing the fiber link length.

B) Variations of the received power from each channel, P_R , pW/ch

Variations of the received power from each channel are investigated against variations of the controlling set of parameters as displayed in Fig. 5. This figure clarifies the following results:

i. As the number of transmitted channels increases, this leads to decrease the received power per channel.
ii. For certain number of transmitted channels, the received power per channel decreases with increasing the fiber link length.

C) Variations of the bit error rate, BER

Variations of BER are investigated against variations of the set of parameters as displayed in Fig.6. This figure clarifies the following results:

i. As the number of transmitted channels, increases, BER also increases.
ii. For certain number of transmitted channels, the BER increases with increasing the fiber link length.

D) Variations of the total pulse broadening τ_{sys} , ps

Variations of total pulse broadening are investigated against variations of the set of parameters as displayed in Figs. (7, 8) These figures clarify the following results:

i. As the number of transmitted channels, increases, total pulse broadening also increase.
ii. For certain number of transmitted channels, the total pulse broadening increases with increasing the fiber link length.
iii. For certain number of transmitted channels, the total pulse broadening increases with increasing the receiver bandwidth.

E) Variations of the transmitted signal bandwidth BW_{sig}, GHz

Variations of the transmitted signal bandwidth are investigated against variations of the set of parameters as displayed in Figs. (9, 10) These figures clarify the following results:

i. As the number of transmitted channels, increases, this leads to decrease the signal bandwidth.

ii. For certain number of transmitted channels, the transmitted signal bandwidth decreases with increasing the fiber link length.
iii. For certain number of transmitted channels, the transmitted signal bandwidth increases with increasing the receiver bandwidth.

F) Variations of the optical signal to noise ratio in decibel, $OSNR_{dB}$, dB

Variations of the $OSNR_{dB}$ are investigated against variations of the controlling set of parameters as displayed in Fig. 11. This figure clarifies the following results:

i. As the number of transmitted channels, increases, this leads to decrease the $OSNR_{dB}$.
ii. For certain number of transmitted channels, the $OSNR_{dB}$ decreases with increasing the receiver bandwidth.

G) Variations of the channel capacity, B_{sh} , GHz

Variations of the channel capacity are investigated against variations of the set of parameters as displayed in Figs. (12, 13) These figures clarify the following results:

i. As the number of transmitted channels, increases, this leads to decrease the channel capacity.
ii. For certain number of transmitted channels, the channel capacity decreases with increasing the fiber link length.
iii. For certain number of transmitted channels, the channel capacity increases with increasing the receiver bandwidth.

V. 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. It is observed that there is inverse relationship between *the number of transmitted channels,* and the following variables (transmitted power per channel, received power from each channel, transmitted signal bandwidth, optical signal to noise ratio and the channel capacity), but there is a linear relationship between *the number of transmitted channels*, and the following variables (BER and the total pulse broadening). Also we have indicated that *the length of the optical fiber* has the same effect on the previous parameters as the effect of the number of transmitted channels on the previous parameters. Finally the effect of the receiver bandwidth has been studied. It is observed that there is inverse relationship between *the receiver bandwidth*, and the following variables (the total pulse broadening and the $OSNR_{dB}$), but there is a linear relationship between *the receiver bandwidth*, and the following variables (the transmitted signal bandwidth and the channel capacity).

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