Australian Journal of Basic and Applied Sciences, 2(4): 968-976, 2008
ISSN 1991-8178

The Hybrid Protection Scheme in Hybrid OADM/OXC/MUX

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Abstract: The paper describes our recent approach towards advanced in optical survivability scheme by introducing the new wavelength reconfigurable device. It is designed by improving the drawbacks appear in the previous devices with some excellence features added. The first proposal of hybrid OADM/OXC/MUX will be named as Optical Cross Add and Drop Multiplexer (OXADM). O.X.A.D.M which has presenting the concept of filtering, add-drop function, accumulation, cross-connecting, u-turn mechanism and multiplexing in a single device architecture could also increase the vast application in optical trunk network. With these features, three restoration schemes have been developed to form a hybrid mechanism which is activated according to the degree and location of failures. The OXADM focuses on providing survivability through restoration against failure such as cable cut, power decreased and not functioning EDFA by means of linear protection, multiplex protection and ring protection (also be called as "u turn protection"). This paper also presents the characteristic of OXADM by using simulation, experimentally and analytically. The limitation has also been discussed as the results are compared with previous device such as OXC.

Key words: OXADM, Hybrid protection scheme, Accumulation, U turn mechanism

INTRODUCTION

Wavelength division multiplexing (WDM) can significantly enhance both transmission capacity and provide more flexibility in optical network design (Tzanakaki *et al*., 2003). Demands for large transmission capacity increase due to recent popularization of Internet. And such demands will head not only for subscriber network but also for local area network and backbone network. In order to satisfy the increasing demands for the expanding networks services, the flexibility, survivability, efficiency and multifunctional device is required (Eldada *et al.,* 2000). The disability of available devices to support the growth application system has led on research and development of the next generation of optical device. The new devices have been designed to improve drawbacks occur in previous with some excellent added (Mutafungwa, *et al.*, 2000). These devices include Optical Cross Node (OXN) (Mutafungwa, et al., 2000), tunable Ring Node (TRN) (Eldada *et al.,* 2000), Arrayed Waveguide Grating Multiplexer (AWGM) (Takagi *et al*. 2000) and many more that had been reported previously.

OXADMs - The hybrid of OADM/OXC/MUX, are elements that provide capability to add and drop function and cross-connecting traffic in the network similar to the previous OADM and OXC. OXADM consists of three main subsystems; a wavelength selective demultiplexer, a switching subsystem and a wavelength multiplexer. Each OXADM is expected to handle at least two distinct wavelength channels each with a coarse granularity of 2.5 Gbps of higher (signals with finer granularities are handled by logical switch node such as SDH/SONET digital cross connects or ATM switches. The device has at least two input and two output ports which be connected to the optical trunks.

For 2x2 OXADM, there are eight ports for add and drop functions which are controlled by four lines of MEMs switches. The other four lines MEMs switches will be used to control the wavelength routing function between two different paths (Fig. 1). OXADM featuring two different bandwidths which operate in working and protection line in a ring configuration. OXADM is designed by improving all the drawbacks appear in the previous device with some excellence features added. The 'accumulation' feature has expanded their application tremendously in wavelength management and restoration system. In contrast to the conventional devices such as OADM and OXC which use segmentation and 'drop and re-add' function to restore the failure

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(Tzanakaki *et al*., 2003). Meanwhile the 'U turn mechanism' increases the potential of OXADM in survivability with looping back the signal against the direction of incoming signal. This can be described using route path in Figure 2 to both extra features added in OXADM architecture. The function of OXADM includes terminating node, drop and add, routing, multiplexing and also provides mechanism of restoration for point to point, ring and mesh metropolitan and also customer access network in FTTH.

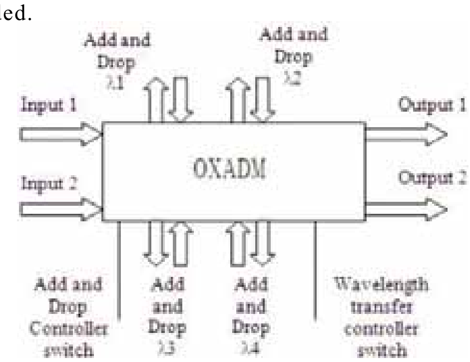
In our previous publication, we have shown OXADM has excellence specification such as insertion loss is 6 dB, crosstalk is 60 dB and return loss is 40 dB (Rahman *et al.*, 2007(1)). We proposed also OXADM is able to easier the network migration without the need of restructuring process. With the setting of the MEMs switch configuration, the device can also be programmed to function as other optical devices such as multiplexer, demultiplexer, coupler, OADM, wavelength round about and etc. for the single application (Rahman *et al.*, 2006 (1); Rahman *et al.*, 2007).

The test done under ideal condition using Optisystem simulator indicates that the operational loss is less than 0.052 dB. The loss for every single operation of OXADM is shown in Table 1. Under this condition, the maximum length that can be achieved by OXADM with the presence of losses is 94 km.

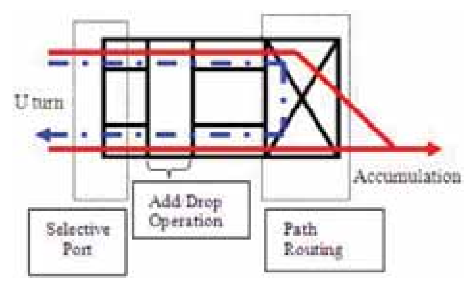
However, when the loss of every OXADM's element is considered, the maximum length that can be achieved in point to point configuration (using two OXADMs) is 71 km without regeneration. Figure 3 verifies this scenario based the following equation:

$$y = -3.9151x + 94.434 \quad [1]$$

The experimental data is also collected to study the maximum output power that can be achieved at a certain distance in point-to-point configuration (Figure 4). Here, the output power is measured by varying the input power at different length of fiber. The results obtained are then compared with the simulation results to validate the synchronization of correctness. At 50.4 km, the output power is 31 dB after considering the losses of OXADM. The sensitivity of the detection is about –35dBm which means the length of fiber can be extended.



(Fig. 1)



(Fig. 2)

Fig. 1: The block diagram of Optical Cross Add and Drop Multiplexing (OXADM).
Fig. 2: The classification of OXADM architecture and route path for accumulation and u turn mechanism.

Table 1: The operational insertion loss of OXADM in ideal and real condition.

Parameter	Value			Unit
Insertion loss	Operation	Ideal	Actual	
	Pass Through	0.051	6	dB
	Add	0.037	4	dB
	Drop	0.037	3	dB
	Single Path Exchange	0.051	6	dB
	Double Path Exchange	0.051	6	dB
	Linear Protection	0.051	6	dB
	Multiplex Protection	0.051	6	dB
	Ring Protection (To East)	NA	10	dB
	Ring Protection (To West)	NA	12	dB
Crosstalk		>60		dB
Return Loss		>40		dB
Operating Temperature		-20 to +70		^{0}C
Storage Temperature		-40 to +85		^{0}C

Mathematical expression:

In ring topology, OXADMs are located in the nodes, which have more than two switching directions in rings network. The function of OXADM is to flexibly switch the wavelengths among the different input and output ports. Because of the OXADM's imperfect performance, the insertion loss and crosstalk are induced (Figure 3). The magnitude of the crosstalk depends on the number of input/output ports connected to the fiber lines, and the number of wavelengths per line. Due to the presence of crosstalk which causes signal impairment, additional signal power is required to maintain a specified bit error rate (BER). Expressed in decibels, the power penalty is defined in (Rahman *et al.*, 2006 (1); Shen et al., 1999; Stevens, 2005):

$$\text{Power-Penalty} = 10\log_{10}\frac{[\text{Power required with impairment}]}{[\text{Power required without impairment}]} \quad (2)$$

Assuming aligned polarization, the probability density function (PDF) for the resultant aggregate interference is approximately Gaussian, which leads to a theoretical power penalty:

$$P_{Penalty} = -5\log_{10}[1\text{-}4x\sigma^2_{RIN}xQ^2] \quad (3)$$

Where Q is the Q factor corresponding to the reference BER, σ^2_{RIN} is the autocovariance of the beat noise resulting from interferometric intensity noise. Note there is an error floor, corresponding to the BER, at $4Q^2\sigma^2_{RIN}=1$, where the power penalty tends to be infinity. It is impossible to achieve BER valueto be smaller than the error floor because of the nature of crosstalk. Here we apply the worst case scenario depicted in Figure 5 for the power penalty caused by incoherent crosstalk, which is induced when optical propagation delay differences between signal and crosstalk in an OXADM exceed the coherent time of the laser. Assuming the OXADM is fully loaded, each signal passing through the OXADM will be interfered by MN-1 crosstalk, caused by leaked signal from demultiplexer/multiplexer pairs. Based on above assumptions, the power penalty from crosstalk contributions in one OXADM is given in Equation 4. The maximum power penalty (pp) caused by MN-1 incoherent crosstalk contributions from one OXADM is (Rahman et al., 2006 (1)):

$$\begin{aligned} \text{Max}(pp)_{OXADM} &= -5\log10[1\text{-}4x\text{Max}(\sigma^2_{RIN})x\ Q^2] \\ &= -5\log10[1-4x\varepsilon x(MN\text{-}1)xQ^2] \quad (4) \end{aligned}$$

Thus, the OSNR analysis for OXADM ring network can be defined as

$$OSNR = G_{Preampt} - (P_{Rx} + NF_{Rx}) + \Sigma\ [P_{out} - 10\log_{10}(M_{ch}) - Loss_{sp} - NF_{ASE} - 10\log_{10}(NUM_{span} + 1)] + 5\log_{10}[1\text{-}4\ x\ \varepsilon\ x\ [(\Sigma N_iM_i\text{-}\ L)\ x\ Q^2 \quad (5)$$

Limitation:

Computer simulations using MATLAB has been carried out to validate the analytical formulation presented earlier. The purpose of this study is to define the limitation of new OXADM device in scalability feature as compare to other existing device. OXC is used to be compared with OXADM. Figure 6 illustrates the maximum of nodes that can be achieved with the increment of number of ports in OXADM. The analysis has shown that in point to point configuration, the maximum ports at two operating wavelengths is 43 ports while at three operating wavelengths the figure decreases to 29, compared to the OXC device with 86 ports and 85 ports respectively.

Referring to Figure 7, the increments numbers channel also give significant effect to the number of OXADM nodes that can be cascaded. With 2 ports in point-to-point configuration, the maximum channels that can be operated are 43 channels but in OXC the figure is double. The maximum channels that can be handled by OXADM at 4 ports are 26 channels compare to that of OXC which are 84 channels. But, in real application, the maximum value for the cascaded OADM is only 16 (Rahman *et al.*, 2007(2)).

The differences are due to the accumulation features (MN) that were embedded in OXADM architecture. Although the accumulation features may decrease the scalability of OXADM it is undoubted that it has wide range of applications. Because OXAM has lower in scalability therefore OXADM is designed to fit the CWDM technology with low number of operating wavelength (18 channel).

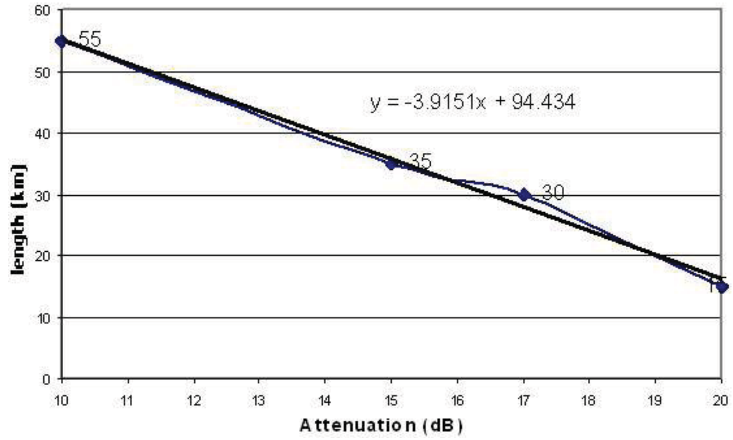


Fig. 3: The decrement of length (in kilometers) occurs by increasing the attenuation of OXADM which represent the device losses.

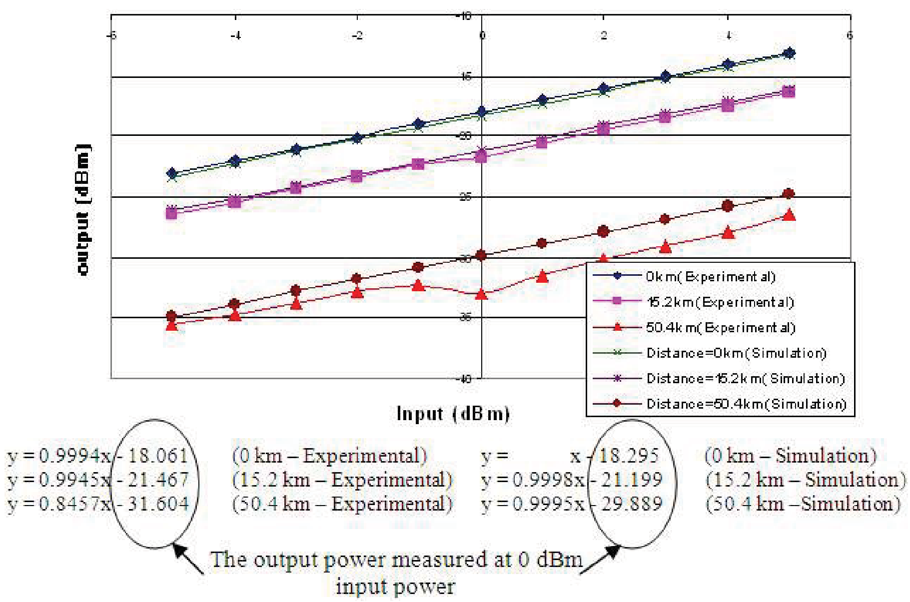


Fig. 4: Comparison between the simulation and experimental result for output versus input power in point-to-point configuration.

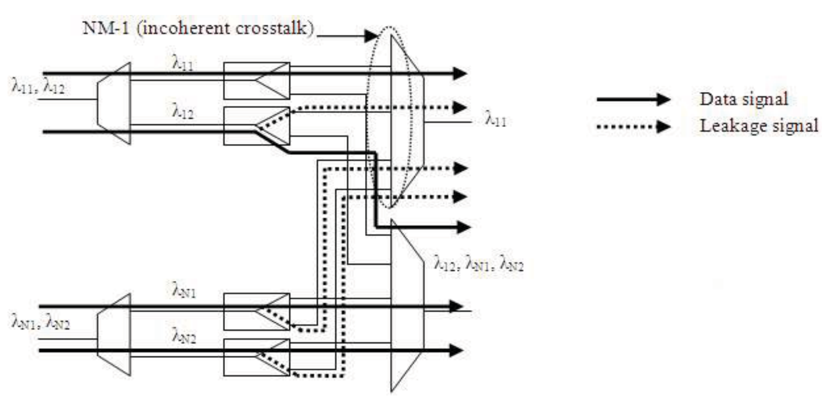


Fig. 5: Induction of incoherent crosstalk due to the leakage signal of each channel operates in OXADM.

Restoration:

OXADM introduced two types of restoration mechanism to be implemented in OXADM ring/mesh network by means of linear/multiplex protection and ring protection.

Restoration using OXADM is more efficient compare with the previous devices due to function of drop and re-add or segmentation concept is needed to re-close the loop or transfer the traffic to the alternative path. But in OXADM the internal mechanism is implemented to activate the restoration scheme.

Liner & multiplex protection scheme:

OXADM provides a linear protection scheme to implement the dedicated protection in ring and mesh network (Held *et al*., 2006). In path switching, restoration of traffic is handled by the source node and the destination node. Dedicated protection normally activates when one of the transmission line breakdown (Das 2006). When a link failure occurs within the ring, the signal will be switched to the alternative route as illustrated in Figure 8. The restoration is significant to ensure signal flows continuously. The device is compatible with 1:1 and 1+1 types of link usage. The accumulation feature will support the shared protection to be performed in case of two different set of wavelengths going to east and west links. The restoration in 1+1 can be called as multiplex protection. Figure 8 depicted the activation of dedication protection when failure occurs between Node 2 and Node 3. The affected node will switch the signals to the protection route. The switching performed within the optical layer will be able to achieve high-speed restoration against the failure/degradation of cables, fibers, and optical amplifiers. It is important to avoid huge losses of data and great influence upon a large number of users over a wide area (Rahman *et al*., 2006 (3); Rahman *et al*., 2007(2)).

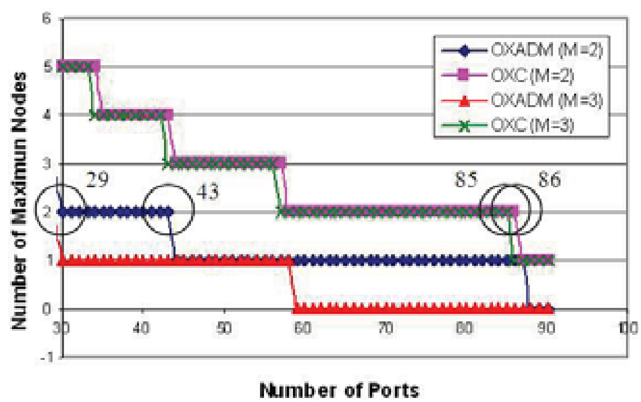


Fig. 6: Number of maximum nodes associated with the number of ports in OXADM nodes as compared to the existing OXC nodes.

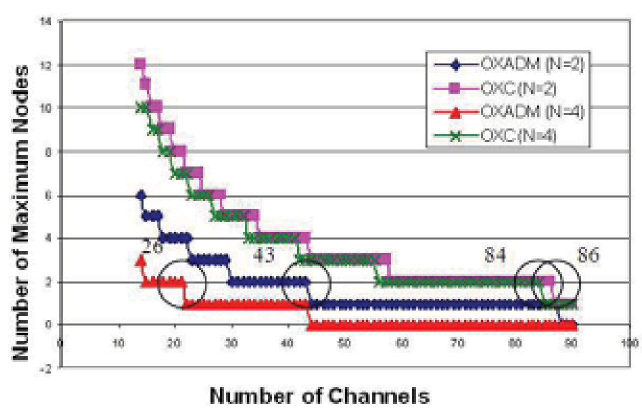
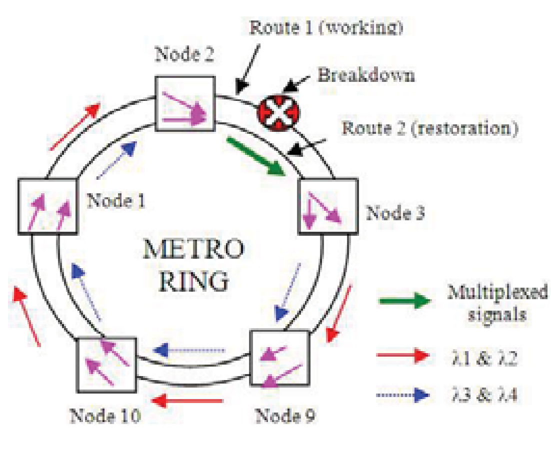


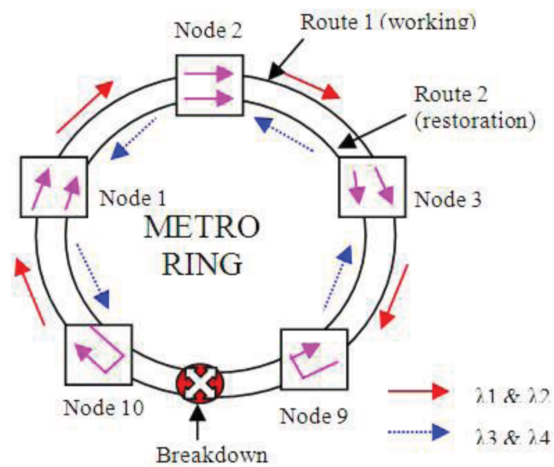
Fig. 7: Number of maximum nodes associated with the number of channels in OXADM nodes as compare to the existing OXC nodes.

Ring protection scheme:

Now suppose an entire node fails, or both the primary and the protection fibers in a given span are severed, which could happen if they are in the same cable duct between two nodes. In this case, the nodes on either side of the failed internodal span internally switch the primary-path connections from their receivers and transmitter to the protection fiber, in order to loop traffic back to the previous node (Cisco System Inc.). This process again will form a closed ring, with all of the primary and protection fibers in use around the entire ring as shown in Figure 9. The protection scheme is called shared protection. OXADM provide a ring protection scheme to implement shared protection. The ring protection is activated when both fiber or node breakdowns. In the event of a failure condition, the OXADM adjacent to the failure loop back the affected signal on the protection route of the ring. The 'U turn' mechanism is applied in OMS-SPRing (BLSR). OXADM implements the shared protection by using internal route that is activated by E switches. The mechanism is different compared to other devices such as OADM which use their drop function and re-inject the signal to add port to perform 'U turn' protection but the node based on OXC architecture cannot perform this mechanism. Thus it is not suitable to be applied in ring topology network.



(Fig. 8)



(Fig. 9)

Fig. 8: Dedicated protection mechanism in metroring network. When a link failure occurs within the ring, the affected is switched over to the protection path.

Fig. 9: Ring protection mechanism in metro ring network. When a cable/node failure occurs within the ring, the node adjacent to the failure loop back the affected signal on the protection route of the ring.

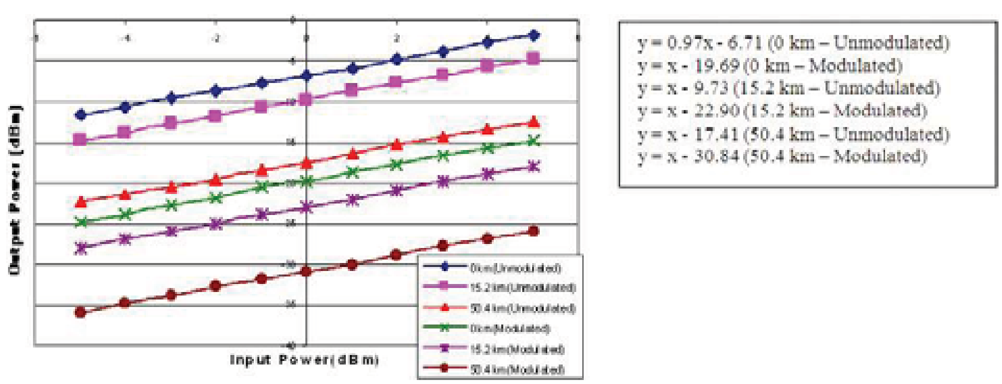


Fig. 10: The modulated and unmodulated output power at different input power in multiplex protection mechanism at three different distances in point to point configuration.

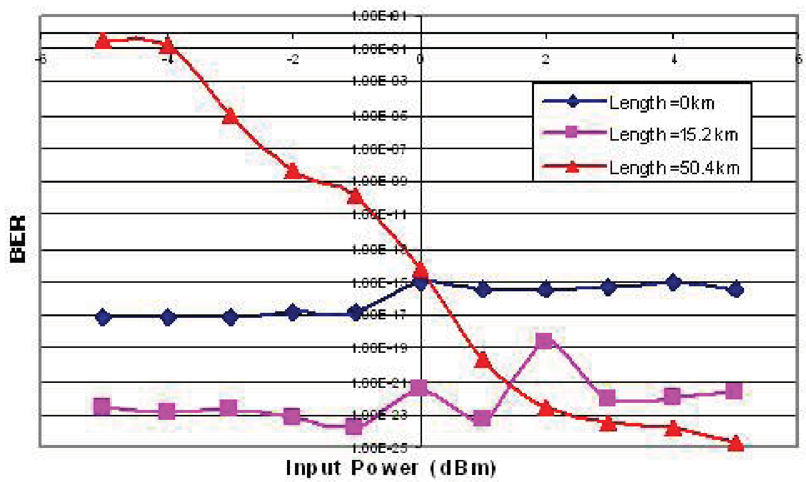


Fig. 11: The BER performances at different input power in multiplex protection mechanism at three different distances in point to point configuration.

Experimental result:

The OXADM device is characterized by using two tunable light sources and two optical spectrum analyzer. The measured output power for continuous & digital signal transmission and BER performance at difference 3 different distances (0 km, 15.2 km and 50.4 km) under multiplex protection condition is shown in Figure 10 and 11 respectively at sensitivity of -30 dBm. The values are acceptable (<1x10-9) at 0 dBm input power. The result hence verified the maximum length can be achieved in point-to-point configuration is 71 km without regeneration similar to the result obtained by simulation in Rahman *et al*., 2007 (2).

Figure 12 and 13 shows the output power analysis and BER performance test applied to ring protection mechanism respectively. The BER values measured are less than 1x10-9 at sensitivity-30 dBm. Direct connection (0 km) and available 15.2 km fiber are used to prove the system feasibility. The ring protection involves the 'u turn' mechanism in which double the distance at point-to-point configuration. Thus, the result for 50.4 km link cannot be shown due to power decreasing because the signal is not regenerated**.** But in real application, the post and pre-amplifier will be added to compensate the losses.

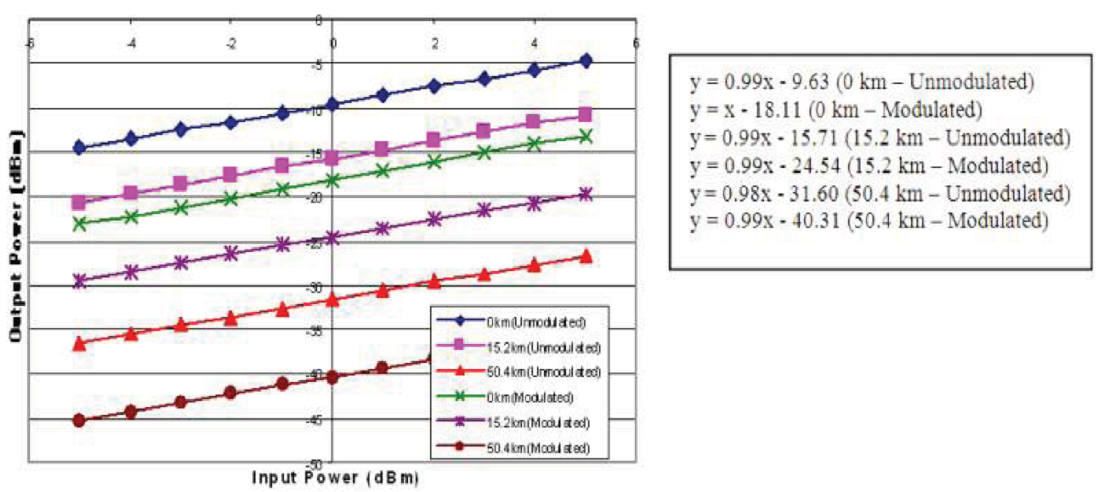


Fig. 12: The modulated and unmodulated output power at different input power in ring protection mechanism at three different distances in point to point configuration.

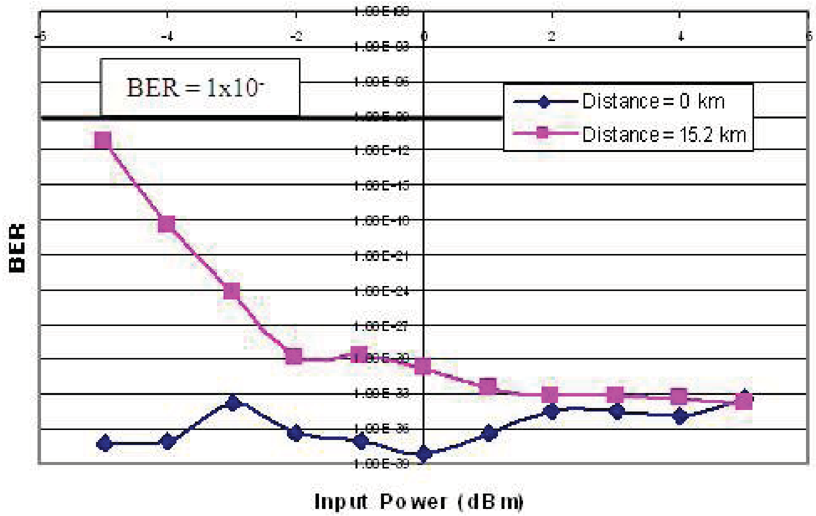


Fig. 13: The BER performances at different input power in ring protection mechanism at two different distances in point-to-point configuration. The result for 50.4 km link cannot be showed due to power decreasing (loop back will double the length) because the signal is not regenerated.

Conclusion:

We have introduced a new device which expected to increase vast application in optical trunk network. It utilizes the combined concepts of optical add and drop multiplexing (OADM), optical cross connect (OXC) and multiplexer (MUX) operation through the development of an Optical Cross Add and Drop Multiplexer (OXADM). The OXADM has been characterized by simulation, analytical and experimental to prove its feasibility. The results obtained clearly indicate that the insertion loss of OXADM is 6 dB with OSNR which is bigger than 20 dB for every single function of OXADM. Although the scalability of OXADM is decreased with the presence of accumulation features, its application is in particular widely used in network restoration and migration. Thus, the multifunctional device is particularly designed for CWDM metro application.

Security applications have been proposed in this work with the simulation and experimental results as feasibility approach. The OXADM provides survivability through restoration against failure by means of dedicated and shared protection which can be applied in CWDM ring metropolitan network. The BER characteristics were measured at 1 Gbps and no degradation was observed in linear protection and 2 dB degradation for shared protection, as confirmed by comparison of the simulation results with those obtained from systems without restoration mechanisms (bypass).

In our previous publication, OXADMs have shown its outstanding function in application, it enables the network to be migrated without the need of restructuring process, with the switch configuration, the OXADM is able to function as a single device such as OADM, OXC, Wavelength selective coupler, multiplexer, demultiplexer and etc., OXADM is also first report switch in this time to have the function of accumulation/multiplexing.

Future plan:

The ideal of OXADM will be realized through the Optiwave simulators (OptiSystem and BPM_Cad) and after that the designed layout is being used to produce the photomask for actual fabrication for waveguide-based OXADM. The technology assure the cost expenditure for device fabrication is lower compare with fiber based device. Lower in losses with the smaller in size is also expected (Chen *et al.*, 2003; Kirihara et al., 2000; Rahman *et al.*, 2004).

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