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Restoration Scheme in Optical Cross Add and Drop Multiplexer (OXADM) Device - The Transparency Test

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Abstract: In this paper, an optical cross add and drop multiplexer (OXADM) is presented as a new optical device that is highly promising for the application in CWDM metro area networks. Conceptually, OXADM is the hybrid of optical add/drop multiplexing (OADM) and optical cross connect (OXC) between two transmission lines so that wavelength routing operation can be executed. The device is particularly designed having superior features in favor of advancing network efficiency, flexibility and reliability. The incorporation of MEMS optical switches in OXADM is to ensure that the device is reconfigurable. In application, it is possible to fix OXADM in point-to-point, ring or mesh network to provide multi-functions in optical domain such as routing, supervision, transport, multiplexing and restoration of client digital signals. In principle, the wavelengths on each optical trunk can be switched to each other while executing add and drop functions concurrently. In terms of performance, we have analyzed the comparison between OXADM and other conventional technologies such as OXC, TRN and OXN. In our previous report, OXADMs can operate with the maximum length of 71 km at insertion loss 6 dB without regeneration. Besides, it can run performance test at 2.5 Gbps (OC-48) with BER less than 10^{-9}. This paper highlights the effect of the wavelength size on the each node performance while the restoration scheme is activated by means of Transparency Test (TT). The TT is important in observing whether the OXADM switch can function in various range of wavelength in optical communication. In this case, four CWDM wavelengths are injected into OXADM and the profile of output power of each node is compared. The result reveals that OXADM has capability to execute the reliable transparent switching in optical network.

Key words: *OXADM, Transparency Test, Survivability, Add/drop, Cross-connect.*

INTRODUCTION

Generally speaking, OXADMs are the element that provides capability to add/drop and cross-connect traffic in the network similar to OADMs and OXCs (Tzanakaki, *et al.*, 2003). In principle, an OXADM is composed of three main subsystems; wavelength selective demultiplexer, switching subsystem and wavelength multiplexer. The device is designed having four lines of MEMs-optical switches for controlling set of add/drop ports. On the other hand, the other four lines of MEMs-optical switches are assigned to execute wavelength routing function between two different paths (see Figure 1a).

Predominantly, OXADMs is capable to perform multiple tasks including the execution of drop and add functions, optical node termination, wavelength routing, multiplexing and restoration scheme for point-to-point, ring or mesh metropolitan as well as customer access network in FTTH. By mean of a particular configuration of MEMS optical switch, the device can be programmed to be assigned as a multiplexer, demultiplexer, coupler, wavelength converter, OADM, wavelength roundabout (WRB) and etc.

An asymmetrical architecture of OXADM can be extracted to three individual blocks; selective port (wavelength selective demultiplexer), add/drop operation (switching), and path routing (wavelength multiplexer) as depicted in Figure 1b. The first element, selective port is designed to pass only a desired wavelength channels while filtering out the radiation of other wavelengths. By mean of add/drop function block, the second element in OXADM, one or more new wavelength channels can be added to or dropped from an existing multi-wavelength signal. The signals can then be re-routed to any output port or/and execute an accumulation task that multiplex all signals onto single path and then directed out to any output port, this task is assigned to the third element. Apparently, ‘accumulation’ is the most critical function which cannot be implemented by the traditional add/drop multiplexing technologies, e.g. ROADM, OADM and OXC. With these features, the OXADM node concentrates on providing functionally such as transport, multiplexing, routing, supervision, terminating and survivability in optical layer with ring and mesh topologies (M.S.A. Rahman, *et al.,* 2006).

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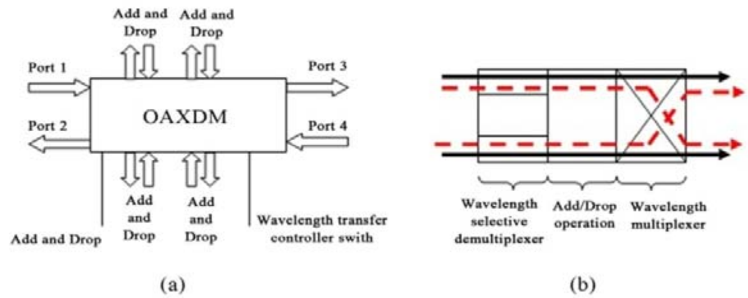

Fig. 1: The architecture of Optical Cross Add and Drop Multiplexing (OXADM); (a) Block Diagram and (b) Signal Direction Flow.

This paper focuses mainly on transparency test since it is implemented to determine transparency characteristic of the tested device when controlling each wavelength channels that pass through it. In order to accomplish the test, the tested device needs to execute the simulation of wavelength range varied by function. In this paper, transparency test is implemented to study the OXADM transparency in ring network when the linear and ring protection is switched by the network security system. The experimetal set up of Transparancy Test (TT) is shown in Figure 2. The Tunable Laser Source (TLS) is modulated by PRBS and the signal is send to the N+1 connected OXADMs. The last OXADM is connected to Digital Communication Analyser (DCA) to measure the output power and BER. The TLS is varied by wide range of wavelength but in this case for the Coarse wavelength Division Multiplexing (CWDM) application, four wavelength which are 1510 nm, 1530 nm, 1550 nm, and 1570 nm have chosen. The characteristic of each wavelength upon the restoration scheme (linear and ring protection) activated is observed and compared.

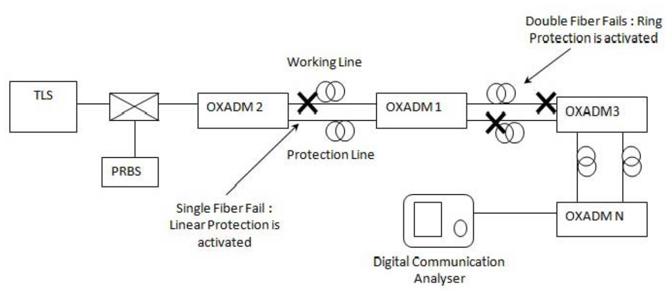

Fig. 2: The experimental Setup for Transparency Test on Restoration Scheme of OXADM Network.

The Constraints Of Conventional Devices:

In optical telecommunication, both of OADM and OXC known as the most common devices deployed for optical termination. A practical OADM is embedded symmetrically between two substations whereas OXC is installed in a network which demands for switching wavelength amongst optical mesh network. In principle, an OADM drop a specific wavelength that is equivalent to a single application to the optical node, while a different signal with corresponding wavelength is added and directed to output fiber. In this case, cross-connecting is the most critical task which can be assigned to OADM. In contrast to OADM, OXC is capable of cross-connecting signal to particular outlet. Nevertheless, OXC is certainly afflicted with some disadvantage which the protection scheme cannot be implemented. As result, OXADM is developed to cater the drawbacks raised by both of OADM and OXC through which the hybrid concept of OADM and OXC is encouraged uniquely in the realization of novel OXADM.

Optical Add & Drop Device (OADM):

The single input/output port limits the application:

In this section, we will discuss on the limitation for OADM that commonly used to execute the switching task. For many years, the OADM architecture has indeed inspired the innovation of many new generations such as TRNs, ROADMs and others. According to some sources, the OADM is reported have been used as optical nodes in ring networks whether the switching is implemented in wavelength or data layer (Kayaoka, *et al.*, 2004). Since the OADM architecture only consists of single input and output port, the device has limited the working line application (Figure 3). None of protection lines have minimized the restoration function in the network application. In consequence, in the case of failure, the only alternative is executing the drop and segmentation. In response to the limitation, an intensive study has been undertaken by researchers in order to overcome the constraints and to enhance the performance of OADM whereby the device architecture is reconstructed demonstrating excellent features. For instance, Tunable Ring Node (TRN) is the enhancement version of OADM (Eldada & Nunen, 2000). In this case two OXADMs are connected in parallel and the drop port has connected to add port of the other device. To perform linear and drop protection, the switch is connected in between.

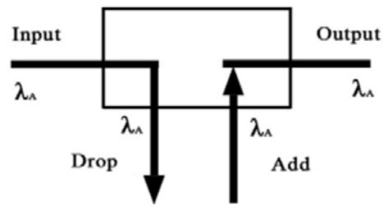

Fig. 3: Diagram of a simple signal flow in OADM architecture.

Optical Cross Connect (OXC):
No accumulation function:

Despite the fact that OXCs is capable of executing particular configuration command in ring-to-mesh topology without a restructuring process, the device has low-security feature. Since the architecture of OXCs can be expanded especially in case of ring-to-mesh topology transformation without the need for new optical nodes, OXCs need to be equipped with a security system considering both situations (Tsushima *et al.*, 1998). Security system is the priority target for an accumulation operation. This is to avoid failure on the output line while multiplexing all data inputs. There is a possibility that damage occur on either line resulting in transmission shut-down if both transmission lines are in use. In this case, the data cannot be sent from the second input to any output terminal. As shown in Figure 4, the damage on the second outlet resulting in failure when directing optical data from second input since the data is blocked. Thus, the implementation of OXC has to be complemented with high-security feature. For instance, Tunable Ring Node (TRN) is realized with advanced security and flexibility features (Mutafungwa, 2000).

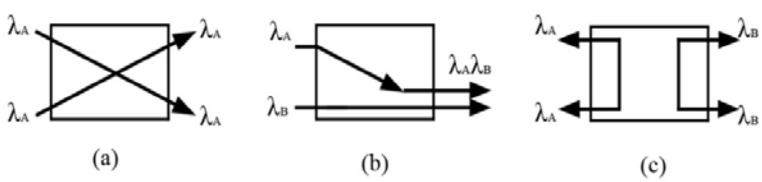

Fig. 4: The Signal Flow Diagram in OXC; (a) Cross-Connecting, (b) Accumulation and (c) 'U' Turn Mechanism that cannot be implemented by the OXC.

Ring protection cannot be done:

Obviously, the optical data cannot be delivered through any ports if the damage occurs either in both optical lines or at a nearby node in ring network. In essence, ring protection is required security feature that is commonly used in OMS-SPRing architecture. Through the ring protection, incident radiation of signal passes through the first fiber inlet, then directed to another input port in U-turn direction allowing the implementation of segmentation process on the damaged area. However, the protection is not adapted in OXC architecture as security feature. In case of optical ring network using OXC node, if the damage is present in two or all lines as well as the nodes, a node alongside spoilt area will acts as a terminal node and all signals will be dropped or directed to a new path which involves a large segmentation area and includes undamaged nodes. This situation bears flaws in fiber optic communication that is said to be indestructible and able to fix all possibilities of damage. Figure 5 shows a segmentation process of quarantine of the damage area in a ring network using OXC nodes (Tzanakaki, 2000).

The Application of OXADM: Point-To- Point:

In optical telecommunication, Wavelength division multiplexing (WDM) is the most promising technologies for transport network with high capacity. WDM has initially been deployed in point-to-point transmission to offer bandwidth relief on congested fiber. Directing a multiplexed multitude of wavelengths on a single link permits sharing of network devices such as amplifiers thus the cost can be scaled down. WDM is used today in virtually all network topologies, including metropolitan area (metro) rings (Mutafungwa, 2000). Wavelength division multiplexing (WDM) allows the point-to-point data transmission system handles over 100 WDM channels and Tb/s magnitude throughput data streams. In the near future, fiber optic communication will be in real use since WDM technology has been recommended in networking, flexible routing and survivability. In such an optical network, a flexible switching device is an important element to support high quality and reliable multi-media services (Rahman, *et al*., 2006). In order to provide flexibility in optical networks, OXADMs is demonstrated as the next generation of OADMs and OXCs. The device is designed having the value added features thus placing it in any point in point-to-point architecture is possible. OXADMs are proposed in three different applications to support the point-to-point carrier distribution function (Figure 5):

1. Single carrier splitter switch – *The OXADMs is assigned as a wavelength splitter which a single wavelength is diverted from the main transmission line while the other wavelengths channel are merged producing a multiplexed signal towards their destinations. The device is fixed at the interchange points. (Figure 5a)*

2. *Carrier combiner switch* – Both optical signals from two main transmission lines will be merged through an OXADM, and then sent to their destinations onto a single line of fiber (Figure 5b).

3. *Carrier exchange switch* – In order to increase the flexibility and reliability of the optical network, OXADM functions to cross-connect both signals from two transmission lines (Figure 5c).

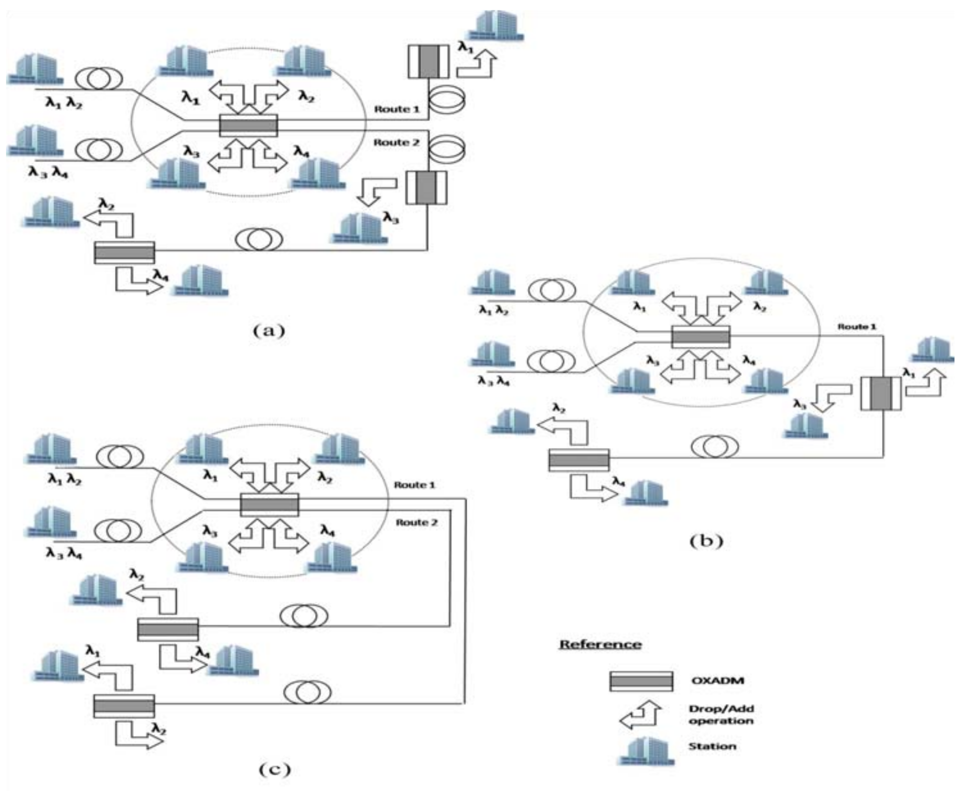

Fig. 5: Three applications using OXADMs are proposed to support the point to point carrier distribution function (a) Single carrier splitting switch (b) Carrier combiner switch (c) Carrier exchange switch.

Other than executing switching operations, the OXADM can also implement both add/drop and routing functions similar to OADMs and OXCs. By mean of additional 'accumulation' feature, the application of OXADMs has been extended so that the restoration task can be effectively executed. Figure 6 indicates the BER performance versus length for four different attenuations of OXADMs in point to point transmission network. The execution of OXADMs at the attenuation of 10 dB can exceed the maximum length of 55 km. On the other hand, the maximum length of 30 km and 25 km can be exceeded at attenuation of 15 dB and 17 dB, respectively. The maximum length of the transmission line is limited to 10 km in case the attenuation is higher than 20 dB. In theory, the insertion loss of OXADM is ~6 dB which means that the maximum length of data transmission in point-to-point network can exceed 70 km (without amplification). Figure 7 indicates the BER performance versus insertion loss in relation to three different values of bit rates for OXADMs. The maximum value of restricted insertion loss can be defined relatively to transmission rate. The maximum insertion loss for OC-12 is 24 dB whereas for OC-48 and OC-192 is bounded at 25 dB and 27 dB, respectively. Thus, we can conclude that the increase of restricted insertion loss in point-to-point data link is the result of the increasing bit rate.

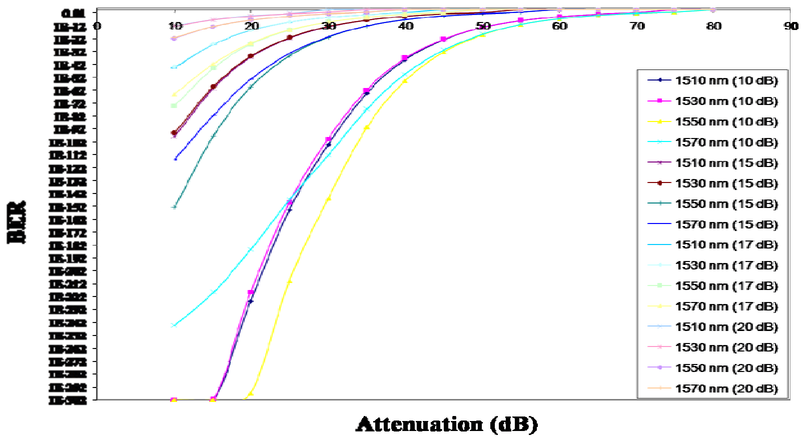

Fig. 6: BER versus Transmission Length for four different attenuations. The graph characterizes the performance of single OXADMs.

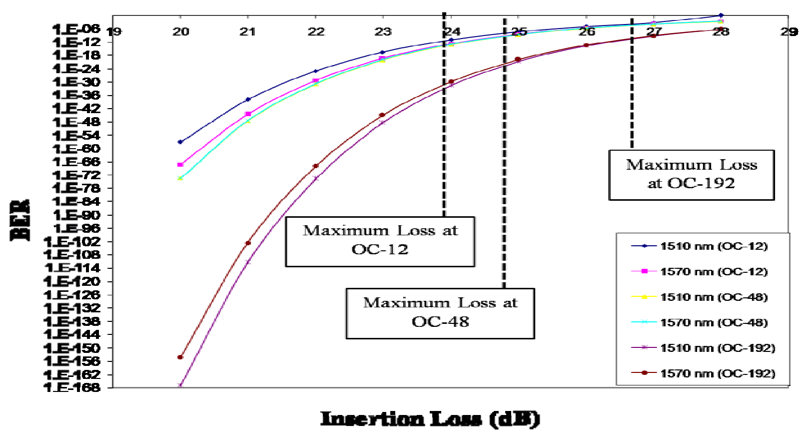

Fig. 7: BER versus Insertion Loss for three different value of bit rates. The graph characterizes the reliability of single OXADMs.

The Application of OXADM: Ring Metropolitan Networks:

The architecture of a ring metropolitan network consisting of eight OXADM nodes is depicted in Figure 8**.** The OXADM nodes provide a large variety of functionalities in optical domain such as routing, supervision, transport, multiplexing and restoration of client digital signals. The position of OXADM nodes in ring topology is also compatible with all functions and restoration mechanisms which will be discussed further later. Two types of restoration schemes can be employed using OXADM node which will be activated relatively to the characteristic of failure. There are two types of restoration schemes; linear protection and ring protection. Predominantly, linear protection activated when one of transmission line breakdown in OCh-DPRing (UPSR) application (Nuzman, *et al.*, 2003). As illustrated in Figure 8, the signal is switched to the alternative route in the event of link failure in ring network. On the other hand, ring protection is activated when either both fiber or node breakdowns. In the event of a failure condition, the OXADM adjacent to the failure loops back the affected signal onto the protection route of the ring. The 'U turn' mechanism is applied in OMS-SPRing (BLSR) as illustrated in Figure 9 (Nuzman, *et al.*, 2003).

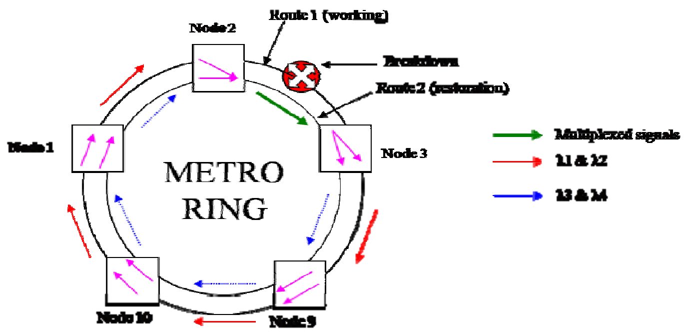

Fig. 8: Dedicated Protection Mechanisms in a Metro Ring Network. When a Link Failure occurs within the Ring, the Affected is switched over to the Protection Path.

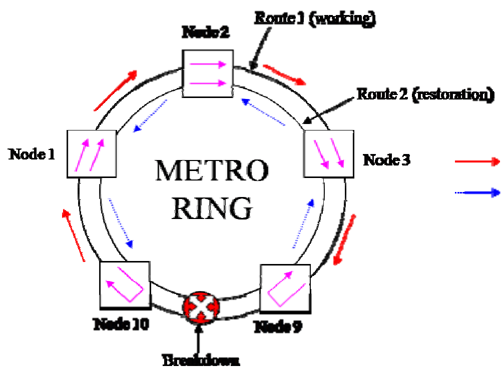

Fig. 9: Ring Protection Mechanisms in a Metro Ring Network. When a Cable/Node Failure occurs within the Ring, the Node adjacent to the Failure loops back the Affected Signal onto the Protection Route of the Rin.

Transparency Test on Linear Protection Scheme:

As shown in Figure 10, the similar values of power output have been obtained as two different operations has been implemented by the OXADM node; pass through and path exchange. Overlapping profiles of power output for both operations proves that no degradation of signal power occur when the route exchange operation has been executed. On the other hand, the breakdown power has occurred between the fifth and the tenth nodes. This is due to the inclusion of optical amplifier whose gain is lower than the total of generated dissipation (load line). Route exchange is an essential operation that implemented by OXADM in mesh network.

Theoretically, for the BER measurement, the execution of direct access and signal path exchange operations will produce similar BER profile with 12.4 dB power dissipation. As shown in Figure 11, the graph indicates the overlapping of BER profile for both directions. This proves the theoretical consideration above. Therefore, we can conclude that OXADM is transparent device since the device has identical BER performance while executing two different types of operations. In case of long haul data transmission, the BER profiles can be recovered by increasing the gain of amplifier.

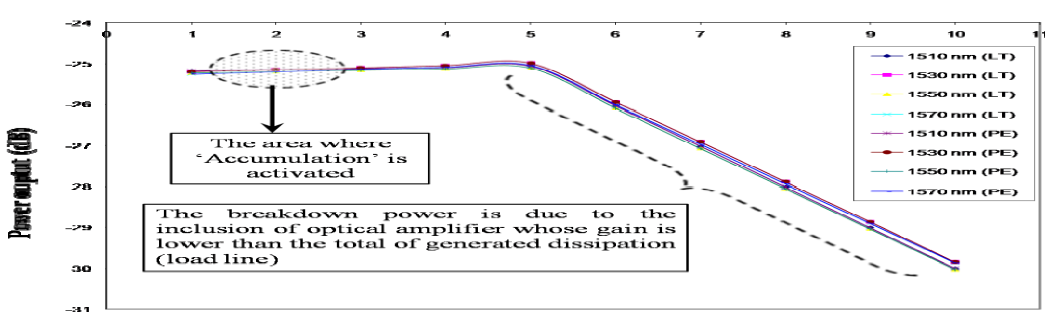

Fig. 10: Overlapping profiles of power output for Pass through and Route Exchange operation proves that the device has transparency while both operations are carried out. The distance between two nodes is 70 km at 2.5 Gbps data transmission rates.

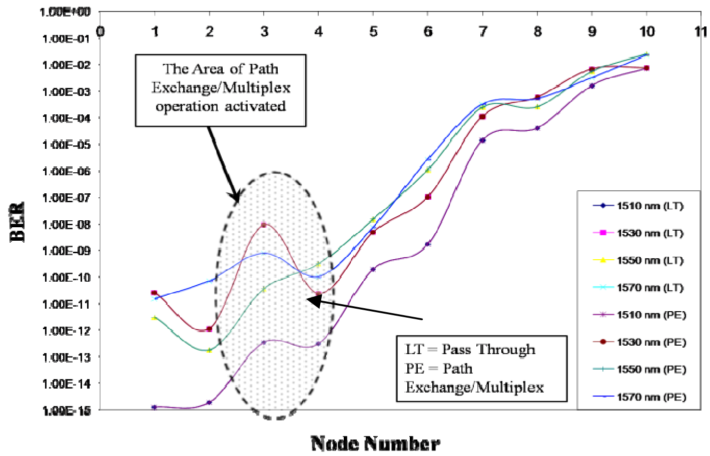

Fig. 11: Overlapping profiles of BER profile for Direct Path and Route Change proves that the device has transparency while both operations are carried out since similar BER performance are produced.

Transparency Test on Ring Protection Scheme:

Predominantly, the wavelength sizes give a small impact on the power output whereas a major impact on the BER performance. This because the size of the wavelength noise impact on the terms and directly provides the different sensitivities of photographs. The sensitivity values of photosensitivity gives the different BER values between each of the operating wavelength, as shown in Figure 12. It is observed that a shift occur on the output power level of each wavelengths after the ring protection mechanism is activated. However, a small displacement occurs and there is no significant impact on BER performance of the transmission system (see Figure 13). In conclusion, while the ring protection mechanism is activated, the wavelength size is not a major problem which affects the conveyed data. Thus, we can conclude that the wavelengths using same window transmission gives a small impact on power output and performance of BER.

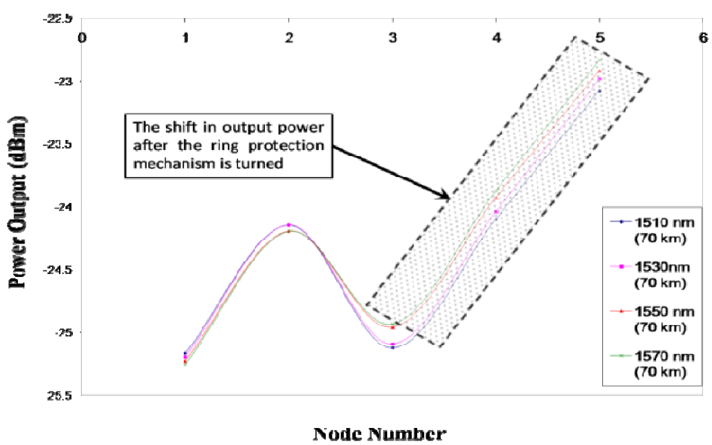

Fig. 12: The effect of wavelength size on output power level at each node with the amplification of 23 dB at 2.5 GHz data transmission rate. The distance between two nodes that is 70 km apart.

Discussion:

CWDM is an optical transmission mechanism that is cooperative with Metro DWDM. In contrast to the DWDM implementation, CWDM is characterized by wider channel spacing since they need to serve smaller bandwidth applications compared to DWDM technology. Since the separation in frequency between each individual channel wavelength in actual fiber is considerably further apart, this leaves an option to system designers; using the lasers having looser tolerances on spectral width and thermal drift thus resulting in an economical cost model.

The structure of CWDM transmission system can be more flexible and efficient by mean of a novel optical device model which is presented as optical cross add and drop multiplexer (OXADM). OXADM will make a debut in its application since it has capability to transfer and exchange the operating wavelength with each other on two main optical trunks. The capability of wavelength transfer between two fiber trunks can reduce the complexity of the network. Thus, the cost of installation and maintenance can be reduced. The number of operating wavelengths can also be reduced because of the cross-connection between two fiber cores and reuse of same operating carrier to carry new information data.

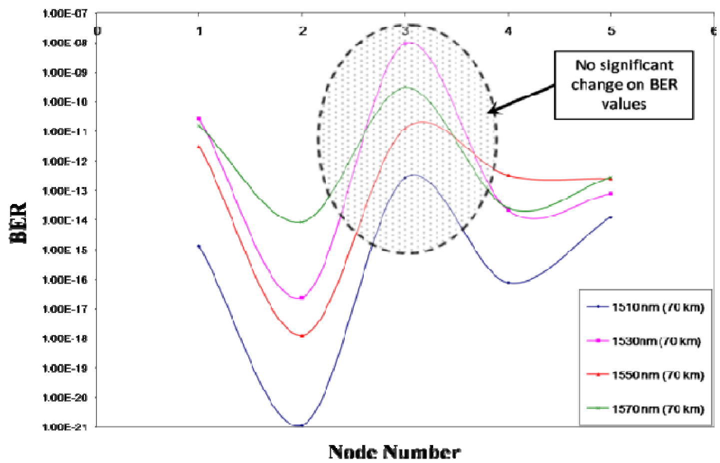

Fig. 13: The effect of wavelength size on the BER performance on each node with 23 dB amplification at 2.5 GHz. The transmission distance is 70 km (between two nodes).

This paper focuses mainly on transparency test since it determines device transparency in controlling each wavelength channels that pass through it. In order to accomplish the test, the tested device needs to execute the simulation of wavelength range varied by function. In this study, transparency test is implemented to study the OXADM transparency in ring network when the linear and ring protection is switched by the network security system. It is revealed that OXADM has performed the reliable and transparent signal switching in optical ring network. Besides, the result shows that the OXADM is a transparent and wavelength independent device. Thus, the device can operate with all size of wavelengths.

Conclusion:

Through the conceptual design of a hybrid optical mechanisms that combine the implementation of optical add and drop multiplexing (OADM) and optical cross connect (OXC), an optical device has been successfully realized which is named as optical cross add and drop multiplexer (OXADM). The device has been recommended for two applications with the simulation results as feasibility approach. With multiple functions, the device has been designed particularly for CWDM metropolitan application. The new OXADM has capability of offering high survivability through restoration against the failure whereby a dedicated or shared protection can be implemented in CWDM metropolitan networks having ring topology. We performed the transparency test on OXADM in order to observe the effect on the wavelength size to the device performance. The result reveals that OXADM has capability to execute the reliable transparent switching in optical network. As a conclusion, OXADM is a transparent and wavelength independent device similar to OXC and OADM.

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