

Review

Application review of add drop multiplexer through OXADM device

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In this paper, we overviewed a new architecture of asymmetrical optical switch device which is expected to have vast application in optical communication and monitoring system. As reported in previous publication, it has many excellent features such as low crosstalk, lossless and multifunction. The multifunctional device means the integration of single functional devices onto single architecture and Optical Cross Add and Drop Multiplexer (OXADM) achieved the point with its unique architecture. With the use of micro-electro-mechanical systems (MEMs) technology has minimized the effect of crosstalk and return loss. With the accumulation feature, asymmetrical OXADM has widened its application to fiber-to-the-home (FTTH) and network security system. The main function of OXADM is to reconfigure the optical channel path while implementing add and drop function simultaneously. The multifunctional OXADM can also work as single optical devices such as multiplexer, demultiplexer, optical cross-connect (OXC), optical add drop multiplexer (OADM), wavelength selective coupler (WSC) and wavelength roundabout (WRB). With such excellent features, the OXADM is expected to be unique, universal and with a high reliability that is used to overcome the various functions in wavelength-division multiplexing (WDM) communication network today. This paper reviewed the application of OXADM through its unique features.

Key words: Accumulation, asymmetrical, optical cross add and drop multiplexer (OXADM), 'U' turn reflection.

INTRODUCTION

The increase of capacity in transmitting data over 10 Gbps has limited the use of coaxial cable as medium for data transmission. Hence, fiber optic technology has been opted to fulfill the requirement for wide band transmission. Introducing WDM into the fiber optic technology has made it the transmission medium without limits that offers few advantages including higher capacity and speed, ability for transmitting long distance data and a better signal quality.

Information transmitted in the domain optic is transferred via point line to point using synchronous optical networking (SONET) / synchronous digital hierarchy (SDH) equipment to create ring and mesh

topology network. In this network, the needs of the devices for add drop operation and cross-connecting optical line are executed by OADM and OXC respectively (Tzanakaki et al., 2003; Mutafungwa, 2000). These two devices have wide application in optical world and have a same basic structure, but both having different characteristics. OADM handled different signal carrier at each of its base, meanwhile OXC operates the same signal carrier. Therefore, both devices have been used at different locations for different functions. But if the function of both devices is merged together, the application of optical technology will be tremendously widened.

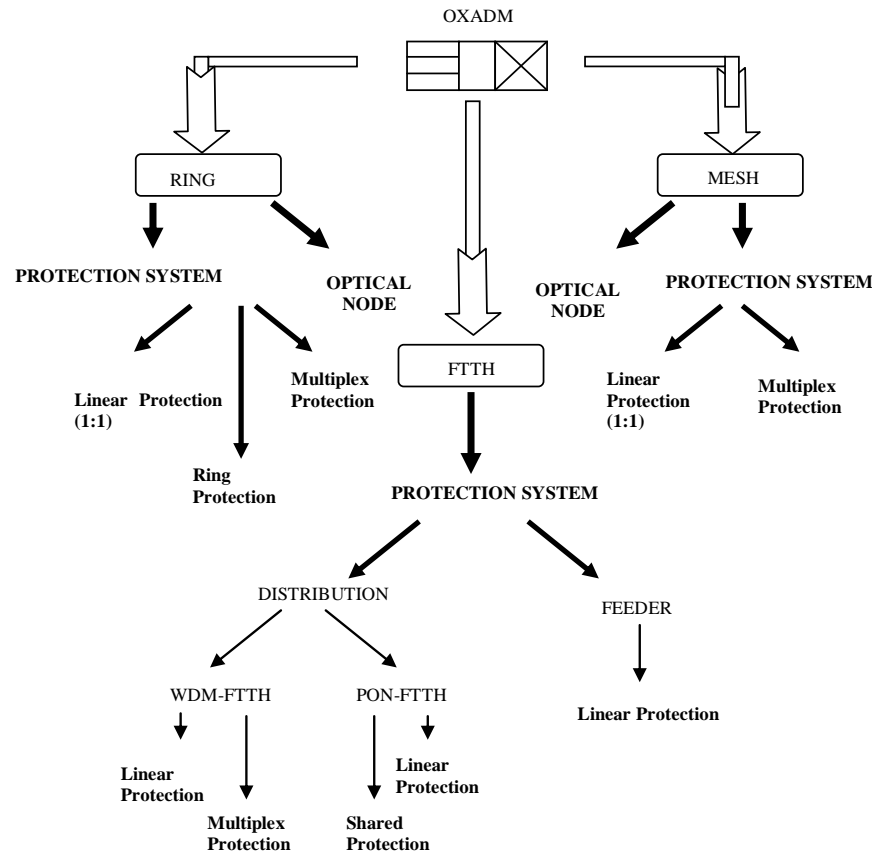


Figure 1. Chart of OXADM applications and functions for the three optical network ring network, mesh and FTTH

The explosive requirement of bandwidth and new randomly nodes presence have led to a demanding of flexible, efficient, survivable and multifunctional device to support all of network topologies and functions (Eldada and Nunen, 2000). The introducing of new architecture of switching device that is designed to overcome drawbacks that occur in migration is expected. The device is called OXADM which use combination concept of OXC and OADM (Rahman et al., 2006a). It enables the operating wavelength on two different optical trunks to be switched to each other; while implementing add and drop function simultaneously. Here, the operating wavelengths can be reused again as a carrier of new data stream. The wavelength transfer between two different cores of fiber will increase the flexibility, survivability and also efficiency of the network structure. To make device operational and more efficient, MEMs switches are used to control the mechanism of operation such as wavelength add/drop and wavelength routing operation. As a result, the switching performed within the optical layer will be able to achieve high-speed restoration against failure/degradation of cables, fibers and optical amplifiers (Rahman et al., 2006b). Two restoration schemes have been proposed to provide survivability in ring and mesh

metro network which are being activated according to the condition of failure by means of linear, multiplex and ring protection (Rahman et al., 2006a; Rahman and Shaari, 2006). The migration of topology will be easier and reduce the restructuring process by eliminating the installation of new nodes because OXADMs are applicable for both types of topologies beside providing efficiency, reliability and survivability to the network (Rahman et al., 2006b).

OXADM function chart

Figure 1 shows the chart of OXADM applications and functions for the three optical network ring network, mesh and FTTH. Besides functioning as a distribution node and bandwidth management, OXADM also offers survivability features to the networks. This is the difference between OXADM with previous nodes. OXADM protection mechanisms which are based on location and type of damage will be advantageous to today's communication system for quality of service (QoS). This is the uniqueness of this OXADM compared with existing protection systems. Extensive areas of this function make

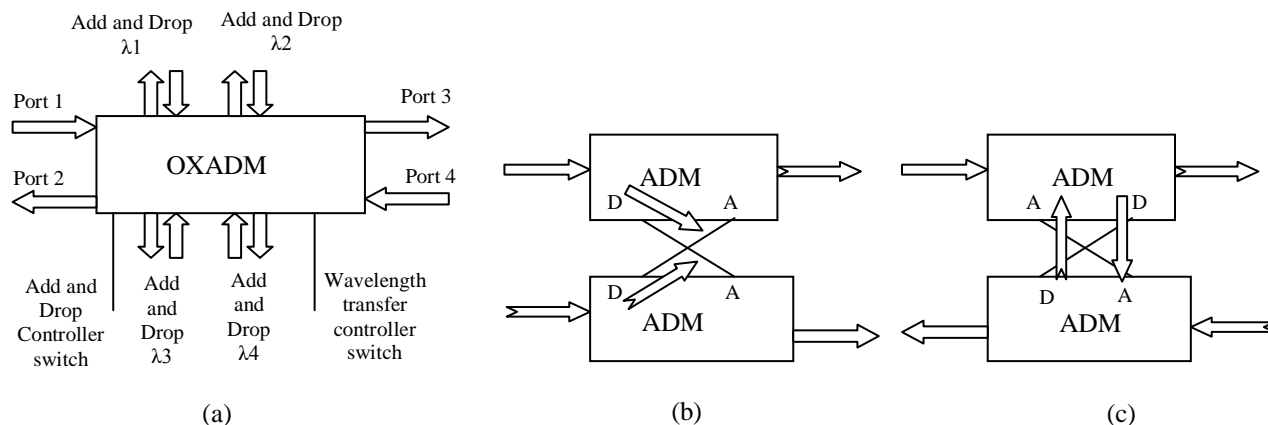


Figure 2. The block diagram of OXADM (a). OXADM is similar to the two ADM connected in parallel, which the drop port connected to add port and vice versa. This enable the cross-connecting (b) and U turn mechanism (c) can be implemented

OXADM a multifunctional device that is yet to be developed first by any research institution or optical device manufacturers today.

OXADM – Next generation of ADM device

OXADMs are elements which provide the capabilities of add and drop function and cross connecting traffic in the network, similar to 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 or higher (signals with finer granularities are handled by logical switch node such as SDH/SONET digital cross connects or asynchronous transfer mode (ATM) switches).

There are eight ports for add and drop functions, which are controlled by four lines of MEMs switch. The other four lines of MEMs switches are used to control the wavelength routing function between two different paths (Figure 2a). The selection of MEMS switch is important in order to minimize the effect of leakage signal. The functions of OXADM include node termination, drop and add, routing, multiplexing and also providing mechanism of restoration for point-to-point, ring and mesh metropolitan and also customer access network in FTTH. With the setting of the MEMs optical switch configuration, the device can be programmed to function as other optical devices such as multiplexer, demultiplexer, coupler, WSC, OADM, WRB etc for the single application. In ring architecture, OXADM perform as a node and the function is similar to the parallel connection add drop multiplexer (ADM) in which the drop port of one ADM is connected to Add port and vice versa. The architecture is depicted in Figure 2b and 2c (Eldada and Nunen, 2000). The designed 4-channels OXADM device

is expected to have maximum operational loss of 0.06 dB for each channel when device components are in ideal condition (Rahman and Wahab 2008). The maximum insertion loss when considering the component loss at every channel is less than 6 dB. In the transmission using SMF-28 fiber, with the transmitter power of 0 dBm and sensitivity -22.8 dBm at a point-to-point configuration with safety margin, the required transmission is 71 km with OXADM (Rahman and Wahab, 2008). The value is calculated based on point to point configuration and without the need of regeneration.

The asymmetrical OXADM architecture consists of 3 parts; selective port, add/drop operation and path routing. Selective port permits only the interest wavelength going through and acts as filter. With the switch configuration, add and drop function can be activated in second part of OXADM architecture. The signals are then re-routing to any port of output. The signals can also be accumulated on one path and exit at any output port (Rahman and Ibrahim, 2008).

OXADM optical switch

The control switch for OXADM optical switch is used to change the path of incoming from the input port. When the control switches in 'off' state, no switching occurs and the signal passes through the device as seen from the Figure 3a. But when the control switch B is 'on' state, the signal from the input 1 will be switched to Output 2 (Figure 3b). The accumulation function occurs which multiplex all the signals from the inputs together and exit at the Output 2. This will be the same if the control switch A is in 'on' state but the entrance is at Output 1 in contrast to the control switch B which is in reverse state (Figure 3c). If both switches are in 'on' state, the signal will be switched to exchange their output port and works as an OXC device (Figure 6b). When switch E is activated,

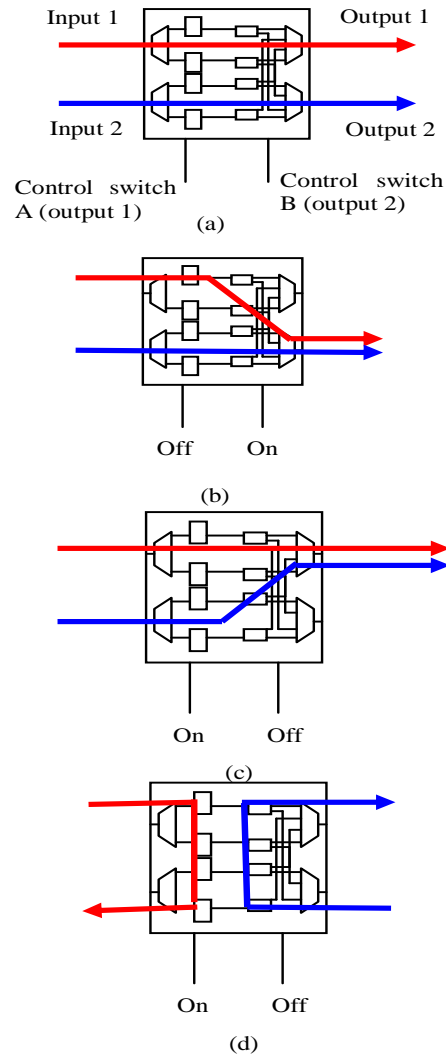


Figure 3. OXADM optical switch works as re-configurable output port multiplexer. (a) Normal condition. (b) Switch B activated – Accumulation signal on output 2. (c) Switch A activated - accumulation signal on output 1 d) Switch E activated – ‘U’ turn mechanism.

the signal will be diverted against the input port as ‘U turn mechanism’ (Figure 3d). The function of an OXADM optical switch can be summarized through the truth functional table shown by Table 1. The incoming signals from the back will be switched to neighbor output port or pass through the device. This is shown in Figure 4. As a conclusion, with such unique function OXADM can be used to replace the malfunction device temporarily before the restoration/replacement has been taken in place.

Device comparison

The OXADM device will be compared with two existing switching devices; directional coupler (DC) switch, OADM

and OXC. The non-selective DC switch has two states and one control element. It has fixed number of input and output port which is two. The wide bandwidth signal comes from the input port and will be switched to either one of the output ports. It works bi-directional with symmetrical function (Palais, 2005; Kirihaara et al., 1993). Figure 5 shows the mechanism of switching for DC switch in normal (a) and active condition (b) and (c). The application of DC switch is to control the signal path in WDM network and optical storage; and can also perform the function of OADM in optical distributed network. OXC is the directional coupler switch but with many ports. The functional of OXC is cross-connecting between output and input port by means of matrix switch controller (Figure 6) (Mutafungwa, 2000). Same with OXADM, the

Table 1. The truth table of OXADM optical switch.

Switch A	Switch B	Output 1	Output 2
0	1	λ_A	λ_B
1	1	$\lambda_A + \lambda_B$	X
1	0	X	$\lambda_A + \lambda_B$

0 = Off; 1 = On; X = No signal; λ_A = Signal enters input 1; λ_B = Signal enters input 2.

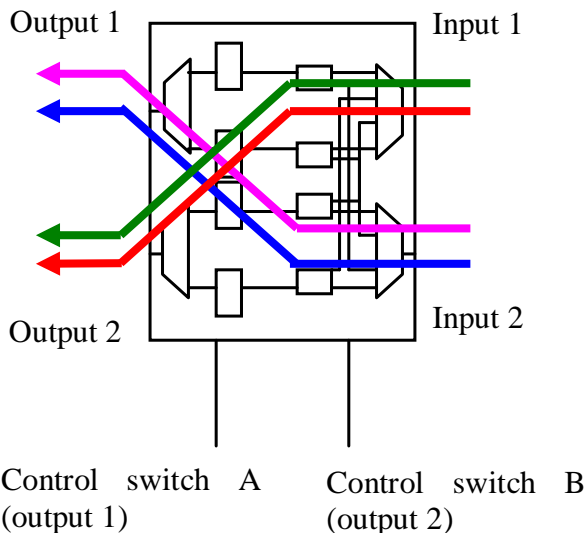


Figure 4. OXADM optical switch works as 2x2 demultiplexer. When the switch is activated, the signal will be switched to any output port.

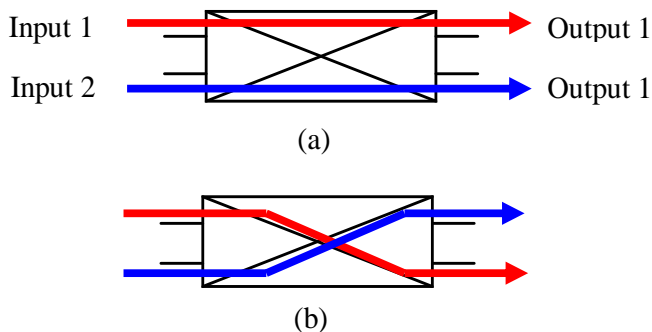


Figure 5. Switching mechanism of DC optical switch, (a) Normal (b) Activate.

OXC and OADM is selective device but it does not have accumulation function. In contrast with OXADM, OXC and OADM work bi-directional with symmetrical function (Rahman and Ibrahim, 2008). The application of OXC is as a switching device in mesh network configuration and also in optical storage. Meanwhile OADM is suitable for

Table 2. Comparison between OXADM, OADM, DC and OXC.

Features	OXADM	OADM	DC	OXC
Selective	Yes	Yes	No	Yes
Accumulation	Yes	No	No	No
Scalability	Yes	Yes	No	Yes
Symmetrical Function	No	Yes	Yes	Yes
U Turn	Yes	NO	No	No

ring configuration. Table 2 summarizes the differences of OXADM with DC, OADM and OXC.

The function of 'accumulation' and 'U turn' has made OXADM one of the unique device in this century. It can be developed as integrated optical system and can also be simplified to be optical switch device. The concept has been extended and specifically used for FTTH-PON application by means of second generation of OXADM. The device has been named as Customer Access Protection Unit (CAPU). CAPU has been widely used in FTTH_PON network which utilizes ring and tree based configuration and the number of failure that can be restored is up to three points for different line and location.

DEVICE TEST

Crosstalk

Two parameters have been studied experimentally to ensure the interference of uninterested signal is minimized. Figure 7 shows the experimental set up to measure the crosstalk and two ports of OXADM and the results have been redrawn in Figures 8 and 9 respectively. The crosstalk value is bigger than 60 dB and means the interested wavelength is in safety mode and the transmitted data can be interpreted at any receiver end.

OXADM is developed through the configuration of the existing devices therefore the selection of devices used has become important to ensure the value insertion loss, return loss and crosstalk are acceptable. This ensures the OXADM can be used in any optical device to perform various function as claimed.

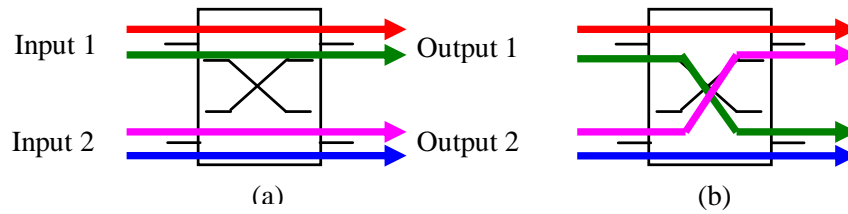


Figure 6. Switching mechanism of OXC, (a) Normal (b) Activate.

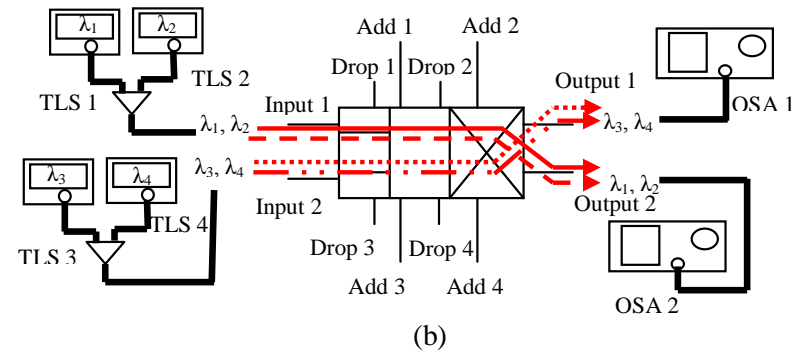
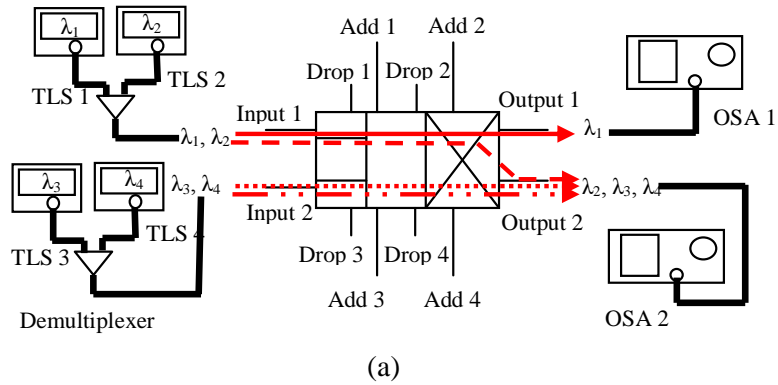


Figure 7. Crosstalk measurement set up. (a) Configuration 1 (b) Configuration 2.

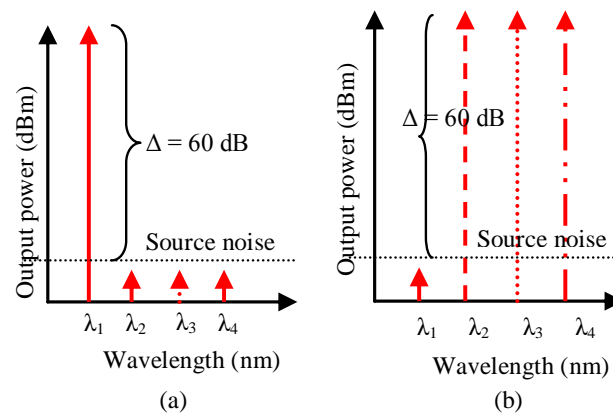


Figure 8. Redrawing of measured output signal for configuration 1. (a) Output 1 (b) Output 2.

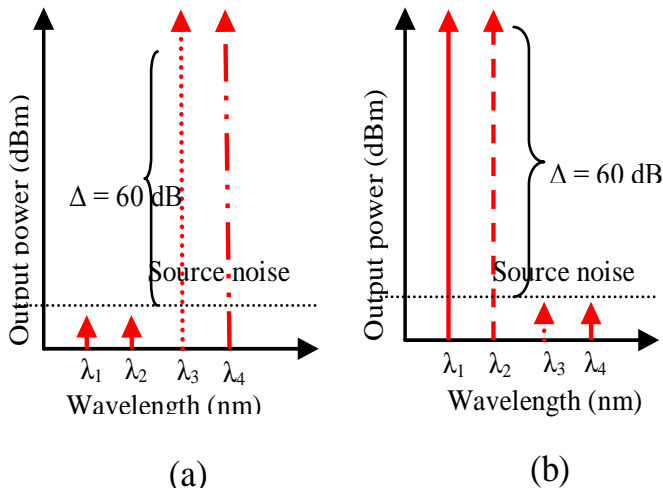


Figure 9. Redrawing of measured output signal for configuration 2. (a) Output 1 (b) Output 2.

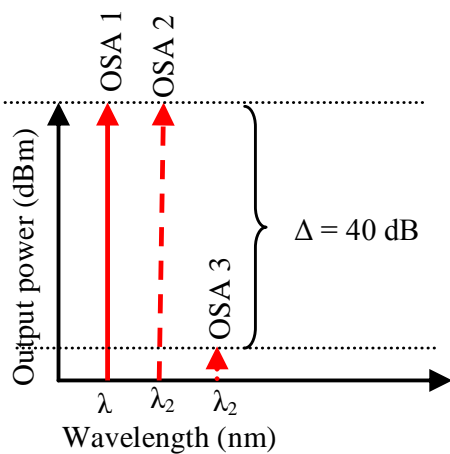


Figure 10. Redrawing of measured signal at every output port for return loss measurement.

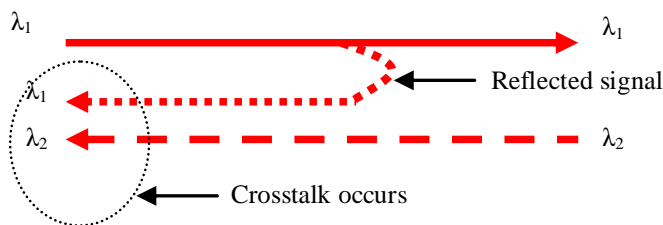


Figure 11. Return loss is a reflected leakage signal which contributes to crosstalk phenomena in bi-directional device

Return loss

The other parameter considered for bi-directional device

is return loss. Return loss is the disturbance of uninterested signals against the direction of interested signal. This can be explained using Figure 11. The return loss is measured by using set up in Figure 7 (adding circulator in front of device and the reflection was measured by optical spectrum analyzer (OSA)) and the result is shown in Figure 10 (redrawn). The value is 40 dB which is higher than minimum safety value. Both experiments have shown that the OXADM optical switch has a good value of crosstalk and return loss. The crosstalk and return loss can be improved by selecting a reliable optical switch.

Insertion loss

Figure 12 represents the maximum distance allowed in point-to-point configuration using two OXADM with the attenuation that varied from 10 to 20 dB. The study is important to determine the exact maximum distance that can be achieved with the real OXADM attenuation. The test under ideal condition ($\alpha = 0$ dB) using Optisystem simulator indicates the operational loss is less under the 0.052 dB. The loss for every single operation of OXADM is shown in Table 3. Under this condition, the maximum length that can be achieved by OXADM with the losses values is 94 km. But when the loss of every element build OXADM is considered, the maximum length that can be achieved in point to point configuration (using two OXADMs) is 71 km without regeneration and Figure 13 indicates this by the equation below. 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 14). Here, the output power is measured by varying the input power at different length of fiber. The results are compared with simulation to ensure 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 -35 dBm, which means that the length of fiber can be extended.

But when the loss of every element build OXADM is considered, the maximum length that can be achieved in point to point configuration (using two OXADMs) is 71 km without regeneration and Figure 13 indicates this by the equation below

$$y = -3.9151x + 94.434 \tag{1}$$

Optical signal-noise-ratio (OSNR)

The OXADM device is characterized by using two tunable light sources (TLSs) and two OSAs. The designed 4-channels OXADM device is expected to have maximum operational loss of 0.6 dB for each channel when device components are in ideal condition. The maximum insertion loss when considering the component loss at every channel is 6 dB. The testing is carried out for every

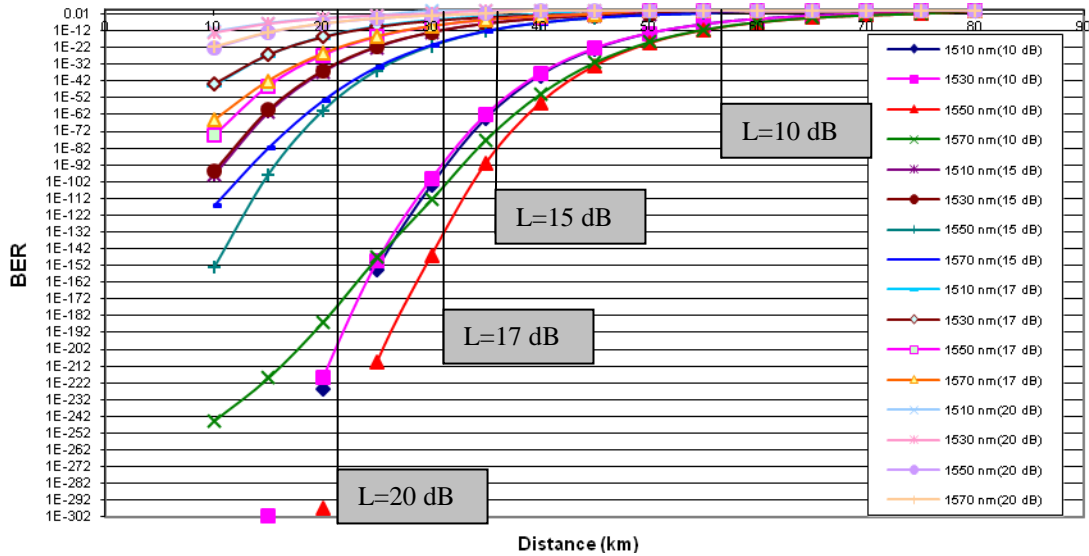


Figure 12. The maximum distance allowed at different attenuation of OXADM (10 dB to 20 dB) in point-to-point OXADM configuration at 2.5 Gbps

Table 3. OXADM operational insertion loss in ideal condition.

Operational	Feature	Insertion loss (dB)
Demultiplex	Separate the signals	0.028
Multiplex	Combine the signals	0.038
Accumulate	Accumulation all signals on one path	0.038
Exchange	Path exchange	0.051
	Double path exchange	0.051
Pass Through	Bypass	0.051
Drop	Drop a wavelength	0.037
Add	Add one wavelength	0.037

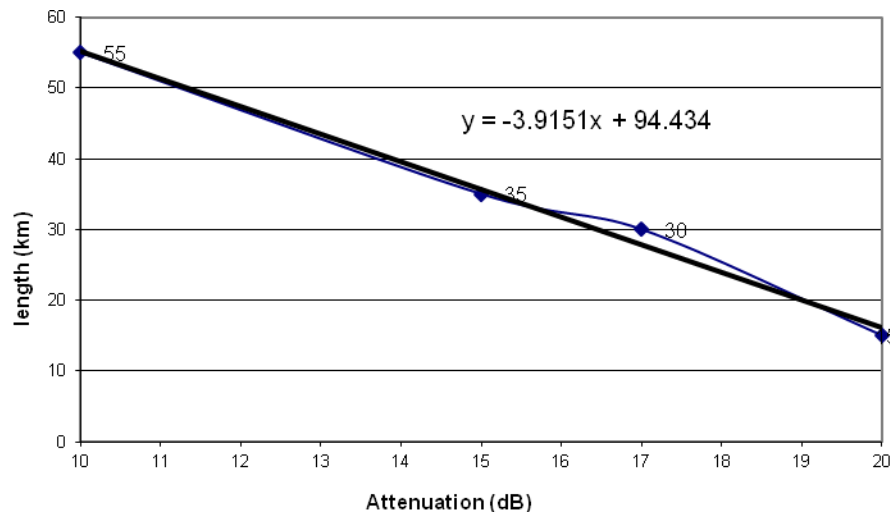


Figure 13. The decrement of kilometers occurs by increasing the attenuation of OXADM which represent the device losses

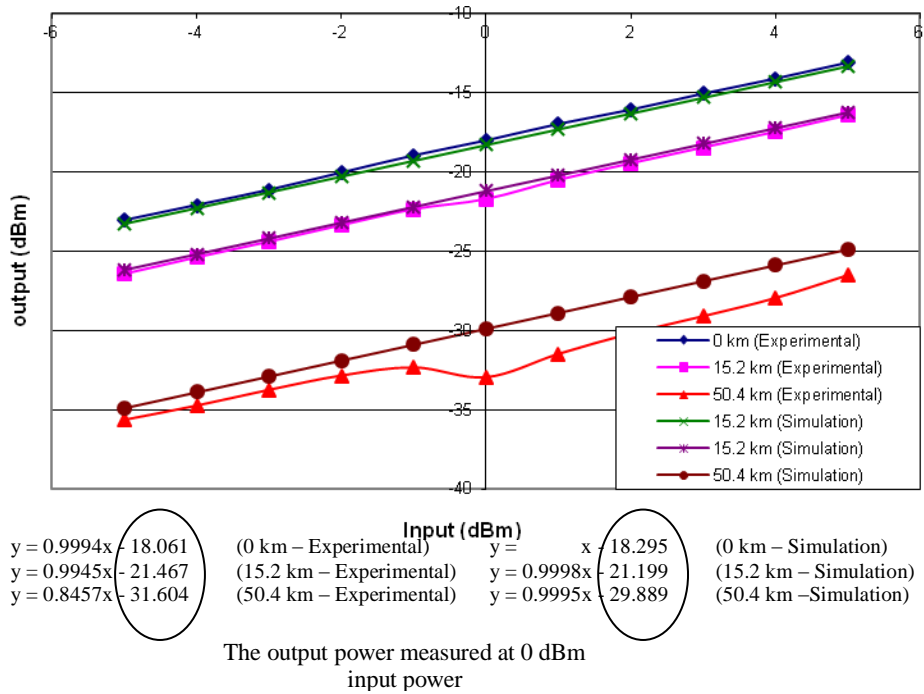


Figure 14. Comparison between the simulation and experimental result for output versus input power in point-to-point configuration.

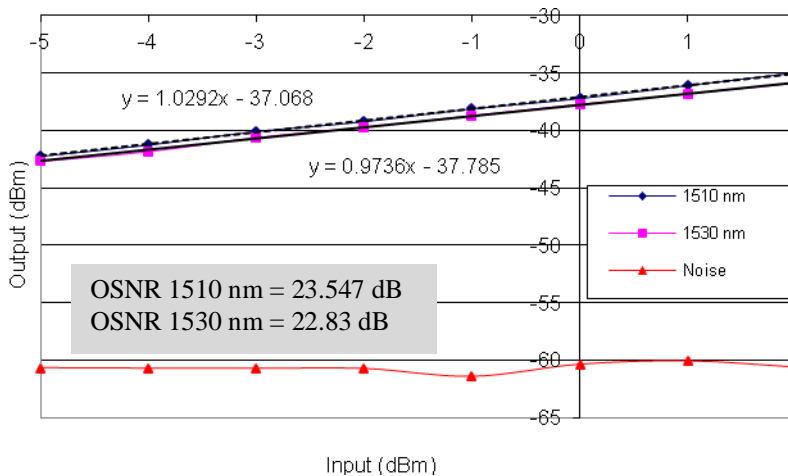


Figure 15. The measured output power at two operating wavelength for bypass operation.

single function of OXADM. The function includes bypass, path exchange and accumulation.

The single operating wavelength test (wavelength is 1510 nm), the results show the OSNR value for bypass function is 20 dB (as Figure 2a) and path exchange is also 20 dB. Each measurement result is indicated in Figures 15 and 16. The path splitting function (accumulation function in reverse mode as Figure 2b and

c) is also applied and the result shown in Figure 17 with OSNR > 24 dB. For backward operation as depicted in Figure 18, the OSNR values for cross-connecting function (Figure 4) are bigger than 22 dB. This can be defined that the level of signal is 20 dB higher than noise level for all single functions of OXADM optical switch. The 20 dB reference indicates the acceptable value for the signal to noise ratio in data communication.

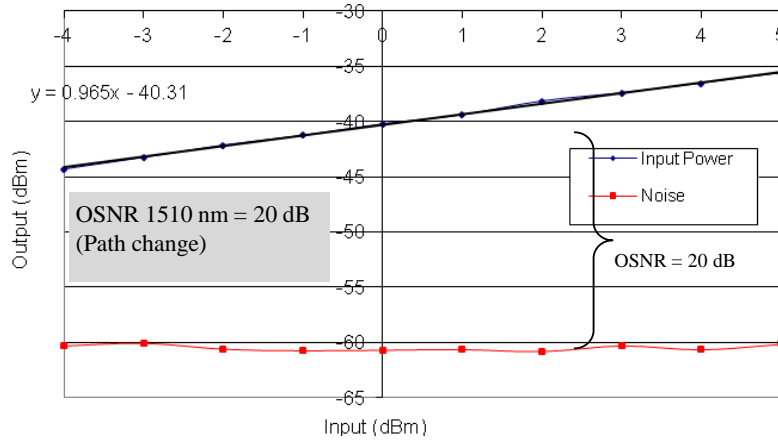


Figure 16. The measured output power for path exchange operation.

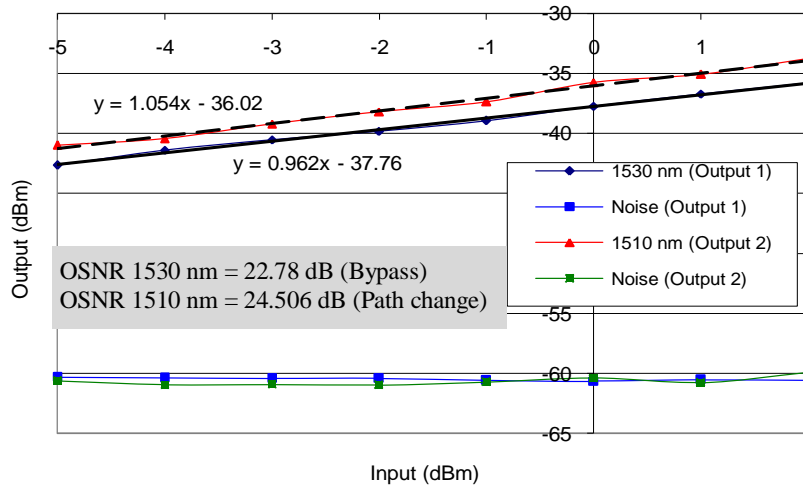


Figure 17. The measured output power two operating wavelength for path splitting operation (accumulation function in reverse mode).

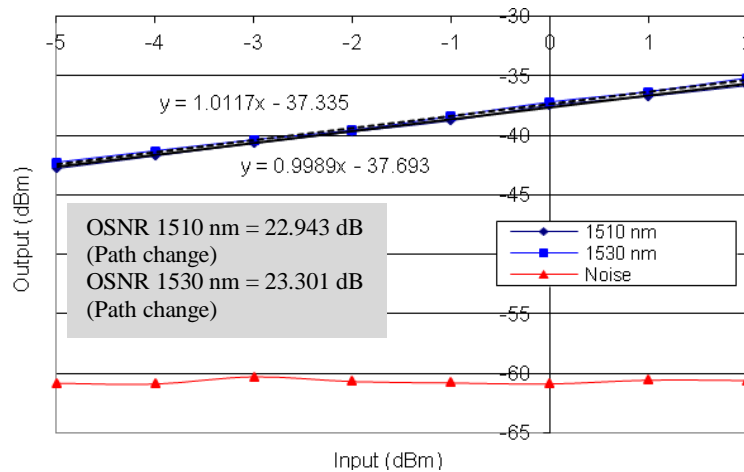


Figure 18. The measured output power at two operating wavelength for path exchange operation.

Table 4. The specification of OXADM prototype device.

Parameters	Values	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		°C	
Storage Temperature	-40 to +85		°C	

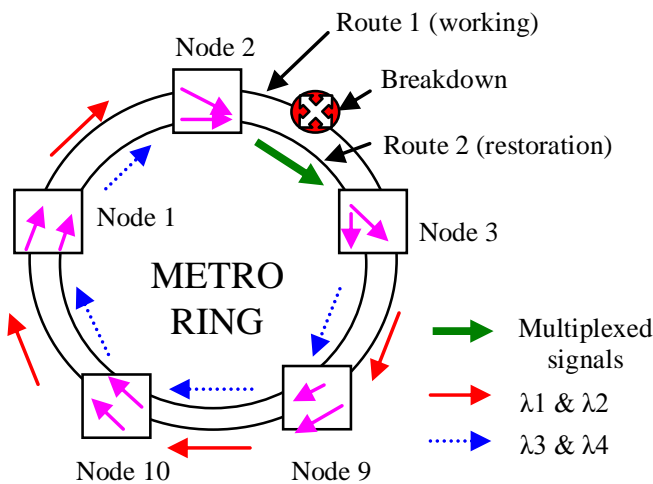


Figure 19. Dedicated protection mechanism in metro ring network. When a link failure occurs within the ring, the affected is switched over to the protection path.

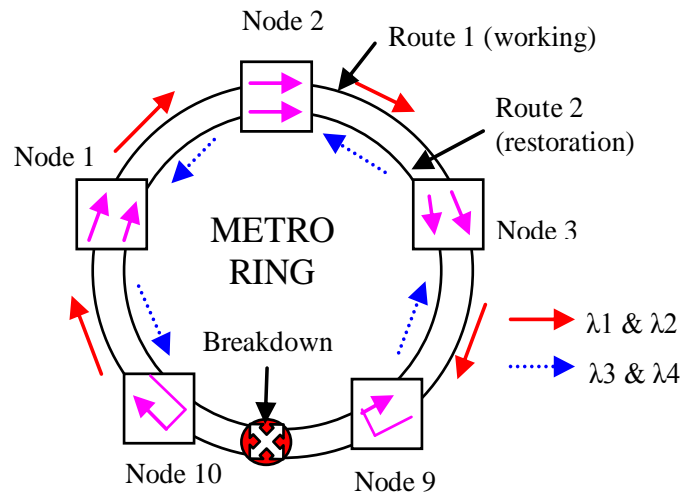


Figure 20. Ring protection mechanism in metro ring network. When a cable/node failure occurs within the ring, the node adjacent to the failure loop back the affected signal on the protection route of the ring

APPLICATION PROPOSAL

Survivability scheme

The restoration is significant for ensuring signal flows continuously. 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. Figure 19 depicted the activation of dedication protection when failure occurs between Nodes 2 and 3. The affected node will switch the signals to protection route. It is important to avoid huge losses of data and great influence upon a large number of users over a wide area. OXADM provide

a ring protection scheme to implement shared protection. The ring protection is activated when either 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 (Figure 20). The ‘U turn’ mechanism is applied in OMS-SPRing (or Bidirectional Line Switch Ring (BLSR)). The detail description and full results analysis of survivability scheme on ring metropolitan network can be found in Rahman and Shaari (2006). We are also extending the scheme in FTTH customer access network (Rahman et al., 2006b).

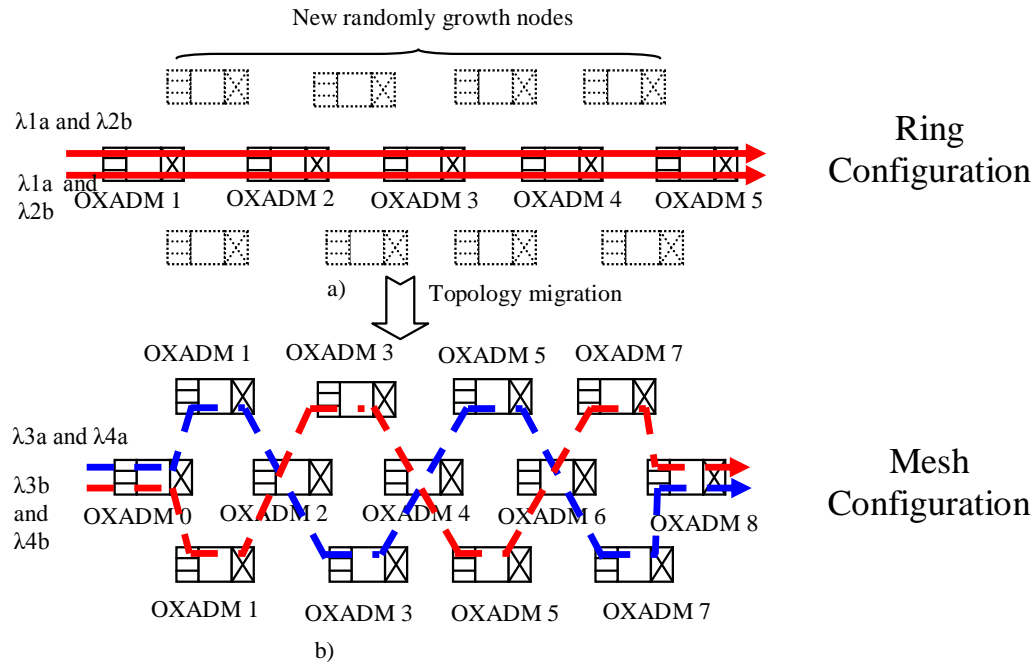


Figure 21. The migration of ring to mesh topology using OXADM nodes. The signals can be cross-connected along the path in optical line. OXADM works as an OADM and OXC in ring and mesh networks respectively (a) Ring network (b) Mesh network.

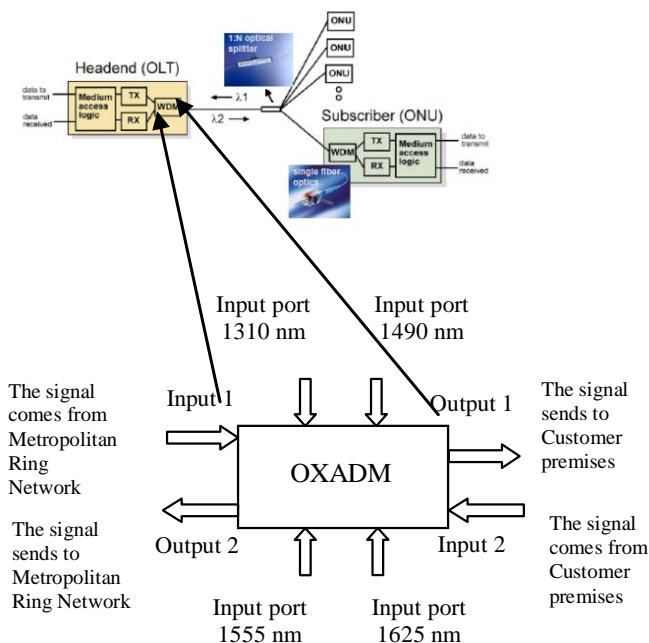


Figure 22. OXADM functions as the wavelength management element in OLT in FTTH technology.

Topology migration

Figure 21 shows the topology migration from ring to mesh configuration utilizing OXADM nodes. Nodes 1,

2, 3, 4 and 5 form the original ring nodes which conduct the signals in unidirectional way. Without altering the original existing network, the new nodes growing in random locations can be integrated into the original network, forming a mesh network. This topology migration from ring to mesh configuration can be easily performed by utilizing the features which the OXADM has to offer. This can lead to cost and time effective because the restructuring and re-cabling process can be avoided. Rahman et al. (2006a) and Rahman and Shaari (2007) covers the theoretical, simulation study and experimental results discussed on the migration scheme utilizing OXADM.

Wavelength management in FTTH OLT

FTTH is a simple, inexpensive, ideal and attractive many parties in optical communication today. It involves the full installment of fiber from central office till to customer houses which is called premises. The technology ensure low capital expenditure (CAPEX) and operational expenditure (OPEX) because all elements in use are a passive optical device with small number used. The maximum achievable distance is 20 km with gigabit of transmission rate. FTTH consist of three significant elements; optical line terminal (OLT), optical splitter and optical network unit as shown in Figure 22. The designed OXADM is expected to be used as the wavelength management in OLT architecture for excellent FTTH

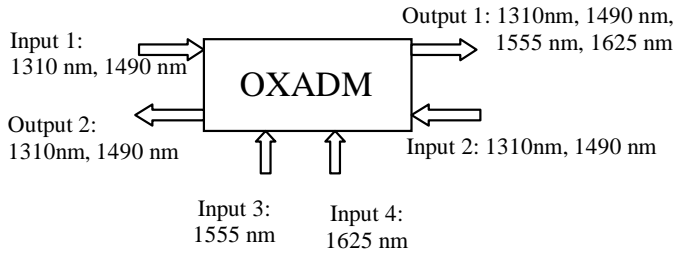


Figure 23. Received data from metropolitan ring network and also from the input terminals 3 and 4. Input terminals 3 and 4 will represent the video signal from satellite television or high-definition television (HDTV).

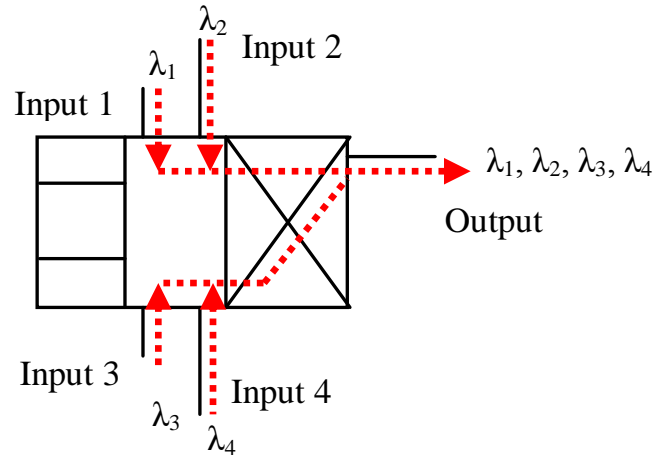


Figure 25. The functional diagram of OXADM:MUX 4x1.

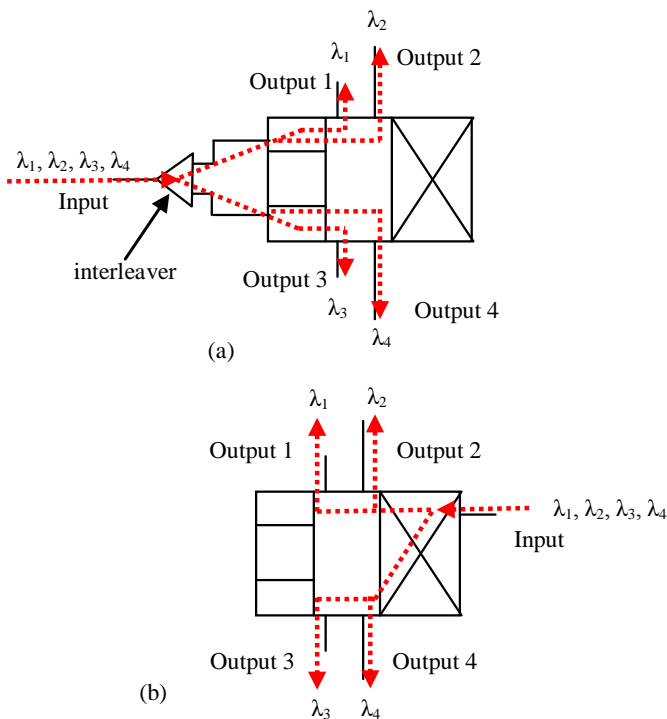


Figure 24. The functional diagram of OXADM:DEMUX 1x4. (a) Configuration 1 (b) Configuration 2.

network. It has four input terminals which represent the four different signal carriers to be multiplexed and exit at Output 1. The signals are then sent to the customer premises. This can be defined in Figure 5 with the wavelength allocation shown in Figure 23. The detail description of OXADM function as the wavelength management can be found in Rahman and Wahab (2008).

Multifunction device

With the setting of the MEMs optical switch configuration,

the device can be programmed to function as other optical devices such as multiplexer, demultiplexer, coupler, wavelength converter (with fiber grating filter configuration), OADM, WRB, etc for the single application. The functional diagrams of OXADM perform as the multi-functional devices can be seen in Figures 24, 25 and 26 for some diagrams. The others can be found in Rahman and Wahab (2008) with detailed explanation.

a) Demultiplexer: There are two configurations of demultiplexer using OXADM, with interleaver and without interleaver. The function of interleaver is to separate the incoming signal before entering the OXADM ports (Figure 24a). In contrast, the signal will enter the back port and has automatically routed to their respective path (Figure 24b).

b) Multiplexer: The input signals enter the add ports of OXADM and the multiplexed signal out of the signal via output port (Figure 25).

c) OADM: The separated wavelengths out of the interleaver have a capability to add/drop function before they are combined and exit one of the output ports of OXADM.

d) WSC: Two WSC devices will be produced by OXADM. The signal will enter the input port and will be separated out through the drop port of OXADM.

e) OXC: The concept is similar to OADM but the OXADM also offer the function of cross- connect the signals. The function is almost the same with OXC device (Figure 26).

f) WRB: The new invented device that offers the management functions of wavelengths. Different from circulator in which the inputs and outputs are built separately.

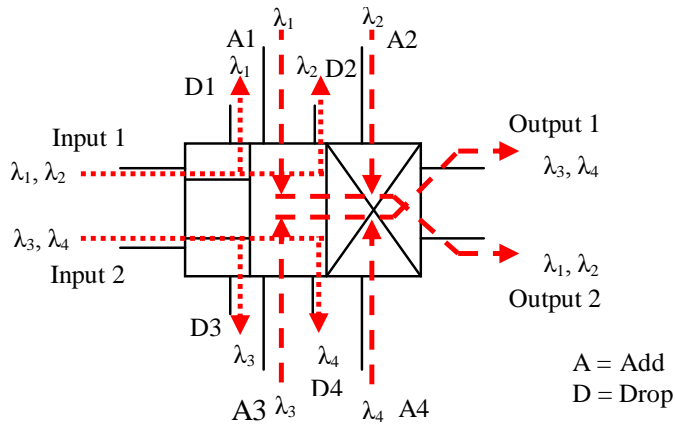


Figure 26. The functional diagram of OXADM:OXC.

CONCLUSION

We introduced a new architecture of optical switching device which utilizes the combined concepts of OADM and OXC operation through the development of OXADM. OXADM optical switch involves the function of wavelength drop, add, cross-connect, accumulation, multiplex and also demultiplex. The experimental results show the value of crosstalk and return loss is bigger than 60 and 40 dB respectively. The OXADM switching mechanism has been explained and compare with other existing optical switch; DC switch and OXC. Analysis has shown the OXADM optical switch is more flexible and multifunctional compare to other existing devices. The OXADM optical device is particularly designed for WDM metro application. It can be used as restoration switch in FTTH network (Rahman, 2008). Additionally, with certain configuration, the switch can also perform a single function device such as multiplexer, demultiplexer, OXC, OADM, WSC and WRB. In other applications, the OXADM can also provide survivability through restoration against failure by means of dedicated and shared protection that can be applied in WDM ring metropolitan network and network migration without restructuring the existing network configuration. With the excellence, multifunctional, and flexible features, it is expected to be key issue to be discussed amongst the researcher and manufacturer soon. We include here the exact specification of OXADM, insertion loss for every function of device, crosstalk, return loss and storage and operating temperature. Due to OXADM is developed based on the combination of other optical devices; therefore specification will be determined accordingly.

The experimentally measured parameter values are shown in Table 4. This paper represents the final and complete version of OXADM invention report after we accumulate all the information from the previous reported paper (could be seen in the Reference list). OXADM is

the first optical device which can perform various functions in photonic communication and application.

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