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ORIGINAL ARTICLE

Effect of Network Parameter to the Digital Performance in OXADM Ring Protection Scheme

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Mohammad Syuhaimi Ab-Rahman: Effect of Network Parameter to the Digital Performance in OXADM Ring Protection Scheme.

ABSTRACT

This paper introduces a new optical device model named as an optical cross add and drop multiplexer (OXADM) which has potential use in CWDM metro area networks. OXADM is capable to restore the network during the failure condition by means of ring protection and linear/multiplex protection. In this paper we observed the network digital performance due to changing of optical network parameters such as Span, Wavelength, Transmission rate and Launched power. Output power and BER is used to measure the system performance under different condition.

Key words: OXADM, Ring, Survivability, Network Parameter, Performance.

Introduction

OXADMs are elements that provide capability to add and drop function and cross connecting traffic in the network similar to OADMs and OXCs (Tzanakaki *et al.,* 2003). OXADMs consists of three main subsystems; a wavelength selective demultiplexer, a switching subsystem and a wavelength multiplexer. There are eight ports for add and drop functions which are controlled by four lines of thermal-optical switches. The others four lines of thermal optical switches will be used to control the wavelength routing function between two different paths (see Figure 1).

The device uses the concepts of combination of optical add/drop multiplexing and optical cross connect between two main transmission lines in order to implement the wavelength routing operation (Ab-Rahman and Shaari, 2006). MEMS optical switches are integrated in the device to make it re-configurable. With excellent features, the device is particularly designed to improve network efficiency, flexibility and survivability (Ab-Rahman *et al.,* 2006a) (Ab-Rahman *et al.,* 2006a). The device can be used in point to point, ring or mesh network topology to provide functionality such as routing, supervision, transport, multiplexing and restoration of client digital signals processed predominantly in the optical domain (Ab-Rahman *et al.,* 2006a). The wavelengths on each optical trunk can be switched between each other while implementing add and drop functions simultaneously. The multiplexer has undergone performance test at 2.5 Gbps (OC-48) with BER less than 10^{-9}. The maximum length can be achieved by OXADMs is 71 km without amplification at insertion loss 6 dB. We also do a comparison between OXADM with the previous devices such as, OXC, TRN and OXN.

The function of OXADMs includes acting as a 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. With the setting of the MEMS optical switch configurations, the device can be programmed to function as other optical devices such as a multiplexer, demultiplexer, coupler, wavelength converter (with fiber grating filter configuration), OADM, wavelength round about etc. for a single application.

The asymmetrical architecture of OXADM consists of 3 parts; selective port (wavelength selective demultiplexer), add/drop operation (switching) and path routing (wavelength multiplexer) as shown as Figure 2. Selective port permits only the interest wavelength pass through and acts as a filter. While add and drop function can be implemented in second part of OXADM architecture. The signals can then be re-routed to any port of output or/and perform an accumulation function which multiplex all signals onto one path and then exit to any interest output port. This will be done by the third part. The ‘accumulation’ is the most interesting features and

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differentiates the OXADM with other previous device such as ROADM, OADM and OXC. The OXADM node focuses on providing functionally such as transport, multiplexing, routing, supervision, terminating and survivability in optical layer with ring and mesh topologies.

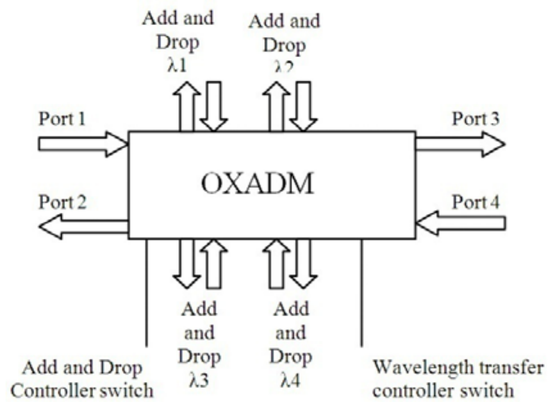

Fig. 1: The Block Diagram Of Optical Cross Add And Drop Multiplexing (OXADM).

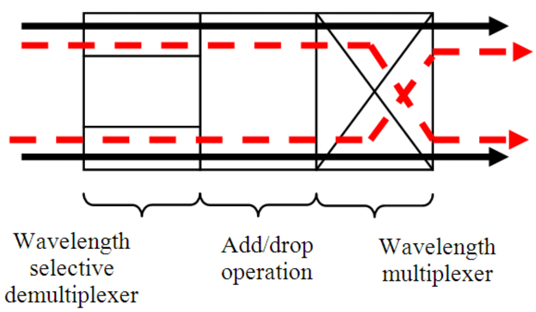

Fig. 2: Block diagram of OXADM.

Comparative Analysis:

Optical Add and Drop Device (OADM):

The Single Input/Output Port Limits the Application:

The OADM is the first reported device which performs a switching function. The OADM architecture was used then to develop the second generation device such as TRNs, ROADMs and others. But according to the previous source, OADMs were reported have been used as optical nodes in ring networks (Kataoka *et al.*, 2004; Nuzman *et al.,* 2003). The OADM architecture which consists of single input and output port has limited the working line application. None of protection lines have minimized the restoration function in the network application. As a result, in the case of failure the drop and segmentation function are utilized alternatively.

Optical Cross Connect (OXC):

No Accumulation Function:

Although OXCs have a capability of being network configuration devices particularly in ring topology to mesh topology without a restructuring process, security in this device is very low. Because the OXC is an architecture that can be expanded especially in topology change from a ring to mesh topology without the need for new optic nodes, OXCs need to have a security system that can be used in both situations (Tzanakaki *et al.,* 2003) (Tsushima *et al.,* 1998). The security system in mind is accumulation. This enables all the input signals to be multiplexed onto one optic path if there is damage on one of the output lines. Because OXCs operate with both its input lines and the mentioned feature is not available this becomes a weakness for existing OXCs. This is because if both transfer lines are used, damage that occurs on one of them will cause transmission to be cut where data from the second input terminal cannot be sent to any output. Figure 3 shows damage at the second output line causing data at the second input to be blocked and unable to be sent.

Ring Protection Cannot be Done:

If there is damage on both optic lines or damage at a nearby node in a ring network data can't be sent directly. The security feature that is needed is ring protection that is used in the OMS-SPRing scheme. Ring protection involves the signals at the first input terminal to be directed through a U-turn out to the second input terminal enabling a segmentation process at the damage area to be done. However this feature is not supplied in the OXC's security architecture. In a ring network architecture that uses optic OXC nodes, if there is damage involving two or all lines or damage to the nodes, a node near the damage area will be used as a terminal node and all signals will be dropped or directed to a new path that involves a large segmentation area and includes undamaged nodes. This situation incurs flaws on the optic communication system that is said to be invulnerable and able to heal against all possibilities of damage. Figure 4 shows a segmentation process of quarantine of the damage area in a ring network using OXC nodes (Tzanakaki *et al.,* 2003).

Tunable Ring Network (TRN):

Drop and Re-Add Operation for Surveillance Scheme:

In the OMS-Spring scheme, if there is damage on a node or both transmission lines, the node before the damaged area will activate ring protection that involves a signal to be turned back in a U-turn. In TRN, to perform this mechanism, signals will be dropped and re-added to the addition terminal on the second line using a reserved bandwidth that is specially allocated at the opposite direction to the first line (Eldada and Nunen, 2000). In activating signal path change for the linear protection scheme, signals will also be dropped and re-added to the addition terminal on the second line but at the same direction as the first line using reserved bandwidth (Eldada and Nunen, 2000). This drop and re-adding technique causes a time delay to the data signal that is sent. Besides that the requirement of an external switching system makes the design of a TRN node become more complex. Figure 5(a) shows the U-turn mechanism for activating ring protection in TRNs. Figure 5(b) shows the linear protection mechanism and path change using the drop and re-adding technique.

Optical Cross Node (OXN):

High Cost:

Even though the accumulation feature is included in the OXN architecture, it involves a high fabrication cost to be developed because it is made from a flexible Bragg grating filter configuration and also a high number of circulators. The function of the OXN device resembles an OXC and it is more transparent to operational wavelengths because of the adjustable element of the flexible Bragg grating that enables any carrier to be operated (Mutafungwa, E., 2000). The existence of this flexible Bragg grating gives high persistence and stability to the OXN but the cost per unit of this device is too high and the existence of circulators also contributes to the high cost. Figure 6 shows the architecture of an OXN that consists of costly components making execution cost of the optical network also increase compared when using other optic nodes such as TRNs, OXCs, AWGMs and others. An OXN needs four sets of the same Bragg grating filter and four circulators.

Ring Protection Cannot be Done:

Like OXCs, OXNs also cannot perform the ring protection scheme. Therefore if there is damage on both optical lines or on a nearby node, data cannot be sent directly. Even thought this ring protection feature is not given in the protection architecture of OXNs, when there is damage on all lines or on nodes, a nearby node will be used as a terminal node and all signals will be dropped or routed to a new path. This situation involves segmentation of a large area that includes undamaged nodes. Figure 4 shows the segmentation process or quarantine of the damaged area in a ring network using OXCs which can also be applied to OXNs.

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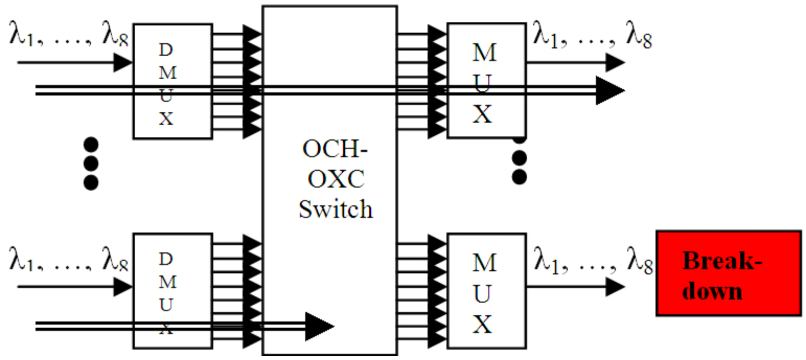

Fig. 3: The breakdown at one of the transmitting lines cause signal propagation to be cut in the case of sending data using both lines especially in mesh topologies.

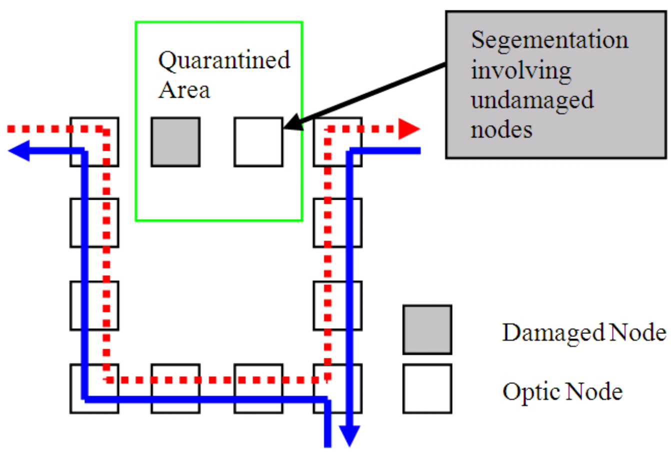

Fig. 4: Segmentation process of the damaged area that is done in a ring network before the damaged that occurred is repaired.

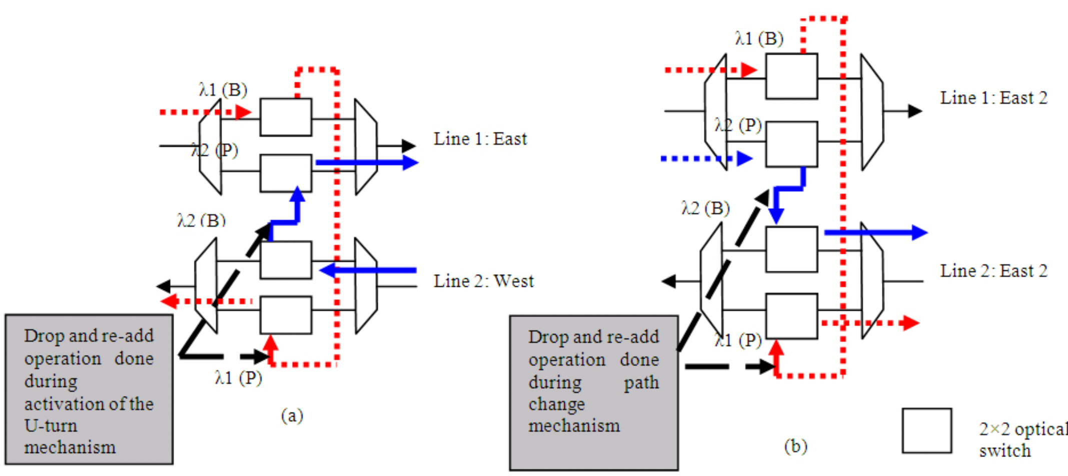

Fig. 5: Drop and re-add operation used to activate (a) ring protection in OMS-SPRing and (b) linear protection in OCH-DPRing.

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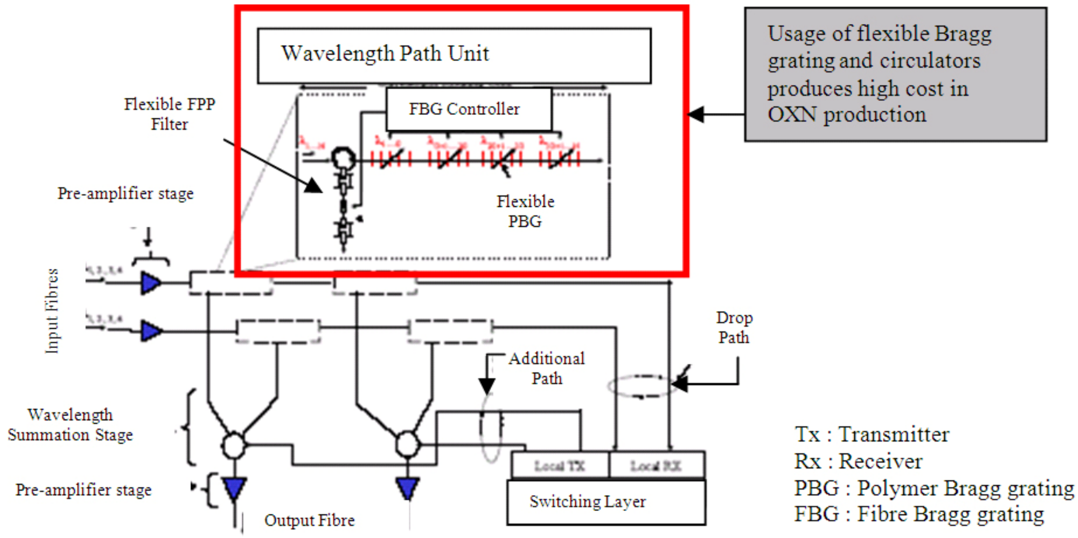


Fig. 6: The OXN architecture that consists of flexible Bragg grating and circulators produces high cost in the production of an OXN. Source: Mutafungwa 2001.

Analytical Modeling:

In a ring topology, OXADMs are located in the nodes, which have more than two switching directions in rings network. The function of OXADMs 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 7). The contribution of crosstalk comes from the number of input/output ports connected to fiber lines and the number of wavelengths per lines. Due to the presence of crosstalk, additional signal power is required to maintain a specified bit error rate (BER) in the presence of a particular impairment. Expressed n decibels, the power penalty is defined as (Shen *et al.,* 1999) (Steven, 2005).

Power Penalty =
10 $\log_{10}$([Power required with impairment] /
[Power required without impairment]) (1)

Assuming aligned polarization, the probability density function (PDF) for the resultant aggregate interference is approximately Gaussian, which leads to a theoretical power penalty (Ab-Rahman *et al.,* 2006a) (Ab-Rahman *et al.,* 2006a):

$$P_{penalty} = -5\log_{10}[1-4\times\sigma^2_{RIN}\times Q^2] \quad (2)$$

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 infinity. It is impossible to achieve BER smaller than the error floor because of the nature of crosstalk (Ab-Rahman *et al.,* 2006b). Here we apply the worst case used as in Figure 7 for the power penalty caused by incoherent crosstalk contributions, which are induced when optical propagation delay differences between signal and crosstalk contributions in an OXADM exceed the coherent time of the laser (Ab-Rahman *et al.,* 2002) (Steven, 2005). Assuming the OXADM is fully loaded, each signal passing through the OXADM will be interfered by MN-1 crosstalk contributions, which are leaked by the demultiplexer/multiplexer pairs. Based on the above assumptions, the power penalty from crosstalk contributions in one OXADM is given in equation 3 below (Ab-Rahman *et al.,* 2002).

The maximum power penalty (pp) caused by MN-1 incoherent crosstalk contributions from one OXADM is:

$$Max(pp)_{OXADM} = -5\log10[1-4\times Max(\sigma^2_{RIN})\times Q^2]$$

$$= -5\log10[1-4\times\varepsilon x(MN-1)\times Q^2] \quad (3)$$

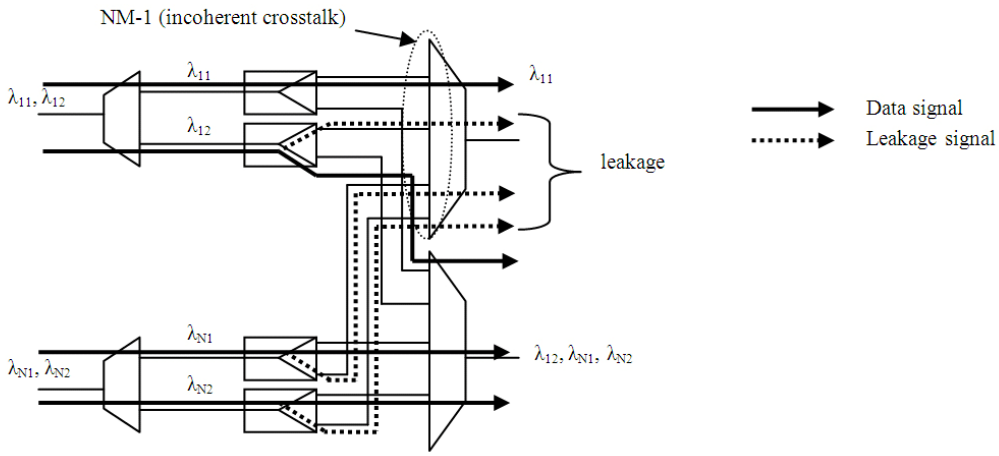


Fig. 7: Induction of incoherent crosstalk due to the leakage signal of each channel operates in OXADM.

Application: Ring Metropolitan Networks:

Figure 11 depicts the architecture of a ring metropolitan network consisting of eight OXADM nodes. OXADM nodes provide functionality such as transport, multiplexing, routing, supervision and survivability of client signals processed predominantly in optical domain.

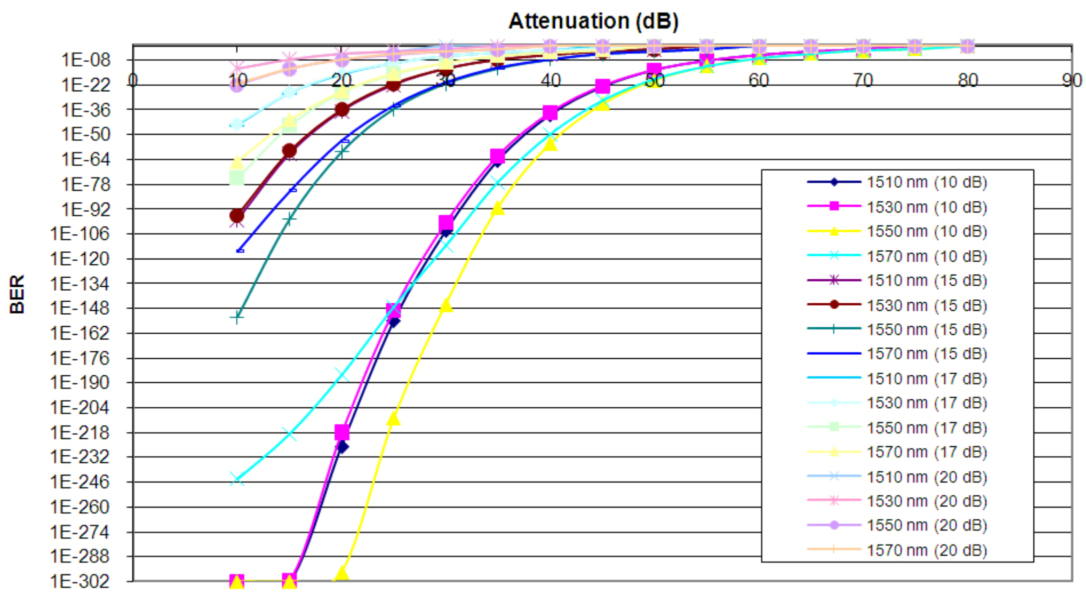


Fig. 8: BER versus Length Transmission for Four Different Attenuations Characterizing the Performance of Single OXADMs.

The position of OXADM nodes in ring structure is also compatible with all functions and restoration mechanisms that will be described in detail. Two types of restoration schemes can be employed using OXADM node that is activated according to the types of failure. The restoration schemes are linear protection and ring protection. Linear protection activates normally when one of transmission line breakdown in OCh-DPRing (UPSR) application (Ab-Rahman *et al.,* 2006b) (Ab-Rahman and Shaari, 2006). When a link failure occurs within the ring, the signal will be switched to the alternative route as illustrated in Figure 11 below. 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. This 'U turn' mechanism is applied in OMS-SPRing (BLSR) as illustrated in Figure 12 (Ab-Rahman and Shaari, 2006).

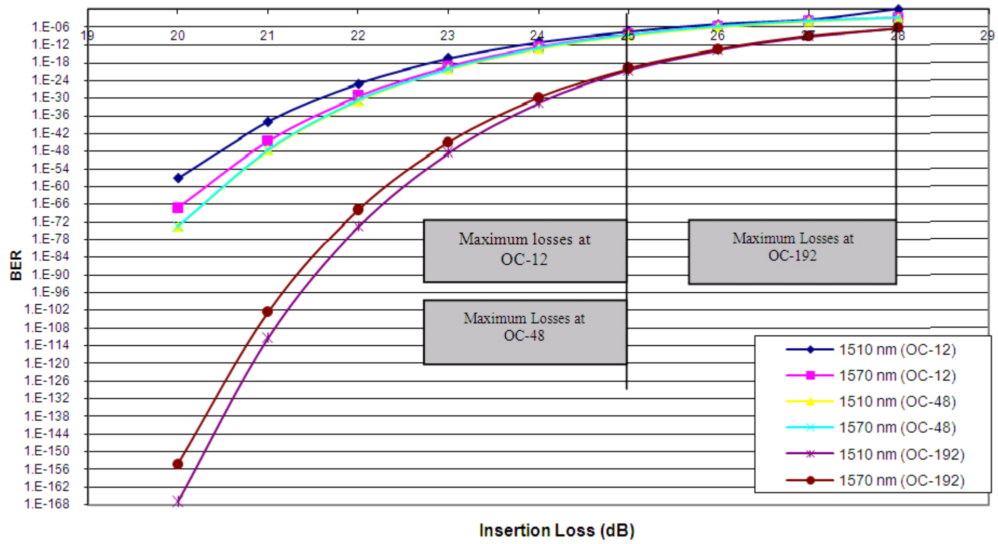


Fig. 9: BER versus Insertion Loss for Three Different Bit Rates Characterizing the Reliability of Single OXADMs.

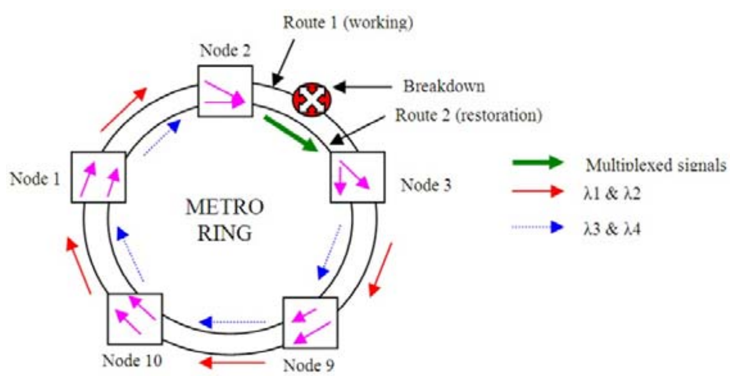


Fig. 10: Dedicated Protection Mechanism in a Metro Ring Network. When a Link Failure occurs within the Ring, the Affected is switched over to the Protection Path.

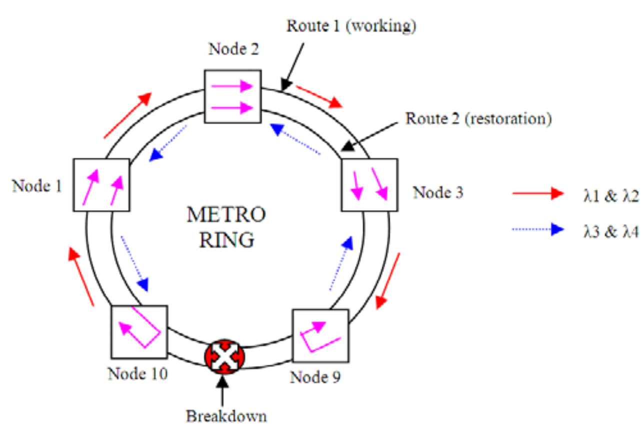
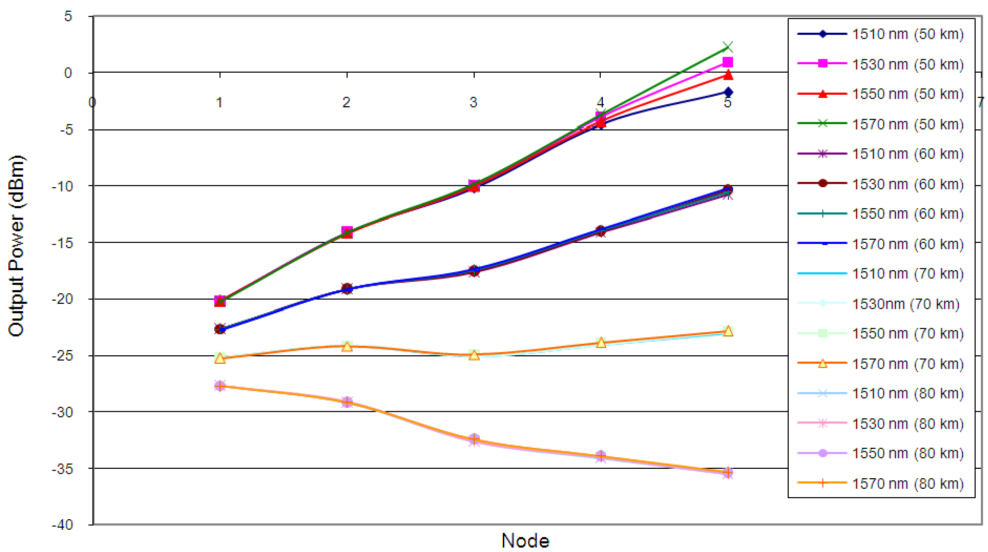


Fig. 11: Ring Protection Mechanism in a Metro Ring Network. When a Cable/Node Failure occurs within the Ring, the Node adjacent to the Failure loops back the Affected Signal onto the Protection Route of the Ring.

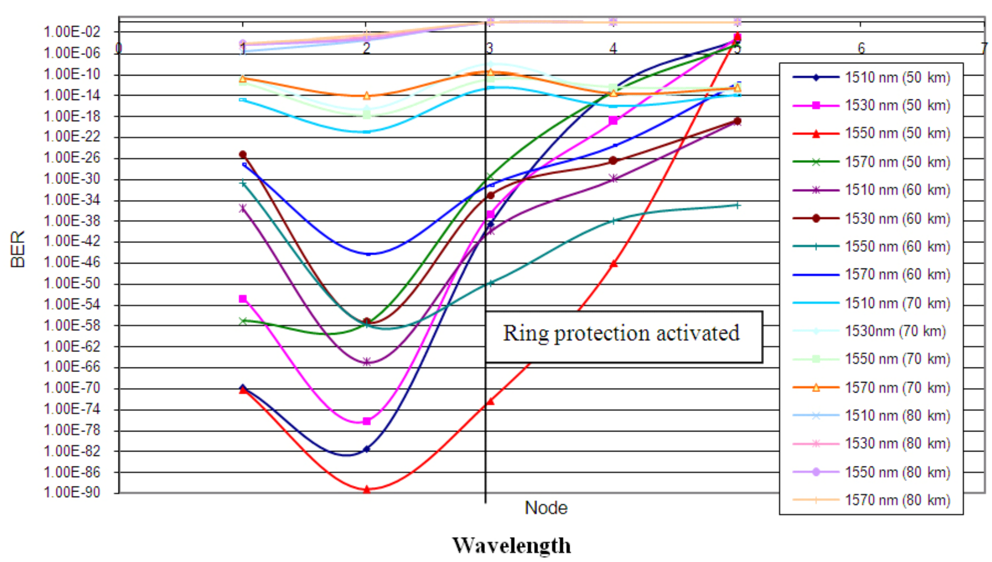
Ring Protection Analysis:

Span (Distance between Nodes):

The distance between two nodes also has a major effect on the value of output power and BER performance for each node. It is shown in Figure 13 and Figure 14. For Post amplification gain of 23 dB, the minimum distance between two nodes that can be received is 70 km. If this distance should be increased to 80 km the post amplification value needs to be increased by 1 dB. The observation in Figure K.4 shows the output power is in stable circumstances, at a distance of 70 km between two nodes. It also gives a satisfactory BER readings ($<1x10^{-9}$) in the range. Power output at a distance of 70 km between two nodes is more stable and suitable to be used as the ideal distance from the other range (especially at 60 km and 80 km) as a stable profile and low signal to match the signals from the add terminal which has low power and low sensitivity photodetector to reduce network costs. The stability of BER profile and output power which have been designed by gaon profile is important because the value of new injected signal can be known accurately and have the same amplitude with the pass through signal during the drip and add operation.



Rajah 12: The effect of node span on optical output power measured at every node with post amplification of 23 dB at 2.5 GHz transmission rate.



Rajah 13: The effect of node span on BER performance measured at every node with post amplification of 23 dB at 2.5 GHz transmission rate.

The size of the wavelength of a small impact on the power output but have a big impact on the BER performance. This is because the size of the wavelength give impact on the thermal noise and directly give a different sensitivity value to the sensitivity of the photodetector. Sensitivity of photodetector makes the different BER values for each operating wavelength as in Figure 15. Observed after the protection mechanism activated the shirting occurs on the output power level of each operating wavelength. However small shifting caused no significant effect on the BER performance of the system (Figure 16). In conclusion the ring protection mechanism is activated, the size of the wavelength rather than the main problems that affect the data it carries. Thus it can be concluded, the wavelength in the same window a small impact on power output and performance of BER (Figure 16).

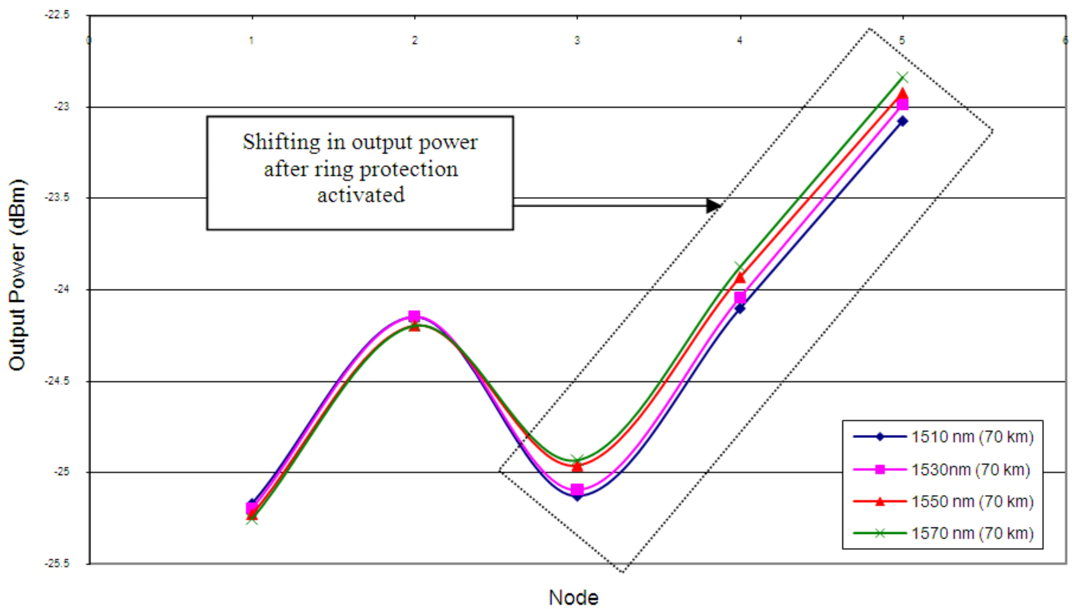


Fig. 14: The effect of wavelength size on optical output power measured at every node with post amplification of 23 dB at 2.5 GHz transmission rate and span 70 km.

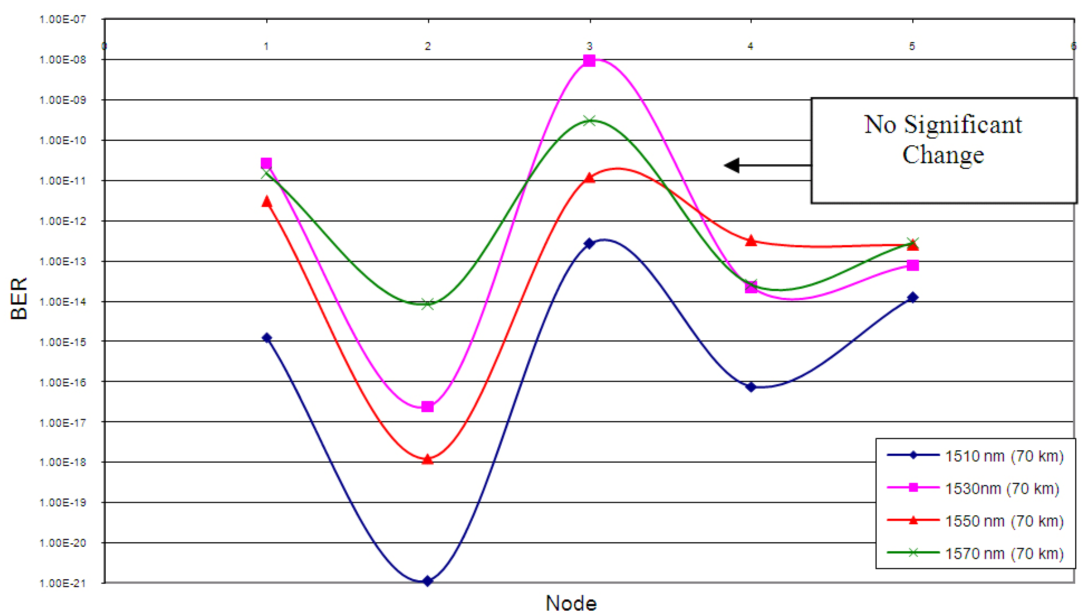


Fig. 15: The effect of wavelength size on BER performance measured at every node with post amplification of 23 dB at 2.5 GHz transmission rate and span 70 km.

Transmission Rate:

Data transmission rates did not have a significant effect on power output at each node (Δ <0.5 dB) but they have a big impact on the performance of BER (Based on amplification value of A1 and A2). This is because the higher data transmission rates greater probability of damage transmitted bits (Derickson, 1998; Kaiser, 2000). It is shown clearly in Figure 17 and Figure 18. In practice in the event of migration from low data transmission rates to higher rates will also need improved the sensitivity of photodetector. Inversely to the migration of data from high to lower rate may require only be reduced or maintained their sensitivity value. Thus it can be concluded photodetector sensitivity is directly proportional to the rate of data transmission (Saleh and Teich, 1991). This happens because when the data transmission rate is increased, high optical power required to maintain the number of photons per bit (the value of constant BER) (Saleh and Teich, 1991). Observed a decrease in the rate of data transmission after a ring protection mechanism is activated resulting in the recovery effect on the BER. This shows the high sensitivity and increase in power output will improve BER performance. This is due to the lower data transmission rate (in terms of noise set) increase the sensitivity of photodetector used.

Referring to Figure 18 obtained BER performance in stable condition and satisfactory data transmission at 2.5 GHz where the noise terms is 3.1347 x 10-23 W / Hz. This is because the optimization performed on the data transmission rate of 2.5 GHz and obtained values of thermal noise refers to the value of the transmission rate. This stability occurs because the consistency in the sensitivity of photodetector used to line load and gain of the amplifier is used. In addition, the noise terms also play an important role in stabilizing the value of the BER at a certain rate of data transmission.

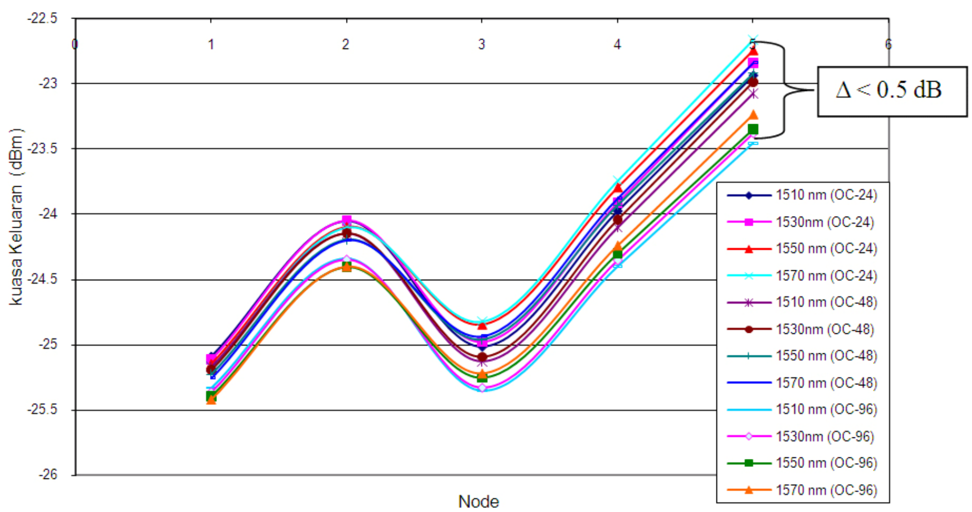


Fig. 16: Effect of transmission rate on optical output power measured at every node with post amplification of 23 dB at span 70 km.

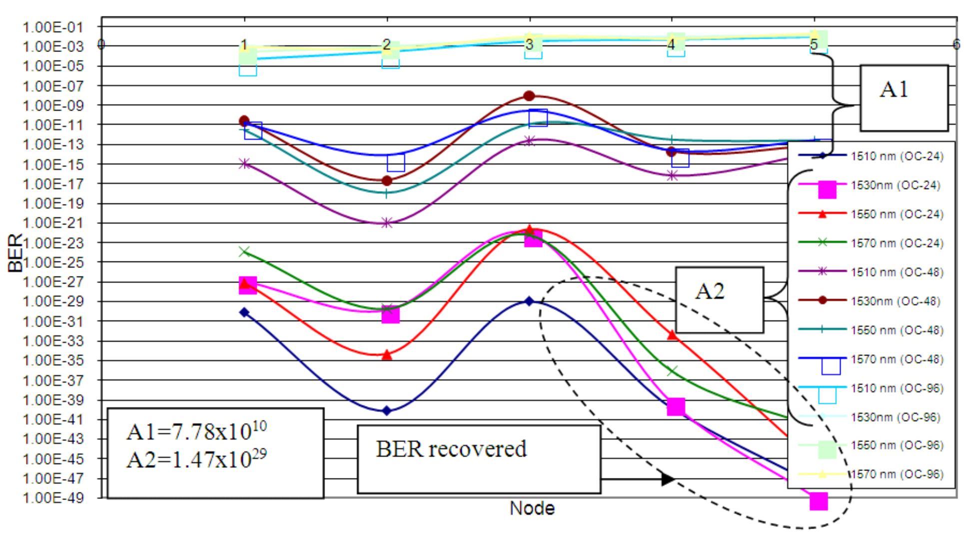


Fig. 17: Effect of transmission rate on BER performance measured at every node with post amplification of 23 dB at span 70 km.

Launched Power:

The simulation study is to obtain the relationship between the launching power of the signal source to the output power and BER performance at each node the preamplifier gain of 7 dB and post amplifier gain of 23 dB) during the ring protection mechanisms activated. The value of the first preamplifier is 3 dB. The increment of input power increase output power value at each node is measured, particularly when the signal is reflected back. The suitable launch power value for data transmission at 2.5 Gbps is 4 dBm (BER $<1x10^{-9}$). The difference of 1 dB between the output power and input power is observed at node-5 (node 1, because the power is reflected back to node-3) is indicated by the value of ΔX and ΔY (Figure 19). It shows a linear relationship between power input and power output at each node.

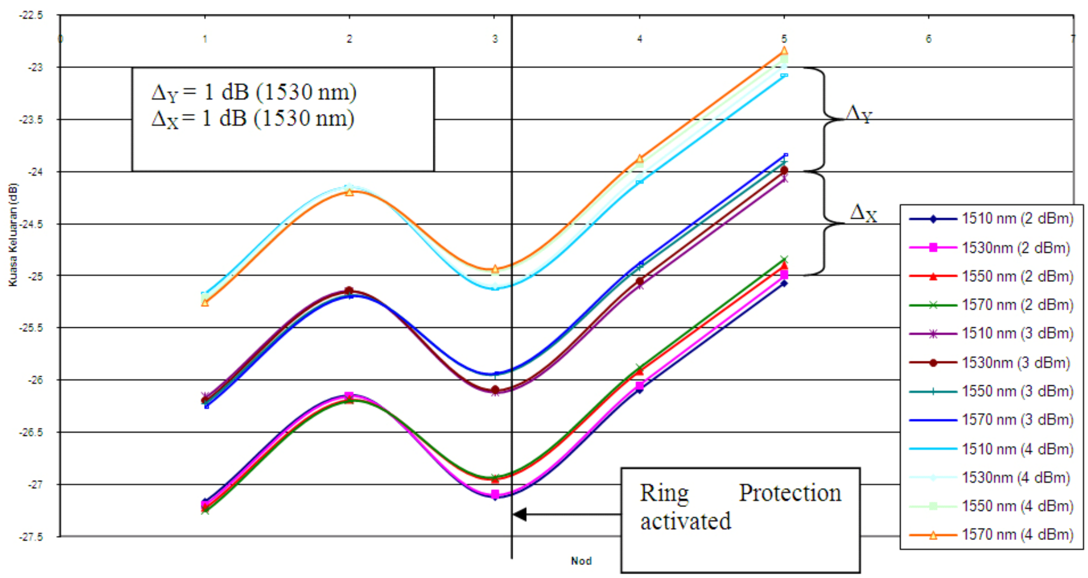


Fig. 18: Effect of magnitude of launched power on optical output power measured at every node with post amplification of 23 dB at 2.5 GHz transmission rate and span 70 km.

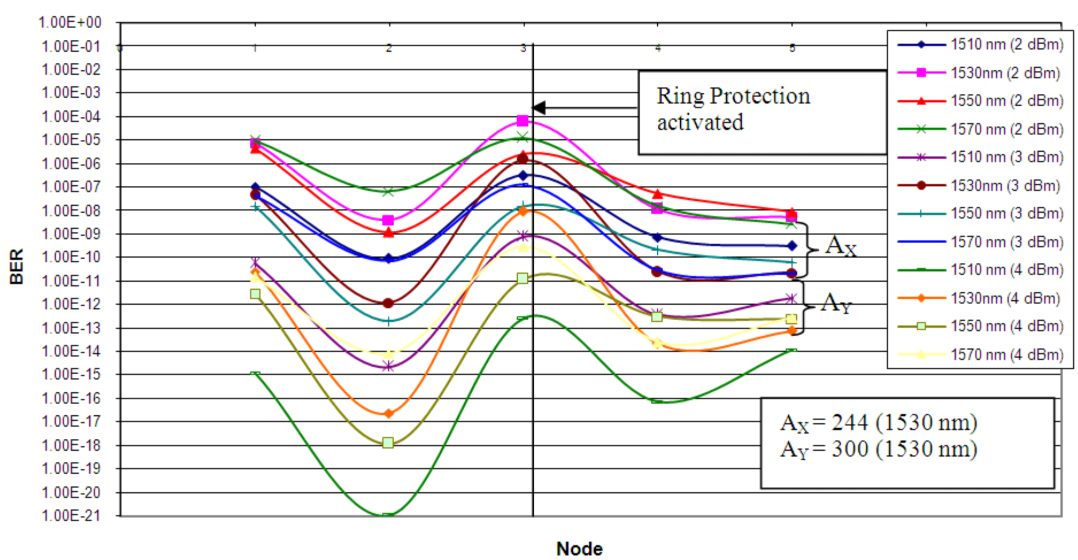


Fig. 20: Effect of magnitude of launched power on BER performance measured at every node with post amplification of 23 dB at 2.5 GHz transmission rate and span 70 km.

The effect of the launch power on the BER performance at each node are shown in Figure 20. BER value is compromised by a decrease in the launch power. Gain difference for the BER at the output node (Node 1) as the reflected signal is shown on the A_X and A_Y, each valued at 244 and 300. Observed a decrease in the value the better the BER performance after the signal has been reflected at node-3. In conclusion, ring protection mechanisms that cause the signal reflected back no adverse effect on output power and BER performance at the specific pre and post amplifier gain despite there is increment in loss in a ring of protection scheme at Node 3. However, it can be compensated by the gain of the amplifier is used.

Because they need to serve smaller bandwidth applications than DWDM system, CWDM based systems are characterized by wider channel spacing than DWDM optical networks. The frequency separation between each individual color of light on the actual fiber is significantly further apart, which allows the system designers to use lasers that have looser tolerances on spectral width and thermal drift and therefore are less expensive. CWDM is a network technology that is synergistic with Metro DWDM, i.e. not in competition. Standardization of CWDM technology; and simple, cost effective service interoperability between CWDM and DWDM systems will enable its adoption. Development of a new device for CWDM application will make the structure more flexible and efficient. The modeling of the new device named as the optical cross add and drop multiplexer (OXADM) will make a debut in its application because of the capability on two main optical trunks to transfer and exchange the operating wavelength between each other. The capability of wavelength transfer between two fiber trunks will reduce the complexity of the network links. This will thus reduce the cost of installation and maintenance. The number of operating wavelengths can also be reduced due to cross connection between two fiber cores and reuse of same operating carrier to carry new information data.

Conclusion:

We have introduced a new device with the concept of combination between optical add and drop multiplexing and optical cross connect operations through the development of an optical cross add and drop multiplexer (OXADM). Two suggested applications have been proposed with the simulation results as feasibility approach.

This paper introduces a new optical device model named as an optical cross add and drop multiplexer (OXADM) which has potential use in CWDM metro area networks. OXADM is capable to restore the network during the failure condition by means of ring protection and linear/multiplex protection. In this paper we observed the network digital performance due to changing of optical network parameters such as Span, Wavelength, Transmission rate and Launched power. Output power and BER is used to measure the system performance under different condition.

The multifunctional device is particularly designed for CWDM metro application. The ideals of OXADMs 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 OXADMs (Ab-Rahman and Shaari, 2004). The OXADM can also provide survivability through restoration against failure by means of dedicated and shared protection that can be applied in CWDM ring metropolitan networks. 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 a comparison of these simulation results with those obtained from systems without restoration mechanisms (bypass).

Though a successful proposal have been obtained, it is apparent that there are still many issues which have to be solved in order to establish complete optical layer routing and supervision is also expected to be integrated in the optical layer. For the global interworking of the optical layer through to customer access networks, a development which satisfies the requirements of international standardization such as ITU-T is important. UKM Photonics will continue to make efforts toward the development of advanced optical layer network through realizing the OXADM.

Acknowledgements

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