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A Colorless, Directionless and Contention-less ROADM that Utilizes Interconnected WSSs

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Abstract: We propose a novel colorless, directionless and contention-less (CDC) reconfigurable optical add/drop multiplexer (ROADM) that is composed of interconnected wavelength selective switches (WSSs). The key components of this ROADM are interconnected WSSs. Using the connecting branches from WSS to WSS, the channels at any wavelengths from any input may exploit any transponder in the photonic ROADM node. Both of simulation and analytical results showed that when the number of connecting branches (r) equals 2, same blocking performance may be achieved as CDC case (where r equals to N-1). Meanwhile, it achieves significant capital expense saving when compared with other equivalent CDC-ROADMs while assuring 5000 microsecond latency with the First Fit selection algorithm.

Keywords: ROADM(Reconfigurable Optical Add/Drop Multilplexers),Blocking probability, All Optical Networks, WSS(Wavelength selective switch),

1 Introduction

Reconfigurable optical add/drop multiplexers (ROADMs) are crucial to wavelength division multiplexing (WDM) networks because they support dynamic photonic layer switching without manual intervention [1]. The next generation ROADM requires three main features: colorless, directionless and contention-less (CDC). Colorless means that any wavelength channel on an express fiber may be directed to any transponder associated with that fiber. A colorless transponder includes a pair of transmitter and receiver to add/drop traffic without any color limitation. Here define the group of transponders associated with that fiber as transponder bank hereafter in this paper. Directionless means that all transponder banks be shared among all wavelength channels from any nodal degree (where N denotes the number of input/output fibers). Contention-less means that the setup of the cross-connects between input and output fibers and add/drop ports does not prevent other cross-connects from being setup. Researches [2][3] showed that CDC ROADM outperforms non-CDC counterpart due to their wider freedoms on transponders resource allocation and frequently utilized wavelength selective switch (WSS) in overcoming the Micro-electro-mechanical-systems (MEMS) barrier in scaling (from the perspective of increase in the number of wavelength channels and nodal degree). A ($1\times S$) WSS is capable of switching an arbitrary combination of input wavelength channels to any of its output fibers independent of the number of wavelength channels, where S denotes the number of service ports. Thanks to the emergence of tunable transponder and WSS, the colorless foundation is laid for WSS based ROADM to share and reuse the transponder banks. Thus the WSS based ROADMs are widely investigated to provide directionless and contention-less characteristics and several schemes have been proposed in [2][3]. Scenario 5 in [2] and Fig. 6 in [3] introduced two different CDC ROADMs respectively. The former used MEMS to settle the direction issue and the latter used $N\times M$ WSSs to offer directionless feature. However, $N\times M$ WSS is still some years away from implementation and MEMS is rigid in upgrading. This poses additional challenge for the WSS based ROADMs towards CDC.

In this paper, we propose a novel CDC ROADM on basis of tunable transponders and $1\times S$ WSSs. The directionless feature is achieved by interconnecting $1\times S$ WSSs whereas the contention-less issue is addressed by

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reconfiguration of WSSs. For each 1×*S* WSS, *r* service ports will be reserved for connecting WSSs in overcoming the directional issue, which will be referred to as connecting branches hereafter in this paper. The remaining service ports (*S*-*r*) are connected directly to transponders one by one for dropping wavelengths. An analytical model is presented in analyzing the blocking performance against the number of transponders in each bank (*T*) as a function of different number of connecting branches (*r*). Both of simulation and analytical results showed that when the number of connecting branches (*r*) equals 2, same blocking performance may be achieved as CDC case (where *r* equals to *N*-1). Researches also showed that adopting the First Fit algorithm in transponder bank selection will decrease the time latency caused by reconfiguration of WSSs to 5000 microsecond level. More importantly, the novel CDC ROADM achieves significant capital expense saving when compared to other two CDC ROADMs with same blocking performance.

The paper is organized as follows: the proposed ROADM that utilizes interconnected WSSs is designed in section II, an analytical model is presented in analyzing the blocking performance against the number of transponders in each bank (*T*) as a function of different number of connecting branches (*r*) and their simulation results are discussed in section III and section IV respectively. The relative costs and time latency due to reconfiguration of WSSs are presented in section V. Finally, conclusions are drawn in section VI.

2 CDC ROADM with OXC and the add/drop sections

Typically, the ROADM architecture is divided into two independent sections, one is optical cross-connect (OXC) section for the express traffic and the other for add/drop traffic. A standard Spanke topology is used to integrate cross-connection of wavelength channels passing through the ROADM (as illustrated in OXC section). The input 1 × 9 WSSs select the input channels for various output fibers and drop the traffic to its drop port. Here we define the port, where the drop traffic originally came from, as the local port. Add traffic along with any selected channels from each WSSs are combined together by 6 × 1 coupler to each output fiber. This is a well-known OXC architecture that is being deployed in [4][5], but its add/drop section is totally different and the add/drop traffic still needs to be separated and routed to individual transponders.

The proposed add/drop sections are shown in Fig. 1. In this example we will focus in on a degree 3 node (where *N* equals 3) with add and drop function independently. It should be noted that MEMS is absent on both add and drop side. Such design relies on 1×S WSS only for interconnection. On add side, couplers and WSSs

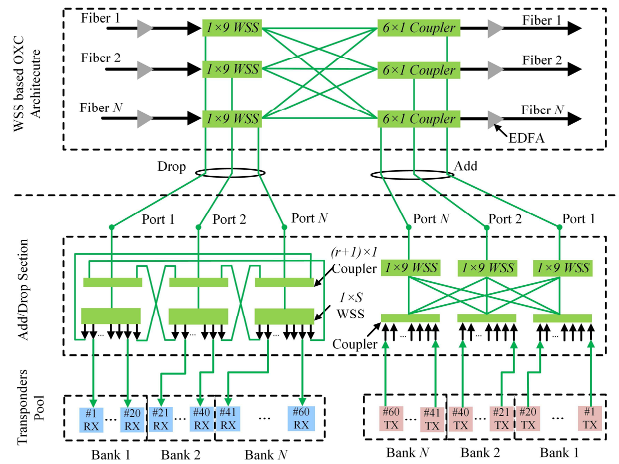

Fig. 1: CDC ROADM with OXC and add/drop sections where the nodal degree N equals 3, the connecting branches *r* is *N*-1, here equals 2, S equals 23, 40 wavelengths per fiber and 50% add/drop ratio, RX: Receiver (in blue), TX: Transmitter (in red).

are connected as broadcast and select configuration and provide a full interconnection. Optical coupler is responsible for combining channels and 1×9 WSSs select the channels from various banks and add traffic to OXC section. When there are multiple local channels that need to be added, couplers are also cascaded to combine them together.

On drop side, this broadcast and select configuration is not adopted since the drop traffic needs to be separated one by one to individual transponders, and hence interconnection is more difficult than the add side scenario. On drop side this example is made up two components: passive (*r*+1)×1 couplers and 1×*S* WSSs. The dropped channels from its local port are sent directly to its local WSS. Hereafter we will call the WSS, which belongs to the local port, as the local WSS whereas the other *r* WSSs as the deflection WSSs. The local WSS afterwards will block any unwanted wavelengths, select the non-blocking wavelengths and demultiplex them to (*S*-*r*) service ports. Here we define the transponder bank directly connected to the local WSS by (*S*-*r*) service ports as the local bank. The overflow wavelengths here are defined as the drop traffic that beyond the accommodation capability of the local WSS. They will be selected by local WSS and be sent to other WSSs through *r* connecting branches. Afterwards, the (*r*+1)×1 coupler will combine all the wavelengths together and sent them to its local WSS. Likewise, the overflow wavelengths will be sent to available transponders by the deflection WSSs to their local banks.

In the proposed ROADM, the directionless feature is achieved by interconnecting WSSs. As above-mentioned, *r* service ports of WSS will be reserved for deflecting the overflow wavelengths from WSS to WSS in overcoming the directional issue. Since one service port of WSS is allowed to accommodate multiple wavelength channels, one service port is adequate for the local WSS to deflect the wavelengths from the local WSS to the WSS. In doing so, the wavelength channel, which originally may only exploit transponders in its local bank, can exploit other available transponders in other r banks. In total, the wavelength channel may exploit (r+1) banks of transponders. If r equals to the N-1, directionless feature is achieved that any wavelength channel from any input may exploit any transponder in any bank. For instance, when N equals 9, r equals 8 to offer CDC feature.

Although various interconnection architectures for connecting WSSs exist, we assumed one of the simplest interconnection architectures, the ring-like connection where only adjacent WSSs are bridged since r equals 2 in Fig. 1. Since WSS provides colorless service ports, any service port can be reserved for connecting branches.

There are many possible variations for this architecture. For example, the overflow wavelengths may be deflected continuously from one WSS to the other for an available transponder through just one connecting branch. However, the optical insertion loss for each WSS is relatively high (12dB) that recursive inter-WSS deflection is not considered in this paper. To obtain same optical insertion loss for all wavelengths, the number of connecting branches (r) can be increased to N-1 by reserving more service ports for deflection. In fact, the number of connecting branches r ranges from 0 to N-1, where N denotes the number of fibers.

It should be noted that partially add/drop ratio is a prerequisite to implement the proposed ROADM. Otherwise the requests will be rejected at the entrance of the add/drop section. Therefore, it suggests that the WSSs stage of the OXC section should be installed on the first stage for drop traffic.

Since each WSS only allows for one instance of wavelength channel to pass simultaneously, the color blocking may rise as issue. Color issue occurs that overflow wavelengths from other drop ports will prevent the future use of the drop traffic riding on the same wavelength from its local port. In the proposed ROADM, the contention-less feature is realized by reconfiguring the WSSs that other channel on the non-blocking wavelength will be deflected to this bank to avoid contention. This issue shall be discussed in detail in subsequent section and we will adopt an algorithm that makes best use of the proposed ROADM by assuring microsecond latency.

3 Blocking performance of the proposed ROADM with different connecting branches

3.1 Analytical Model for the proposed ROADM with different connecting branches

In this section, we present an analytical model that evaluates the blocking performance (P_B) of the proposed ROADM against different number of transponders in each bank (T) with different number of connecting branches (r). The model is largely extended from the [6] to support partial directional ROADM on the basis of colorless add/drop transponders. Their main differences are as follows. For the CDC case, all the transponders at a node can be used for establishing a light-path, while, for partial directional case, only the (r+1) banks of transponders can be used.

The related notations of the model are as follows.

$\lambda(s,d)$: the call arrival rate of the light-path request between node pair s and d.

$X_p(s,d)$: a random variable denoting the number of idle wavelengths on the light-path route between node pair s and d.

W: the maximal number of wavelengths available on each fiber link.

$1/\mu$: the average holding time of an established light-path, we set the average holding time as unity for simplicity.

$X_l(i)$: a random variable denoting the number of idle wavelengths on link i in equilibrium.

$q_i(w) = \Pr[X_l(i) = w](w = 0,1,\cdots,W)$: the probability that there are w idle wavelengths on link i.

$\alpha_i(w)$: the call setup rate on link i when there are w idle wavelengths on that link.

$f_1(i)$: the probability that a particular wavelength is free on link i.

$B_n(i)$: the blocking probability due to lack of suitable add/drop transponders at node i.

$\lambda_n(i)$: the total light-path request arrival rate at node i.

T: the number of add/drop transponders in each bank.

N_i: the nodal degree of node i; it also denotes the number of banks.

$\max(N_i)$: the maximum nodal degree in the network topology.

T_i: the total number of add/drop transponders at node i; which equals $N_i \cdot T$.

$P_b(s,d)$: the light-path blocking probability between node pair s and d.

P_B: the light-path blocking probability of the whole network.

With the above notation, the offered load at node i in a network with colorless add/drop transponders is calculated as

$$\lambda_n(i) = \sum_j \lambda(i,j)\frac{1-P_b(i,j)}{1-B_n(i)} \tag{1}$$

Given $\lambda_n(i)$, the blocking probability $B_n(i)$ at node i can be calculated by the Erlang-B formula as

$$B_n(i) = E(\lambda_n(i), \min(T_i, (r+1)\cdot T)) \quad (2)$$

In which T_i is the total number of add/drop transponders at the node if it is CDC, and the (r+1) banks of add/drop transponders that can be exploited by a certain nodal degree if it is partial directional with r connecting branches, where $(0 \le r \le N_i - 1)$. It should be noted that Eq. 2 is the original contribution of this paper whereas other equations 3-9 are introduced by [6].
Based on a birth-and-death process, we can find the probability that there are w idle wavelengths on link i as

$$q_i(w) = \frac{W(W-1)\cdots(W-w+1)}{\alpha_i(1)\alpha_i(2)\cdots\alpha_i(w)} q_i(0), w = 1,2,\cdots,W. \quad (3)$$

where

$$q_i(0) = [1 + \sum_{w=1}^{W} \frac{W(W-1)\cdots(W-w+1)}{\alpha_i(1)\alpha_i(2)\cdots\alpha_i(w)}]^{-1} \quad (4)$$

By considering all the light-path requests that traverse link i, we can further find the setup rate on link i where there are w available wavelengths on the link, $\alpha_i(w)$, as

$$\alpha_i(w) = \begin{cases} 0, & if \quad w = 0 \\ \sum_{s,d;i\in path(s,d)} \lambda(s,d) P\{X_p(s,d) > 0 | X_l(i) = w\}, & \\ & if \quad w = 1,2,\cdots,W. \end{cases} \quad (5)$$

Based on Eq. (3), the probability that a particular wavelength (say λ) is free on link i, $f_l(i)$, is calculated as

$$f_l(i) = q_i(1)\frac{1}{w} + q_i(2)\frac{2}{w} + \cdots + q_i(W) \quad (6)$$

Eq. (6) finds the probability that a particular wavelength is free on link i when there are idle wavelengths on the link.

$$P\{X_p(s,d) > 0 | X_l(i) = w\} = (1 - E(\lambda_n(s), T_s))(1 - E(\lambda_n(d), T_d)) \times (1 - (1 - \prod_{k\in path(s,d); k\neq i} f_l(k))^w) \quad (7)$$

Similarly, the light-path blocking probability between node pair s and d can be expressed as

$$P_b(s,d) = (1 - E(\lambda_n(s), T_s))(1 - E(\lambda_n(d), T_d)) \times (1 - (1 - \prod_{i\in path(s,d)} f_i(k))^W) \quad (8)$$

Finally, the average light-path blocking probability around the whole network is

$$P_B = \frac{\sum_{s,d} P_b(s,d)\lambda(s,d)}{\sum_{s,d}\lambda(s,d)} \quad (9)$$

In order to solve the above equations for calculating P_B, an iterative method is employed. The detailed steps of this method are given below.
1. Let $P_b(s,d)$, P_{B_temp} and $B_n(i)$ be zero; let $f_l(i)$ and $\alpha_i(w)$ be arbitrary values between 0 and 1.
2. Calculate $\lambda_n(i)$ using Eq. (1) and $B_n(i)$ using Eq. (2).
3. Obtain $\alpha_i(w)$ using Eq. (5) and Eq. (7).
4. Get $q_i(w)$ using Eq. (3) and Eq. (4).
5. Calculate $f_l(i)$ using Eq. (6).
6. Obtain $P_b(s,d)$ using Eq. (8).
7. Get P_B using Eq. (9). If $|P_B - P_{B_{temp}}| < \varepsilon$, then stop; otherwise, $P_B = P_{B_{temp}}$, and return to Step 2. Here, ε is defined as 10^{-6}.

Table 1: The two reference networks. (a) NSFNET network (b) Italy Network.

Network Topology [6][7]		NSFNET (a)	Italy (b)
Number of nodes		14	14
Nodal degree N_i	Min	2	2
	Max	**4**	**9**
	Ave	3	4.14
Number of links		21	29
Number of shortest hops	Min	1	1
	Max	3	3
	Ave	1.87	1.87

3.2 Blocking performance analysis

A dynamic light-path traffic model is assumed for our simulation studies. The light-path traffic demands between each pair of nodes follow a Poisson distribution at rate λ, and that the holding time of each established light-path follows an exponential distribution with mean unity. The traffic load between each pair of nodes has the same value $\rho = \lambda$. Two test networks are considered for the simulation studies, including a 14-node NSFNET and 14-node Italy network (as shown in Table. 1).

In addition, each simulated light-path blocking probability is evaluated based on 10^6 light-path request arrival events. In this section, we evaluated the blocking performance under different connecting branches (r) constraint under fixed shortest path routing. The maximum number of available wavelengths on each link (W) was assumed to be the same 40. The number of transponders installed in each node was $T \cdot N_i$. We employed the analytical models presented in Section 3.1 and compared them with simulations for such an evaluation.

Fig. 2 and 3 show the light-path blocking probabilities (P_B) against add/drop transponders in each bank (T) under different connecting branches (r) constraints with 1.5 *Erlang* traffic load per node pair of NSFNET network and Italy network, respectively. The dashed curves represent the results of the analytical models and the solid curves are the results of simulations. Comparing the analytical results and simulations, we see that the analytical models can predict the overall light-path blocking performance. The differences between analytical and simulation results are attributed to the fact that the analytical model is based on the link-independent assumption, which ignores the potential correlation between link traffic flows and beyond our discussion.

For the CDC case (with r equals N-1), with the increase of T, the light-path blocking performance (P_B) is significantly improved at the beginning, and when the number of add/drop transponders in each bank (T) hits $W/2$ (i.e. T equals 20), the blocking performance is saturated; no further improvement is observed with the further increase of the number of add/drop ports. Thus, the same blocking performance as other equivalent CDC ROADM [7] [8] could be observed when r equals N-1.

In addition, the benefits of directionless is scenario-dependent on maximum nodal degree. If the maximum nodal degree was small, directionless feature would not bring much benefit for add/drop transponders sharing among different banks that the colorless and directional case (where r equals 0) performs closely to that of the CDC case in NSFNET network (where max(N_i) equals 4). The directionless property displays much better performance for Italy network (where max(N_i) equals 9) because the colorless and directional case (where r equals 0) was far away from the CDC case.

In particular, with r equals 2, the colorless and partial directional case performs almost the same to that of the CDC case for both networks. This is reasonable, since, as there have been sufficient add/drop transponders in each bank (T), there is a saturated phenomenon with the increase of connecting branches (r). This suggests that in the proposed ROADM, the connecting branches (r) can be limited to 2 rather than N-1 for the same light-path blocking probability.

Since the number of service ports (S) of WSS is jointly determined by the number of transponders in each bank (T) and the number of connecting branches (r), i.e. $S \geq T + r$, smaller r could reduce the number of service ports S and cuts cost for WSSs. This suggests that the number of service ports S can be maintained the same as 20+2 in both networks rather than 20+3 in NSFNET network and 20+8 in Italy network regardless of the maximum nodal degree is big or not for the same blocking probability as CDC case.

4 Time Latency and Costs Comparison

4.1 Time latency comparisons with three different bank selection strategies

As above-mentioned, reconfiguration of WSS is required that the deflecting wavelengths from other drop ports will

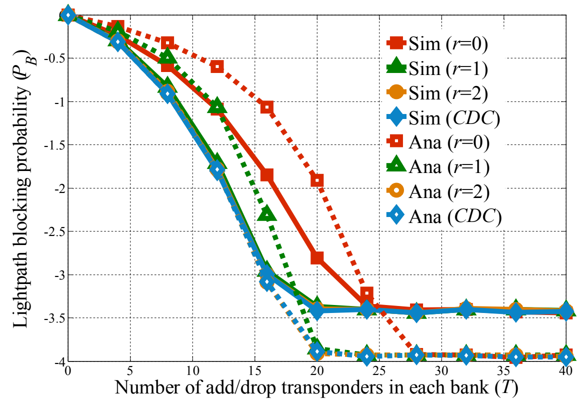

Fig. 2: The light-path blocking performance of the NSFNET network. (Ana: Analysis (dashed curve), Sim: Simulation (solid curve), 1.5 Erlang per node pair, r denotes the number of connecting branches, CDC case: where r equals N-1, where the max (N_i) is 4).

not hinder the future use of the drop traffic riding on the same wavelength from local port. In this ROADM, the contention-less feature is realized by reconfiguring the WSSs that the blocking wavelength channel will be replaced by other non-blocking wavelength channel (at random) to avoid contention. Due to the colorless nature of the tunable transponder and WSS, the traditional add/drop port selection strategy is replaced here by bank selection strategy. To improve the time latency of reconfiguration, in this section we consider three bank selection strategies. Next, we introduce these three strategies: Random (RDM), Least Used (LU) and First Fit (FF) strategies.

To begin with, we assume that the network control system only maintains the link wavelength usage information of the network. We first select a light-path route (through fixed shortest path routing) with an available wavelength λ (based on random strategy) on the route. Then, the strategy checks whether there exists unused transponder at both the source and destination nodes of the light-path. Only if both ends can offer eligible add/drop transponder can the light-path be provisioned. Finally, we will reconfigure the WSSs to provide non-blocking connections (if necessary) and select the available banks that support wavelength λ according to three strategies Random (RDM), Least Used (LU) and First Fit (FF) strategies.

In the Random algorithm, the bank selection step is based on banks availability at the source and destination nodes respectively. It will choose the available bank at random. Thus, situations can occur that the algorithm simply selected the bank with most used number of transponders that may hinder the future use of the

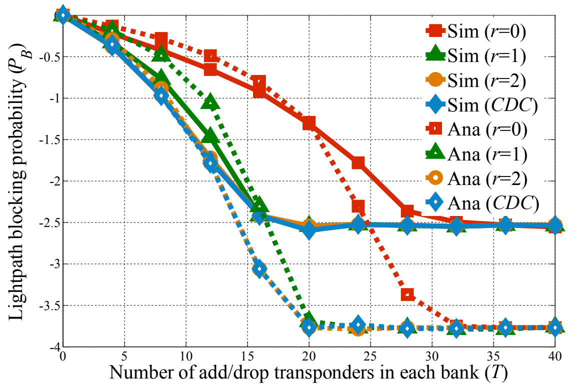

Fig. 3: The light-path blocking performance of the Italy network. (Ana: Analysis (dashed curve), Sim: Simulation (solid curve), 1.5 Erlang per node pair, r denotes the number of connecting branches, CDC case: where r equals N-1, where the max (N_i) is 9).

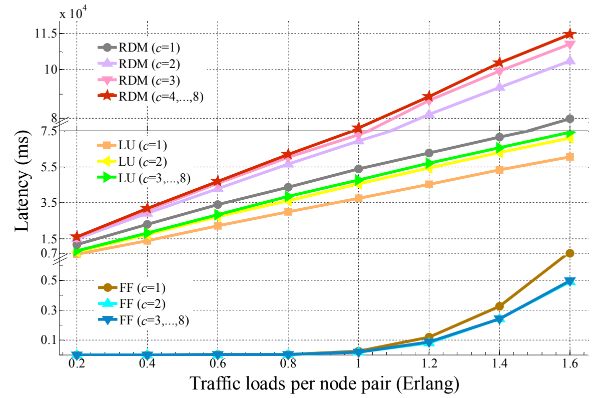

Fig. 4: Latency in function of the traffic loads per node pair. Simulations show comparisons among three bank selection algorithms: Random (RDM), Least Used (LU) and First Fit (FF) with different connecting branches r, from 1 to N-1 respectively. N is denoted as 9 for Italy network topology.

wavelength from the local port right after it was configured.

Least Used algorithm will overcome this shortcoming by choosing the available bank with least used number of transponders. However, situations still occur that the transponders simply selected based on least used banks availability may hinder the future use of the wavelength from the local port right after it was configured. To avoid such situation, First Fit algorithm is adopted. Strategy three is based on the fact that no contention will occur within the wavelengths from the same input port. Thus, the chances that the current bank selection step will prevent the future use of the same wavelength is smaller than strategy two.

We evaluated the performance of three algorithms of bank selection through simulations. The number of reconfiguration times switching penalty of WSSs (10ms) will be plotted against the traffic loads per node pair (*Erlang*) with different the number of connecting branches (r). In all scenarios, the number of transponders in each bank (T) will be identically set to 20 ($W/2$). The simulation was also based on 10^6 light-path request arrival events presented in Section 3.2. From these curves, we have the following key observations.

i) Comparing the results of the three strategy, we see that strategy three achieves the best performance and strategy two performs better than strategy one. The increase of the connecting branches (r) will improve the performance in the First Fit strategy but will deteriorate the performances in other two strategies. Such results are reasonable, since more effort is made for better bank selection from strategy one to three.

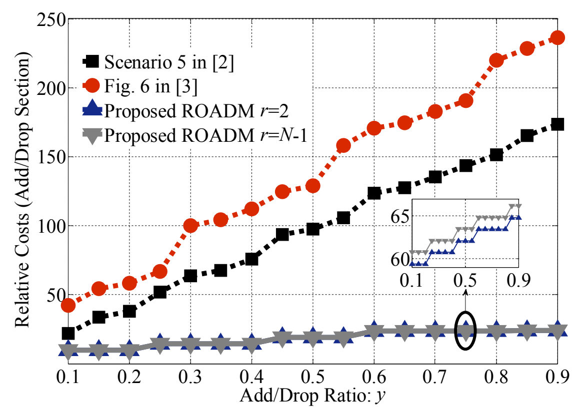

Fig. 5: Relative costs comparisons among three ROADMs: Scenario 5 in [2], Fig.6 in [3] and the proposed ROADMs against various add/drop ratios with two different connecting branches r scenarios, equals 2 and N-1 respectively. N is denoted as 4 here.

ii) Among three, the First Fit case can achieves the best performance due to its lowest reconfiguration possibilities; its time latency is as low as 5000ms when the number of connecting branches (r) increases to 2 under heavy traffic load (1.6 *Erlang*). The Least Used case performs the second best; its latency performance is acceptable low 55000ms when the number of connecting branches (r) decreases to 1. Under the Random strategy, the time latency is as low as 80000ms and deteriorates as r increases. Based on these results, it seems that the First Fit algorithm is more suitable than other two algorithms

Table 2: The relative costs and number of modules of three CDC ROADMs respectively.

Equipment	Relative Cost[2][4][9]	Scenario 5 in [2]	Fig. 6 in [3]	The proposed ROADM
1×9 WSS	1	$N\lceil Wy/8\rceil$	$N\lceil N/8\rceil$	$N\lceil N/8\rceil$
9×1 WSS	1	0	$N\lceil NWy/42\rceil$	0
9×1 Combiner	0.15	$N\lceil Wy/8\rceil$	$N\lceil Wy/8\rceil + N\lceil NWy/42\rceil$	$N\lceil Wy/8\rceil$
1×9 Splitter	0.15	0	$N\lceil Wy/8\rceil + N\lceil NWy/42\rceil$	$N\lceil N/8\rceil + N\lceil (R+1)/8\rceil$
1×23 WSS	3	0	$N\lceil NWy/42\rceil$	N
MEMS Switch Ports	0.01	$2K\lceil 2NWy/K\rceil$	0	0
Transponder	1	$N\lceil Wy\rceil$	$N\lceil Wy\rceil$	$N\lceil Wy\rceil$

N: node degree, W: number of waves per direction, y: add/drop ratio, r: no. of connecting branches,2K is the no. of ports on $K\times K$ (K equals to 64 [2]) MEMS switch.

in improving the time latency due to the reconfiguration of WSSs.

4.2 Relative Costs

Table II. listed the formulae for estimating the number of modules and service ports required along with the relative costs assumptions prescribed in [2][4][9]. Equipment costs shown are normalized relative to that of the 1×9 WSS switch cost. Note that the OXC section is common to all three CDC ROADMs and hence is not included in the cost calculations. In particular, we are interested in the costs comparison in the add/drop section. Fig. 5 illustrates the results of a relatively cost comparison as the add/drop ratio increases from 0.1 to 0.9. In general, the proposed ROADM with r equals to 2 is the least expensive while being the least flexible in terms of add/drop capability. The Fig. 6 in [3], on the other hand offers the most convenient access at the highest cost. The Scenario 5 in [2] requires large MEMS whereas the proposed ROADMs dont and therefore its total cost sits in the middle between the highest and the lowest. The proposed ROADM with r equals to N-1 is a good low-cost option which provides full CDC performance.

5 Conclusion

We have proposed a novel colorless, directionless and contention-less (CDC) reconfigurable optical add/drop multiplexer (ROADM) that is composed of interconnected wavelength selective switches (WSSs). We have studied the impact of the number of connecting branches in each ROADM node on network performance. Analytical model for the proposed ROADM is presented and evaluated and simulations are also done for two network topologies. Based on the results obtained, we found that fully equipping a node with N-1 connecting branches is not necessary. Only 2 connecting branches are required in each node to achieve a performance comparable to that of a network with CDC ROADM at its nodes. In addition, we have studied the time latency issue due to reconfigurations of WSSs. Results showed that First Fit algorithm is more suitable to this ROADM than Least Used algorithm by assuring 5000 microsecond latency. Finally, by comparing the proposed ROADM with other equivalent CDC ROADMs, we can conclude that our ROADM is cost-effective to deal with various kinds of network scenarios.

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