High Degree ROADM Cluster Node

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Abstract: A low-cost ROADM cluster node with flexible add/drop and scalable to 100s of degree is proposed for next generation optical networks. It disaggregate line and add/drop functions of the cluster into different chassis. A proposed order-based connection management algorithm achieves better than 10^{-4} blocking despite less than 30% dilation in cluster design. © 2021 The Author(s)

1. Introduction

ROADMs have been evolved through many generations from the classical ROADM to the speedy commercialization of flex-grid CDC ROADMs [1]. The currently deployed ROADMs are typically 8- or 16-degree with limited flexibility in add/drop functionality [2,3]. With increased traffic and lighting more fibers on each link of an optical network, there is a need for not only higher degree ROADM to permit transmission in many different directions but also flexibility in the add/drop rate. In addition, fully equipped 8- or 16-degree ROADMs, that have long lifetime, are relatively expensive. Given customer's substantial investment in these ROADM nodes, any improved ROADM capacity that require additional investment, i.e., purchasing a new chassis, may be less likely to be adopted. It is desirable to have a low-cost and scalable ROADM solution that provides flexible add/drop rates to respond to the increased traffic. Using existing chassis for future scaling is key to minimize any loss of investments for both customers and optical equipment vendors. This paper proposes a low-cost cluster ROADM node using existing ROADM chassis with pay as grow capability that scales to higher degree with flexible add/drop rates.

2. Cluster Node Architecture

Commercial ROADM nodes may be a 32-slots chassis or a 16-slot chassis that fully interconnects all the slots by an optical backplane. A 32-slot chassis for can be configured as 8-degree ROADM with 8 single-slot line cards housing twin WSS 1x32 (for both directions) and 12 double-width add/drop cards. The add/drop rate of the node depends on the design. For instance, a 24-ports add/drop card results in 45% add/drop rate assuming 80 ITU 50GHz grid. If a 32-slot chassis is deployed as 16-degree ROADM, the number of add/drop cards is limited to 8, resulting in 15% add/drop rate. Given limitation in both scaling to higher degree and add/drop rate flexibility, we propose a low-cost ROADM cluster node that is constructed using existing chassis to allow re-usability and it is designed with flexibility to offer carriers the option to pay for additional capacity as needed. Fig.1 (a, b, c) illustrates the components of a ROADM cluster node that offers a low-cost and scalable solution for next generation ROADM nodes. The functions of a cluster ROADM node is separated into 3 chassis as Line Chassis (LC), Add/Drop Chassis (ADC) and Interconnect Chassis (IC). Let us assume 32-slot chassis is used for both LC and ADC and 16-slot chassis is used for IC. A fully equipped LC chassis with 32 1x32 twin-WSS cards can be viewed as a WSS 32x32 as the cards are interconnected by the optical backplane. Some chassis slots of ADC is equipped with interconnect cards and the remainder is equipped with add/drop cards. The IC chassis, as low-cost common equipment can be

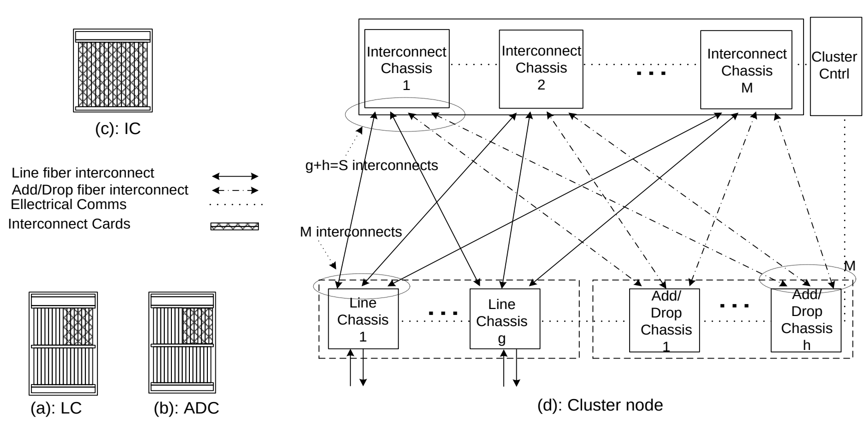

Fig. 1: (a) Line chassis, (b) Add/drop chassis, (c) low cost interconnect chassis, (d) Cluster ROADM.

equipped with 16 1x16 twin-WSS cards interconnected by optical backplane. By separation of LC and ADC, one can increase the cluster node degree with flexible add-drop rate ranging from *0%* to *100%*. In addition, use of existing chassis for scaling minimizes any loss of investments. Fig.1 (d) illustrates an example of ROADM cluster node comprising M×IC interconnecting g×LC with h×ADC along with a cluster controller configured to control the operation of the cluster ROADM node through communications with all the chassis controllers. Each LC comprise N line cards for N incoming and outgoing fibers of the cluster node and M interconnect cards. Each ADC equipped with M interconnect cards and the remaining $32-M$ cards are used as add-drop cards. Each IC has S interconnect cards for interconnecting g×LC and h×ADC, where $S=g+h$. The M interconnect cards of g×LC connect via fiber, shown as solid line, to M×IC. Similarly, the M interconnect cards of the h×ADC connect via fiber shown as dot-dash line, to M×IC. Total number of WSS cards that an LC supports is $M+N$ (e.g., 32). As well, $S=g + h$ is the total number of interconnect cards that each of the M low-cost IC supports, e.g., $S=16$. The total degree of the ROADM cluster node is g×N. The add-drop rate of the cluster is determined by the parameter h and the number of add/drop ports on each add/drop card. Selection of appropriate values for M and N has both cost and performance impact. In a 3-stage classic non-blocking Clos architecture, the relationship between M and N is $M \geq 2N - 1$. As this selection results in more common equipment cost (e.g., $N=11$ and $M=21$) and less number of degrees, we propose to use $N < M \leq 1.3\times N$. While the selection can impact blocking performance, we propose to use an order-based algorithm that result in blocking rate better than 10^{-4}. With selection of $N=14$, $M=18$ and assuming $h=0$, a cluster node can be scaled to 224 degree in comparison with 176 offered by Clos architecture.

3. Connection Management

The cluster controller in Fig.1 (d) determines connectivity path for a requested wavelength i connection from an input chassis to an output chassis through an IC. It examines availability of wavelength i on all the six WSS cards involved from an input (or add) of the cluster to an output (or drop) of the cluster node. The controller uses an order-based scheme that sets the sequence by which each IC is examined to determine an end-to-end availability. A connection is blocked when none of M×IC can provide connectivity on the same requested wavelength from an input to an output of the cluster. The use of order-based scheme has many advantages. It leads to ordered utilization of M interconnect chassis from the most to the least utilization without calculating time consuming utilization index of each interconnect chassis for the decision making. It also reduces blocking probability as it packs the connections from the most utilized to the least utilized IC [4]. Another advantage is that the last IC in the order list is least utilized and could be used for protection in case of failure situation in any of $M-1$ ICs. Blocking is defined as the probability of an available wavelength k from an input link (line or add) to an available wavelength k of the output (line or drop) is blocked due to unavailability of wavelength k on any of the M interconnect nodes. The blocking is due to inter-chassis as intra-chassis connectivity of LC, ADC and IC is non-blocking. Let ρ denote the probability each wavelength carry traffic and y the blocking probability for the inter-chassis links between first and second stage and the link between the second to the third stage. Use of order-based scheme yields $y=1$ for inter-chassis links 1 to u and $y= (N\rho - u) / (M - u)$ for inter-chassis links from $u+1$ to M, where $u = \frac{1}{80}\sum_{\omega=1}^{80} u_\omega$, assuming 80 wavelength ITU 50GHz grid and u_ω is the packing degree for wavelength ω. The total blocking probability is given by

$$P_b = \left[1 - \left(1 - \frac{N\rho - u}{M - u}\right)^2\right]^{M-u}, \quad u=0,\ldots, N\rho. \qquad (1)$$

It is noted that for the example $N=14$, $M=18$ and $S=16$, the average packing degree observed in the simulation when all input wavelengths of a cluster node are connected to all output wavelengths is around $u=13.1$.

4. Simulation Results

The proposed ROADM cluster node is modelled in simulation at full load with random permutation of the wavelength connectivity for all five cases in Table 1. Case 1 considers a cluster ROADM node with 112 degree and 100% add/drop capability whereas case 5 considers a ROADM degree of 224 with no add/drop connection. Cases 2 to 4 represent more of a deployment scenarios with 14% to 60% add/drop rates. For each case, full-load simulation of 17,920 connections per connectivity map is performed and the blocking rate is obtained for over 100,000 maps. Table 1 summarizes the average blocking rate of these cases and compares the results of order-based method with those of load-balancing and random routing. In load-balancing algorithm, a least utilized center stage IC is used while in random algorithm, a center-stage IC is randomly selected. The order-based connection method outperforms these two algorithms. The results are validated by analytical equation (1) derived for case 5. The average blocking

Table 1: Summary of fully loaded cluster node simulation modeling for N=14 and M=18 for 5 different cases.

	Case 1	Case 2	Case 3	Case 4	Case 5
# of Line chassis (*g*)	8	10	12	14	16
# of Add-Drop Chassis (*h*)	8	6	4	2	0
Number of Degree	112	140	168	196	224
Add/Drop rate	100%	60%	33%	14%	0%
Total traffic Channels	17920	17920	17920	17920	17920
Total Channels Added	8960	6720	4480	2240	0
Total Channels Dropped	8960	6720	4480	2240	0
Pass-through Channels	0	4480	8960	13440	17920
Mean Blocking (Load Balancing)	0.0104	0.0103	0.0102	0.0104	0.0116
Mean Blocking (Random Routing)	0.0079	0.079	0.08	0.0084	0.009
Mean Blocking(Order based)	$3.5X10^{-6}$	$4.7X10^{-6}$	$7.2X10^{-6}$	$1.3X10^{-5}$	$1.8X10^{-5}$

can be obtained as $P_b^{u_k} = \frac{1}{17920}\sum_{i=0}^{17920} P_b(\rho_i)$, where u_k is packing degree and $P_b(.)$ calculated from equation (1) for $\rho_i = 0, \frac{1}{17{,}920}, \frac{2}{17{,}920}, \ldots, 1,$ with $13 \leq u_k < 14$ as maximum utilization is $N\rho$. The simulation result shows packing degree of u=13.1. The analytical results of $P_b^{u=13} = 7.8 \times 10^{-5}$ and $P_b^{u=13.4} = 1.22 \times 10^{-5}$ are within the range of simulation results for blocking rate 1.8×10^{-5} for case 5. Fig. 2(a) shows the histogram of blocking rate for 1,000,000 connection maps for all 5 cases. The maximum blocking rate is 1.7×10^{-4} occurred for 0.2% of maps whereas 84.7% of connection maps had zero blocking rate. Each map composed of 17,920 wavelengths connectivity. While the results of Table 1 and Fig. 2(a) obtained for single channel 50GHz connections, the blocking performance of cluster node is not impacted with super-channels. Fig. 2(b) shows average blocking rate of fully loaded cluster node when each fiber has mix of both single- and supper-channels each with 4x bandwidth of a single channel.

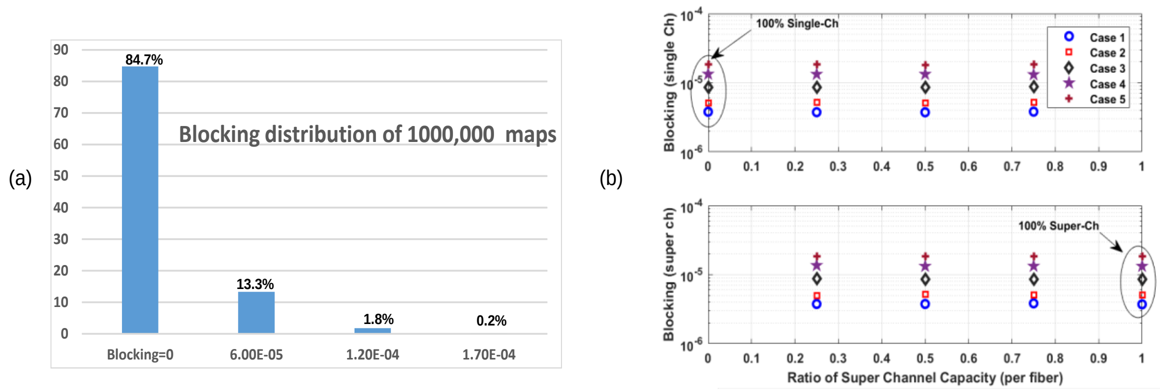

Fig 2. (a) Blocking rate for 1 million full map (randomly permuted) of single-channel connections. (b) Average blocking rate of 5 cases for full fiber loading with mix ratio of single- and super-channel connections.

5. Conclusions

A 3-stage highly scalable, flexible and pay as grow ROADM cluster node was proposed that uses less than 30% dilation for inter-chassis connectivity and deploys an order-based wavelength connection algorithm that is fast due to simplicity and offers better than 10^{-4} blocking for all sizes of connections at full load. Use of existing ROADM chassis to build the proposed cluster node minimizes any loss of investments by both the customer and the vendor.

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