Importance of the Contentionless OXC Property for WDM Networks Handling the Fastest Optical Channels

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Abstract: This paper explains why the contentionless property becomes more than only "nice to have" in the add/drop stages of wavelength-routing OXCs with fewer channels in the C-band as channel symbol rate still significantly grows © 2024 Nokia

1. Introduction

Over the last decade the added value of the contentionless Add/Drop Blocks (ADB) in the wavelength-routing Optical Cross-Connects (OXC) appearing as option B in fig. 1, has been challenged by only Colorless/Directionless (CD) ADBs (option A in fig. 1). Because most of the published network studies comparing them concluded that CD ADBs can achieve very similar performance by making the Routing and Wavelength Assignment (RWA) aware of the internal OXC blocking [1-4]. Moreover, the initial contentionless ADB based on MultiCast Switched (MCS) [5] needed more internal amplification and served much fewer WDM Elastic Optical Transponders (EOT) than one usual CD ADB. Hence, the capital and operational expenditures associated to MCS could be deemed as not competitive enough by some operators. This might change now because: i) the growing channel symbol rate entails fewer channels per fiber and then fewer served EOTs per CD ADB, making then CD and Contentionless CD (CDC) ADBs similar in that regard; ii) by contrast, the more recent NxM add/drop Wavelength Selective Switch (WSS) [6][7] (see fig. 1) allows individual CDC ADBs serving more than 80 transponders whatever their symbol rates; iii) network performance should be assessed under gradual deployment of the ADBs along with the traffic growth as it will more likely happen in the field [8]. In that new context, this paper explains why the most modern CDC ADBs are now even more compelling than the CD ones for WDM networks equipped with EOTs faster than 100 GBaud.

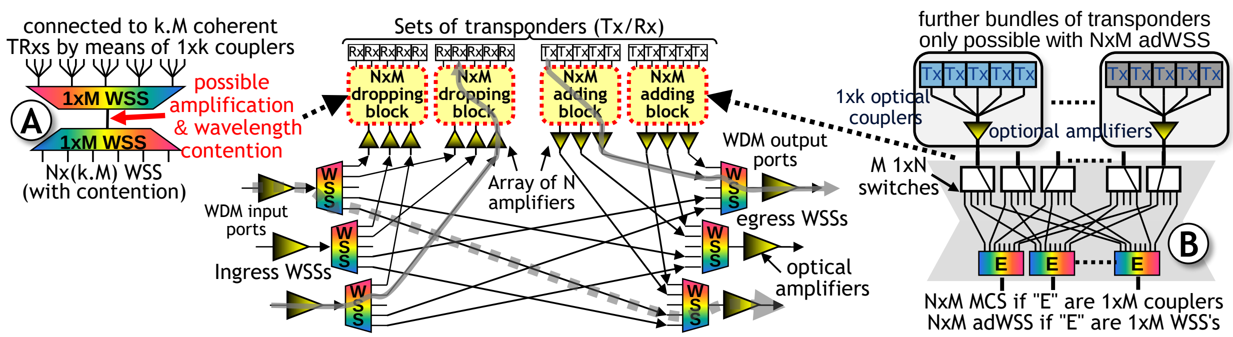

Fig. 1: *3-degree WSS-based OXC equipped with CD ADBs (A) or CDC ADBs (B). If the E components in CDC ADBs are 1xM couplers (resp. 1xM WSS's,) then modules B are MCS's (resp. adWSS's). Tx: transmitter. Rx: Coherent receiver.*

2. Why the CDC OXC setup gains momentum

When the first CDC WDM OXC layouts proposed more than 10 years ago [5] relied upon 8x8 and 8x16 MCS, 50 GHz was still the most common channel spacing in regional/core WDM fiber networks enabling up to 96 channels per fiber in the 4800 GHz-wide C band, and then also in the CD ADBs. The initial 8x16 MCS's could not serve more than 16 EOTs, which is only 17% of this 96-channel maximum capacity in a CD ADB. However, with the new generation of 130/140 GBaud channels 150 GHz apart, C-band will not carry more than 32 channels. Under that condition, one 8x16 MCS can serve 50% of this maximum fiber capacity, and up to 100% with 8x32 MCS now available. But even more than that, by associating 4 EOTs bundled by 1x4 amplified optical couplers with the most sophisticated 8x24 filtering Add/Drop WSS (adWSS) as sketched by option B in fig.1, one adWSS can serve up to 4x24=96 such EOTs under the most favorable conditions, which corresponds to the capacity of 3 fibers operating on the C-band with 150 GHz-spaced WDM channels. So, the situation is now clearly reversed in favor of the CDC approach, and it will further invert with future faster EOTs leading to only 24 or 16 channels per fiber on C band. By contrast, such EOTs bundling with amplified couplers is not possible with NxM MCS's owing to the too impairing optical noise funneling in their internal 1xM couplers multiplexing channels.

3. Relevance of testing the progressive deployment of add/drop blocks

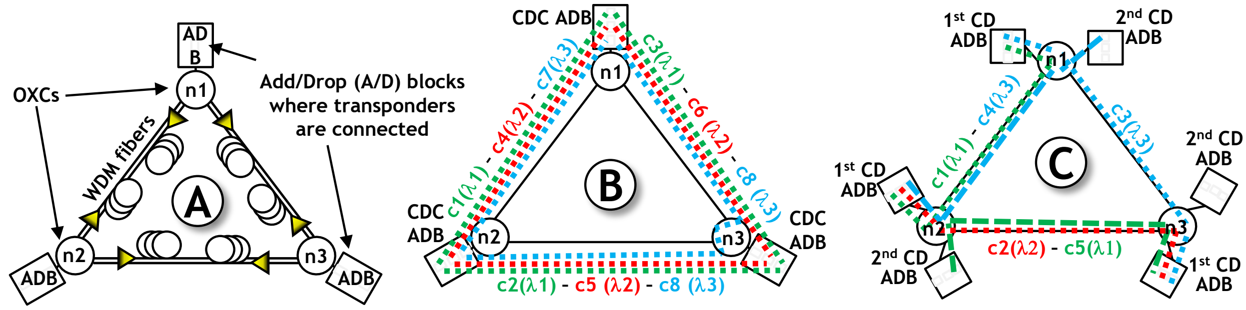

Fig. 2: *(A) 3-node triangle network topology; (B) possible wavelength allocation without add/drop constraint; (C) wavelength allocation with CD constraint in ADBs and gradual deployment of ADBs leading to suboptimal network performance.*

Assessing the impact of CD vs. CDC ADB on the Maximum Network Capacity (MNC) can be quantified via WDM network planning, by comparing MNC for a specified network topology and traffic distribution. Such a comparison is often performed by assuming a given number 1, 2 or 3 of ADBs deployed from the network beginning of life in each of its OXCs. But a large ratio of actual WDM networks starts with a single ADB per OXC and adds extra ADBs only when there is no other way to serve a request for optical connection. This could lead to suboptimal RWA for avoiding extra ADBs at a given moment and eventually to a lower MNC. It can be understood from the basic example illustrated by fig. 2A. It reports a network made of 3 OXCs **n1**, **n2** and **n3** with WDM system carrying up to 3 wavelengths **λ1**, **λ2** and **λ3** per fiber. We examine the scenario when the following 8 bidirectional connections "cn" should be sequentially allocated: **c1**: n1↔n2; **c2**: n2↔n3; **c3**: n3↔n1; **c4**: n1↔n2; **c5**: n2↔n3; **c6**: n3↔n1; **c7**: n1↔n2; **c8**: n1↔n2. With CDC ADBs without constraint, the suite of wavelengths appearing in fig. 2B can transport these 8 connections with c8 going transparently through n3. The 3 wavelengths of each WDM link are then occupied. But with CD ADBs progressively installed along with traffic rise, the wavelength allocation up to connection c5 is as shown by fig. 2C since each ADB cannot serve a wavelength more than once. This wavelength distribution is the one minimizing the whole number of CD ADBs required at each moment in this network. Connections c6 and c7 could then be allocated, but whatever their 2 wavelengths and unlike in fig. 2B, transparent connection c8 is not possible. Because λ1, λ 2 and λ3 are already taken along the transparent light path from n1 to n2 via n3, owing to RWA constrained by the wavelength occupation in the links and in the CD ADBs. Hence, the ultimate number of transmitted channels in case of fig. 2C with gradual installation of CD ADBs drops by 1/8=12.5% as compared to the case of fig. 2B. If each of the 3 OXCs in fig. 2C was equipped with 2 CD ADBs from its beginning of life, such a decay would not happen.

4. Impact of gradual installation of CD add/drop blocks on actual WDM network topologies

After the basic examples of fig. 2, the same question is studied for 3 more realistic WDM networks with practical model of EOT, WDM transmission and traffic. To that purpose, the Deutch N30, German G50 and Indian IND71 topologies are considered as drawn in fig. 3. N30/G50/IND71 respectively has 45/88/97 pairs of bidirectional WDM links and 30/50/71 OXCs classified into 4/8/8 core OXCs and 26/42/63 regional ones. The WDM links are suites of G.652 standard single mode fiber spans interleaved with Erbium doped fiber amplifiers exhibiting 5.5 dB worst noise figure over the 4800 GHz-wide C band. These networks are simulated with OXC layout like in fig. 1. Their ADBs are CD or CDC ones uniformly over the whole network. They serve 130 GBaud EOTs with 32 channels 150 GHz apart per fiber. The EOT carrier capacity can be adjusted from 400 to 1200 Gb/s with 200 Gb/s steps. The capacity of the carriers of each connection is set at the maximum with respect to the quality of its light path. The model of physical impairments incurred by a transmitted channel accounts for its EOT maximum electrical signal to noise ratio and for the accumulations along its light path of amplified spontaneous noise from the crossed optical amplifiers, of non-linear optical noise from WDM transmission by assuming fully loaded WDM links, of polarization dependent loss, of WSS filtering and of optical crosstalk due to imperfect WSS isolation.

This study simulates hierarchical traffic distributions made of a fixed part handled first and then a 2nd random part. In the 1st part, each pair of core OXCs exchanges an 800 Gb/s service and each regional OXC exchanges 400 Gb/s with its 2 closest core OXCs. During the 2nd part, 33% of the connections are between random pairs of core OXCs and 67% of them are required between random pairs of any core and regional OXCs. The throughput of these demands of connection is randomly selected from the set {400 Gb/s, 800 Gb/s, 1.2 Tb/s}. Each connection is initially served by means of partial inverse multiplexing and via end-to-end traffic aggregation whenever possible. If there is not sufficient spectrum resource available in the network for a transparent light path carrying the

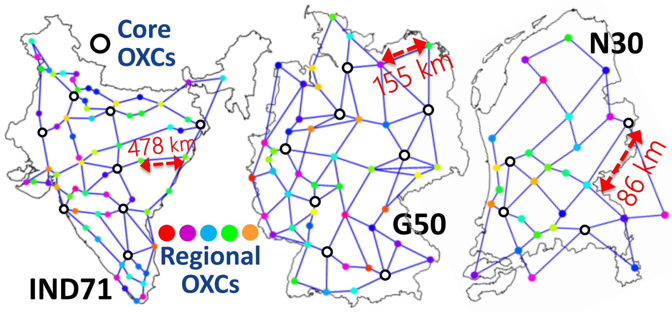

Fig. 3: *Simulated IND71, G50, N30 networks*

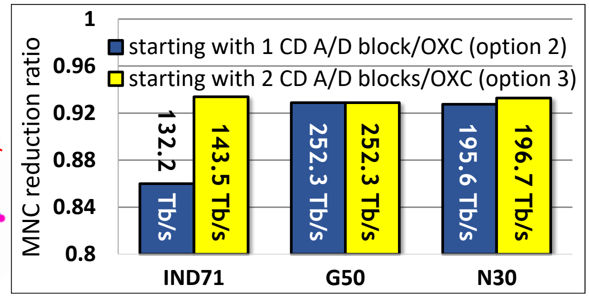

Fig. 4: *MNC reduction ratios comparing options n°2 & 3 versus option n°1*

residual demanded capacity after this initial electrical end-to-end grooming, the whole demand is discarded. The simulation runs until more than 1% of the total demanded capacity is rejected. At this moment, the total throughput accommodated so far is called its MNC.

This study compares 3 options for deploying ADBs gradually along the requested traffic and independently in each OXC. Option n°1 is the reference case with only CDC ADBs. Options n°2 (resp. n°3) assumes only CD ADBs starting with 1 ADB (resp. 2 ADBs) installed in each OXC. Network planning is run 200 times for each network and each of the 3 options with 200 distinct seeds for random traffic draw. The values reported in the remainder are averaged over these 200 draws. In Fig. 4, the vertical values show the simulated mean MNCs for options 2 and 3, and the bar heights represent their ratios versus MNC of option n°1. As expected, these ratios are all smaller than 1, confirming that even if their number is unlimited, progressively installing CD ADBs can notably impact the overall MNC under our simulation conditions. MNC decays range from -6.6% down to -14%. MNCs in G50 and N30 are less affected than in IND71, without meaningful discrepancy between options n°2 and 3. For IND71, MNC decreases more when OXCs start with the fewest ADBs. The lower impact on G50 and N30 can be explained by their topologies with higher average OXC connectivity (3.53 for G50, 3 for N30 and 2.75 for IND71), meaning that RWA has more possibilities across the network to circumvent wavelength blocking from ADBs than in IND71. Because RWA combats CD ADBs blocking by finding alternative light paths via the available OXC directions. These light paths are detours as compared to the most optimal ones that could be established with CDC ADBs instead. The longer these detours, the more extra spectral resources they consume inside the network, resources that will be then missing to reach the ultimate MNC when the traffic will further grow. In IND71, these detours are relatively longer because of its higher ratio of 2-degree OXCs than in N30 and G50. Therefore, IND71 more suffers when the CD ADB constraints augment, for instance by starting with only one ADB per OXC, like with option n°2.

5. Conclusion

This study illustrates and explains why deploying CD ADBs in the OXCs of WDM transparent networks does not ensure network performance as good as with only CDC blocks, even if the number of CD blocks is unrestricted. The discrepancy between these 2 options may lower the total network throughput by down to -14% if rolling out the CD ADBs gradually along with the traffic growth for expense streamlining. This reduction depends on the network topology, on the initial number of CD ADBs in each OXC and on the match between the traffic geographical distribution and the topology (this latter dependency was not examined in this paper). Resorting to CDC ADBs avoids these shortcomings and guarantees the maximum network capacity. Moreover, with the forthcoming new generation of transponder implying less than 50 channels per fiber over the C-band, CDC solutions can be viewed as more cost effective, as one adWSS-based CDC ADB can now serve much more wide carriers than a CD ADB.

6. References

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