# Evaluating add/drop contention blocking in non-contentionless ROADMs

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**ABSTRACT**
In this paper, we evaluate the capacity reduction in a network composed of directionless-colorless ROADMs, caused by the internal blocking of the ROADMs that are not contentionless. We are interested in determining the number of add/drop modules, so-called add/drop contention factor *C*, that eliminate this capacity reduction in practice. Under simulation, we show that a moderated contention factor (*C*=2) is sufficient to roughly provide the same performance as contentionless nodes in terms of either blocking probability in the long-run or carried traffic before the first blocking event. Results were obtained within the Net2Plan tool, and source code is publicly available on Net2Plan website.
**Keywords**: ROADM, Colorless, Directionless, Contentionless, Routing and Wavelength Assignment, Network Planning

## 1. INTRODUCTION

Over the last decade, the success of transparent optical networks was based on the deployment of Reconfigurable Optical Add/Drop Multiplexers (ROADMs) to provide all-optical connections, or lightpaths, simplifying provisioning and maintenance operations. A lightpath originates at a transponder at the ingress node (*add*) and terminates at a transponder at the egress node (*drop*), without the need of O/E/O conversion at intermediate nodes (optical bypass). Nonetheless, current generation ROADMs typically have add/drop ports that are directional (fixed input/output fiber) and colored (fixed wavelength). This still requires on-site manual operation to change the direction of an added or dropped lightpath, or to change its wavelength.

Fortunately, the interest of service providers in delivering lightpath-on-demand services is pushing toward the development of Colorless and Directionless ROADMs (CD-ROADMs) [1]. Several CD-ROADM architectures have been proposed in the literature [1], being the most popular the broadcast-and-select (B&S) design presented in Fig. 1. In B&S CD-ROADMs, each add/drop port can be assigned to any wavelength (colorless) and can access any input/output fiber (directionless), while a given transponder bank can only support a single instance of a given wavelength (non-contentionless). Hence, the number of lightpaths that can be added/dropped at a given wavelength in a node, so-called add/drop contention factor (*C*), is equal to the number of installed transponder banks. Note that in this architecture, no wavelength converters are present, thus wavelength continuity is enforced. Fig. 1 helps us to understand the new intra-node contention arising from B&S CD-ROADMs: because of the existence of a two bank of transponders (*C*=2), it is not possible to add/drop three lightpaths in the same wavelength, even if they are routed through different directions (North, West, East). CD-ROADMs with full interconnection between any add/drop port and any route at any wavelength would have an enormous complexity, and they are not implemented in practice. The client-side fiber cross-connect (C-FXC) decouples ROADM transponders from client line cards, sharing the transponders among potentially many clients of the service, and providing 1:*N* transponder protection.

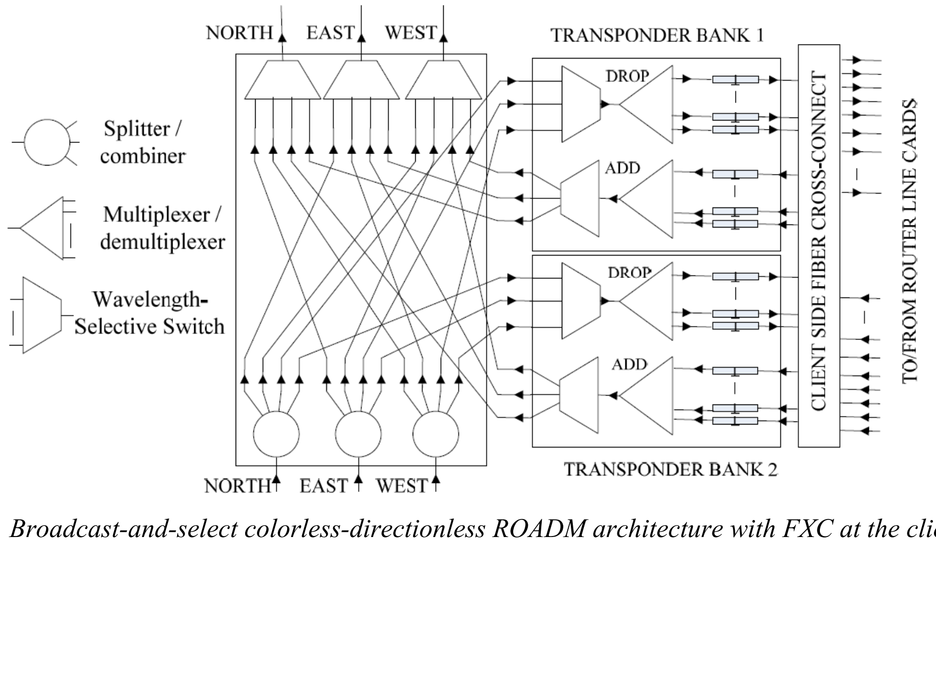



*Figure 1. Broadcast-and-select colorless-directionless ROADM architecture with FXC at the client side.*

In this paper, we are interested in investigating the effects in the network capacity, of the add/drop contention factor $C$ in the nodes. This is relevant for ROADM design, since it may be possible to build ROADMs that are contentionless in practice, that is, which do not produce a significant performance loss in terms of lightpath blocking. We rely on the hypothesis is that if the network is appropriately planned, employing Add-Drop Contention Aware Routing and Wavelength Assignment (ADCA-RWA) algorithms, it is possible to mitigate the lightpath blocking caused by add/drop contention, as demonstrated in [2][3][4][5]. We focus on the online case, when lightpath demands arrive randomly to the nodes. Results are obtained via simulation using the Net2Plan framework [6], an open-source network planning and post-analysis tool.

The rest of the paper is organized as follows. Section 2 collects related work in the topic and describes different ADCA-RWA algorithms for our study. Section 3 describes the case study and methodology. Section 4 reports the results obtained. Finally, Section 5 concludes.

## 2. ONLINE ADCA-RWA ALGORITHMS

ADCA-RWA problem has been investigated in the past [2][3][4][5], as a strategy to alleviate the blocking effects caused by internal contention.

In the offline scenario, where all lightpath requests are known in advance, the work [3] focuses on dimensioning the contention factor in the context of unprotected and 1+1 lightpath protection cases, while [5] studies the lightpath restoration case. Both ILP models and efficient heuristics are provided for the different problem variants. Results show that in these scenarios two transponder banks (and often just one) can be enough to achieve contentionless behavior in practice, if the RWA is adequately designed.

The ADCA-RWA problem has been also investigated in the online planning scenario in [2][4], when lightpath demands arrive randomly to the nodes. In [2] several online ADCA-RWA planning algorithms are proposed and their performances are investigated. Different routing schemes are studied (fixed-alternate and adaptive), while wavelength assignment employs first-fit. Adaptive schemes provide the best performance in terms of blocking, but were discarded for this work because of their higher computational complexity. Similarly, in [4] another online fixed-alternate ADCA-RWA algorithm is presented that, as a novelty, can be implemented into a distributed GMPLS RSVP-TE control plane. This latter one has been implemented in Net2Plan, and is referred in this work as ADCA-RWA. Again, preliminary results in [4] reveal that two transponder banks may be enough in the online case to provide contentionless behavior in practice, in a reference topology.

In addition, we include in this study the Fragmentation and Misalignment-Aware Routing and Spectrum Assignment (FMA-RSA) algorithm, proposed in [7] for OFDM-based (or flex-grid) networks. FMA-RSA algorithm chooses among a set of pre-computed paths, the one that minimizes a fragmentation-related metric. The algorithm allocates each new connection request in such a way that it fragments the least number of continuous spectral blocks on candidate links, while it fills up as many misaligned spectral slots as possible on neighbor links. When applying FMA-RSA to classical RWA problem where all lightpaths occupy the same bandwidth, the fragmentation issue dissapears. Still, the FMA-RSA algorithm will minimize misalignment between neighbor links, which will increase the chances of finding a feasible RWA for multi-hop lightpaths. Again, we implemented the FMA-RSA algorithm within Net2Plan, and we will refer to it as FMA-ADCA-RWA. Minor modifications to the original algorithm were performed to adapt it to the ADCA problem. Here, the RWA is decided so that minimizes the aforementioned metric and at least one available transponder exists tuned at the chosen wavelength in the ingress and egress nodes of the lightpath.

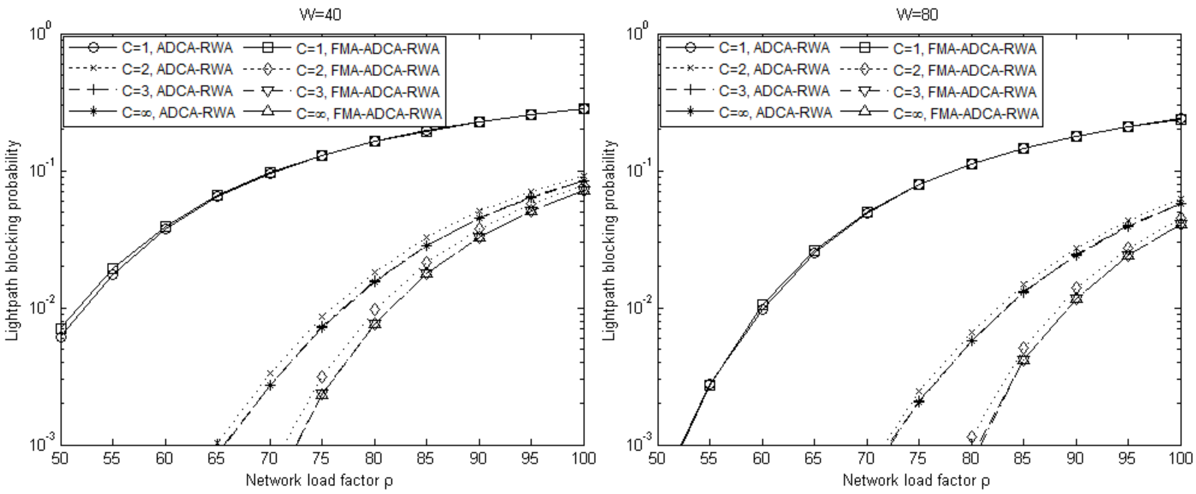
## 3. CASE STUDY

The objective of the study is to analyze and compare the performance, in terms of blocking, of the previously-described ADCA-RWA and FMA-ADCA-RWA algorithms. Lightpath requests arrive randomly and are handled by a centralized network controller (i.e. Path Computation Element, PCE) with global information of the network state (routing, spectrum allocation and transponder-bank usage of active lightpaths), which tries to allocate the lightpath using one of the implemented ADCA-RWA algorithms. Simulations were completed in the Net2Plan Connection-Admission-Control (CAC) simulator, one of the available tools within the open-source Net2Plan framework. All algorithms have been integrated into Net2Plan, and the source code is publicly-available on the website [6] for review and reuse of interested readers.

## 4. RESULTS

In our tests, we consider the 14-node 42-link NSFNET network [8]. Each fiber link provides $W$={40,80} 10-Gbps WDM channels according to the 100/50-GHz ITU-T G.694.1 grid. Nodes are equipped with $C$={1,2,3,∞} transponder banks, and a high number of add/drop modules in each of them (i.e. equal to $W$). The $C$=∞ case represents the contentionless scenario. Lightpath requests are generated following a Poisson process with rate λ, and holding time following a negative exponential distribution with mean time equal to one time unit. Inter-arrival times (1/λ) are adjusted so that the total intensity between two nodes matches the values given by a traffic matrix $M$, which is a scaled version of the reference traffic matrix in [8] for NSFNET network. A normalization process is completed to obtain the traffic matrix to be associated to a fully-loaded network. For this, we use the traffic normalization functionality of Net2Plan, which computes (using linear programming) the maximum scaled version of a given matrix, that can be carried by a given network if optimal minimum-congestion routing is used. We associate this matrix to the 100% load factor. Note that this matrix is an upper bound to the maximum traffic that can be actually carried in our case, since the optimal routing in the normalization process does not consider neither wavelength continuity constraints, add/drop contention, nor integrality in the number of lightpaths. Offered load is varied from 50% to 100% in steps of 10%, and $10^6$ connection requests are simulated for each load factor.

Fig. 2 shows the lightpath blocking probability achieved with both algorithms. As can be observed, ROADMs with only one transponder bank would yield to the worst performance. Interestingly, the difference in terms of blocking between cases $C$=2 and $C$=∞ is negligible, independently of the algorithm. The best performance is achieved by the FMA-ADCA-RWA algorithm, improving the blocking probability up to 85% at moderate loads (<80%) when $W$=80. As expected, the gap between both algorithms reduces as the load increases. Intuitively, reducing misalignment between neighbor links increases the chances to allocate multi-hop lightpaths. However, at higher loads wavelength resources are scarce, independently of the RWA algorithm.




(a) $W = 40$ (b) $W = 80$

*Figure 2. Lightpath blocking probability for NSFNET network.*

### 4.1 Influence of internal contention in blocking probability

In our case study, lightpath requests may be blocked for two reasons: (i) a wavelength path could not be found; and (ii) internal contention, when a free add/drop transponder pair tuned at the given wavelength could not be found. A blocking event is due to internal contention if and only if a feasible wavelength path could be found first.

Table 1 illustrates the relative influence of internal contention over the total experienced blocking. Influence below 0.01% is marked with a dash ("-"). We omit the case $C$=∞ since it is the contentionless scenario, and $C$=1 since almost any blocking event is due to internal contention. In general, results show that internal contention causes 25-35% of the total blocking situations when $C$=2, but it is negligible when $C$=3 (always below 0.4%).

*Table 2. Relative influence of internal contention (%).*

| C | W | Algorithm | Network load factor ρ | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 |
| 2 | 40 | ADCA-RWA | 50.0 | 29.3 | 23.6 | 26.6 | 27.6 | 28.5 | 28.8 | 28.5 | 28.5 | 27.7 | 26.9 |
| | | FMA-ADCA-RWA | - | - | 25.0 | 40.4 | 30.2 | 33.4 | 33.7 | 32.8 | 31.5 | 30.3 | 29.2 |
| | 80 | ADCA-RWA | - | - | - | 24.4 | 28.0 | 27.7 | 30.0 | 29.6 | 29.3 | 28.5 | 28.4 |
| | | FMA-ADCA-RWA | - | - | - | - | - | 30.7 | 34.7 | 32.6 | 33.9 | 32.8 | 31.6 |
| 3 | 40 | ADCA-RWA | - | - | - | 0.13 | 0.12 | 0.30 | 0.16 | 0.31 | 0.31 | 0.36 | 0.37 |
| | | FMA-ADCA-RWA | - | - | - | - | - | 0.33 | 0.25 | 0.22 | 0.35 | 0.38 | 0.34 |
| | 80 | ADCA-RWA | - | - | - | - | 0.20 | 0.26 | 0.17 | 0.28 | 0.30 | 0.25 | 0.31 |
| | | FMA-ADCA-RWA | - | - | - | - | - | - | 0.15 | 0.29 | 0.35 | 0.40 | 0.39 |

### 4.2 Incremental model

To conclude, we perform a set of simulations for the incremental model. This model is included to reflect present-day operation of networks not offering lightpath-on-demand services: permanent connections are set up, and never/seldom modified. In this case, we are interested in determining the maximum end-to-end traffic which can be supported by the network before a capacity upgrade is required. We estimate this as the carried traffic right before the first blocking event occurs, that is, the number of already established lightpaths multiplied by the nominal rate per lightpath (10 Gbps). Simulation starts with an empty network (no lightpath is established), and requests, of infinite holding times (and thus permanent) arrive randomly. When configured as "incremental model simulation", Net2Plan CAC simulator is able to detect the first blocking event, stopping the simulation and collecting traffic metrics.

Table 2 shows the average carried traffic before the first event, obtained over 1000 independent runs. Again, we observed the degraded performance of both algorithms when contention factor equals to one, while a factor $C$=2 suffices to have a contentionless performance in practice. Also, FMA-ADCA-RWA outperforms ADCA-RWA at any contention factor.

*Table 2. Results for the incremental model*

| W | Algorithm | Average carried traffic before first blocking event (Tbps) | | | |
|---|---|---|---|---|---|
| | | $C$=1 | $C$=2 | $C$=3 | $C$=∞ |
| 40 | ADCA-RWA | 3.70 | 4.98 | 4.98 | 4.99 |
| | FMA-ADCA-RWA | 3.75 | 5.42 | 5.45 | 5.46 |
| 80 | ADCA-RWA | 8.05 | 10.19 | 10.21 | 10.23 |
| | FMA-ADCA-RWA | 8.12 | 11.30 | 11.36 | 11.37 |

## 5. CONCLUSIONS

This paper presents different Add/Drop Contention-Aware RWA (ADCA-RWA) algorithms suitable for networks equipped with colorless-directionless ROADMs. These algorithms were implemented within Net2Plan framework, and can be readily integrated in a Path Computation Element (PCE) with no changes in the lightpath establishment procedures. We conduct a battery of simulations using the NSFNET reference topology, under different blocking scenarios (both long-run and incremental models). Results reveal that the performance loss is negligible in the case that only two transponder banks are installed, or even one in case of low network load.


## ACKNOWLEDGEMENTS

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