Blocking Performance in Dynamic Optical Networks based on Colorless, Non-directional ROADMs

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Abstract:
We show that blocking in dynamic networks of colorless, non-directional ROADMs is tolerant to intra-node contention when contention-aware routing/wavelength assignment (RWA) algorithms are used. An optional client-side cross-connect enables low blocking with simpler RWA variants.
OCIS codes: (060.4510) Optical communications (060.4251) Networks, assignment and routing algorithms

1. Introduction

Reconfigurable Optical Add/Drop Multiplexers (ROADMs) are being widely deployed by service providers in long-haul and metro optical networks [1, 2]. These deployments deliver lower CAPEX and OPEX by providing optical bypass (no regeneration) and by simplifying provisioning and maintenance operations. Current generation ROADMs typically have add/drop ports that are colored (fixed wavelength) and directional (fixed fiber route). This requires manual provisioning by operators to connect each transponder to a specific add/drop port. In addition, the wavelength channel cannot be routed to different fiber routes, practically prohibiting the introduction of dynamic wavelength services.

Service providers would like to introduce flexible and dynamic optical networks that will enable rapid service provisioning, adaptability to traffic churn and resiliency to network fiber failures [1-3]. Colorless, Non-directional ROADMs (CN-ROADMs) with network-wide control automation are essential to realizing such dynamic networks. In CN-ROADMs, each add/drop port can be assigned any wavelength (colorless) and can access any fiber route (non-directional). These CN-ROADMs provide full interconnection for transit traffic among fiber routes, as well as full interconnection between fiber routes and add/drop structures grouped in transponder banks. In typical implementations, each transponder bank connects to the ROADM core through a single fiber pair, so any given bank can only support a single instance of a given wavelength. Thus, intra-node contention can arise if two routes request the same wavelength from transponders located in the same transponder bank. Colorless, non-directional, contention-less ROADM (CNC-ROADM) designs have also been proposed to remove the intra-node wavelength contention from the add/drop structure, but such designs may not scale gracefully with the number of fiber routes and add/drop capacity [4]. CN-ROADMs can also be extended with a client-side fiber cross-connect (C-FXC) to support 1:N protection against transponder failure as well as sharing of transponder resources among clients, which is highly desirable in dynamic networks [5]. It was shown that the C-FXC can alleviate intra-node contention in CN-ROADM nodes [6].

In this paper, we evaluate the blocking performance of dynamic optical networks based on CN-ROADMs by simulation, including cases where the routing and wavelength assignment algorithms incorporate intra-node constraints. The blocking rate is an important metric to analyze the performance of dynamic networks as the offered load is increased. We compare the blocking performance for optical networks based on CN-ROADMs with/without C-FXC and CNC-ROADMs.

2. Routing and Wavelength Assignment Algorithms

In dynamic networks, a lightpath is set up for each connection request as it arrives, and the lightpath is released after some finite amount of time. For each lightpath, the route and wavelength are selected by Routing and Wavelength Assignment (RWA) algorithms. In this study, we propose two RWA methods to incorporate intra-node constraints of CN-ROADMs. In the first method, the route selection is dependent only on the network, while the wavelength assignment considers the intra-node constraints. This method is called the network-oriented RWA (N-RWA) and its flowchart is shown in Fig. 1. In the second method, both the route selection and wavelength assignment are influenced by the intra-node constraints. The second method is called the ROADM-aware RWA (R-RWA) and its flowchart is shown in Fig. 2. In N-RWA and R-RWA, we further consider two routing sub-schemes: fixed routing (FR) and adaptive routing (AR) [7]. In N-RWA with fixed routing (N-RWA-FR), the same shortest route for a given source-destination pair is always selected; while in R-RWA with fixed routing (R-RWA-FR), multiple routes pre-calculated using k-shortest path routing are considered to reduce the chance of wavelength blocking due to intra-node constraints. In N-RWA with adaptive routing (N-RWA-AR), the shortest available route from a source node to a destination node is selected dynamically depending on the current network state (e.g.

wavelength usage by existing lightpaths); while in R-RWA with adaptive routing (R-RWA-AR), all available routes between the current source-destination pair are explored to maximize the chance of successful wavelength assignment under intra-node constraints. Compared to schemes with FR, schemes with AR generally result in lower connection blocking, but require full network state information and have higher computational complexity. A path computation engine (PCE) may be needed for adaptive routing to process the state information and cope with the computational load. For the wavelength assignment scheme, we considered first-fit algorithm, where wavelengths are searched sequentially and the first available wavelength is selected. A connection request between the source (S) and destination (D) nodes in the network can be blocked in three ways: 1. network blocking when there is no route between S and D satisfying wavelength continuity, 2. transponder blocking when a free transponder is not available at S or D, and 3. intra-node blocking (for CN-ROADM only) when wavelength contention within S or D prevents the use of a free transponder.

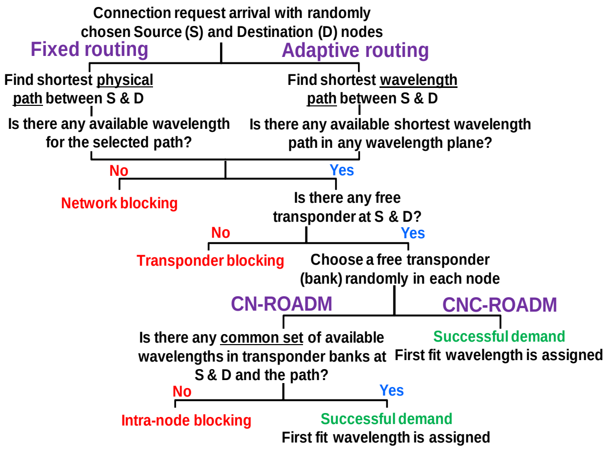

Figure 1: Flowchart for N-RWA.

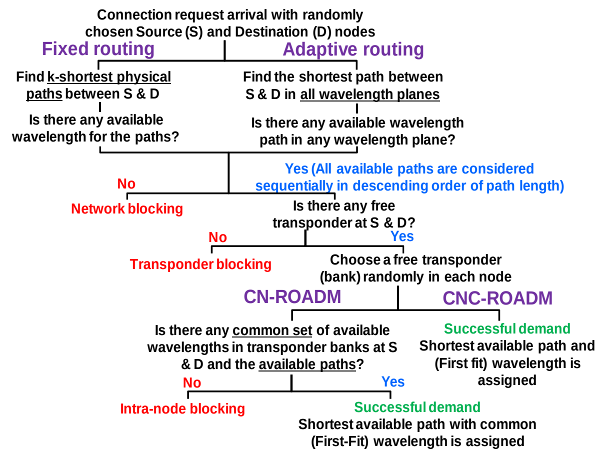

Figure 2: Flowchart for R-RWA.

3. Simulation Method and Results

The simulations were conducted on two network topologies: 1. NSFNET topology with 14 nodes, 19 links and an average hop count of 2.6 [7], 2. CORONET continental US topology with 75 nodes, 99 links and an average hop count of 6.88 [8]. Each link in the network has 88 wavelengths. We simulated all of the above four RWA schemes. All nodes in the network are either CN-ROADMs or CN-ROADMs with C-FXC or CNC-ROADMs. CN-ROADMs are of the design shown in [6]; at each node, the number of transponder banks is equal to the number of fiber routes of the node and the pre-deployed transponders are evenly distributed among the banks. Connection requests for each source-destination (S, D) pair are generated using Poisson arrival rate, ranging from 30 to 250 connections per unit time. The holding time for each connection has a Gaussian distribution with a mean duration of 5 units and a variance of 2 units. Each connection request is associated with a randomly chosen source and destination node pair. The source and destination transponders (with associated banks) are also chosen randomly. For nodes without C-FXC, the transponders are dedicated to clients. For nodes with C-FXC, the clients are chosen randomly and the available transponder is selected from a transponder bank that can support the connection [6]. The network offered load is calculated as the product of the number of connections, the average connection duration and the average hops per connection divided by the product of the total simulated time, the number of links in the network and the number of wavelengths per link. The simulation results are averaged over 10 different runs of 100k connections for a particular offered load. We allocated 44 transponders per bank at each node and observed no transponder blocking.

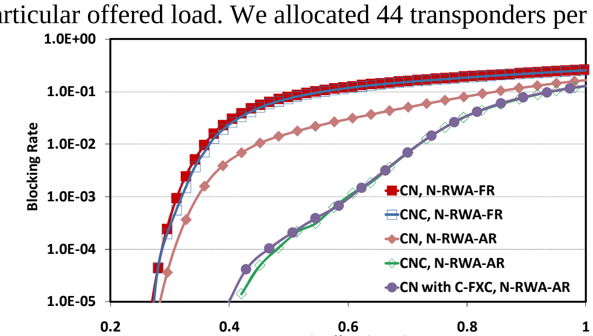

Figure 3: NSFNET with N-RWA schemes.

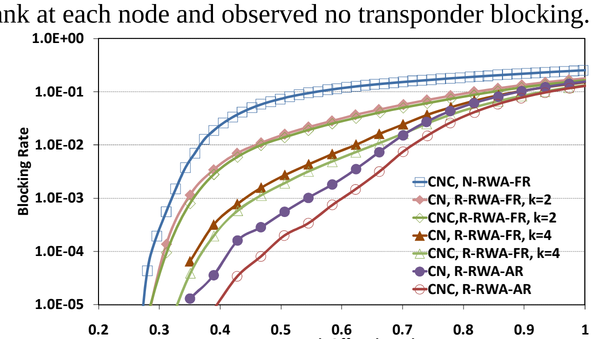

Figure 4: NSFNET with R-RWA schemes.

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Fig. 3 shows the blocking rate versus offered load for NSFNET using N-RWA-FR and N-RWA-AR schemes. The blocking rates for CN-ROADM and CNC-ROADM are very close for N-RWA-FR since the network blocking is severe and it dominates over the intra-node blocking. When adaptive routing is used, the blocking rates for both CN- and CNC-ROADM are reduced. Now the CNC-ROADM shows much lower blocking because the reduced network blocking allows the intra-node blocking in CN-ROADM to become noticeable. The results for CN-ROADM with C-FXC show that introducing C-FXC significantly improves the intra-node blocking, bringing the total blocking very close to that of a CNC-ROADM network.

Fig. 4 presents the results for NSFNET using R-RWA-FR and R-RWA-AR schemes. In these schemes, since both the route and wavelength are assigned with consideration of intra-node constraints, the blocking performance of CN-ROADMs is much closer to that of CNC-ROADM. Note that the performance of CNC-ROADM is the same for N-RWA-AR and R-RWA-AR schemes since there is no intra-node wavelength contention. For fixed routing, we show results for k-shortest path routing with k = 2 and 4. The N-RWA-FR results can be treated as R-RWA-FR with k=1. There are two observations for k-shortest fixed routing: 1. as k increases, the blocking rate for a given load improves, and 2. also as k increases, the blocking performance gap between CN-ROADM and CNC-ROADM slightly widens compared to N-RWA-FR. In the case of R-RWA-AR, the blocking performance of CN-ROADM is significantly improved from that of N-RWA-AR and approaches the performance of CNC-ROADM. Note that these results were computed with a CN-ROADM with no C-FXC.

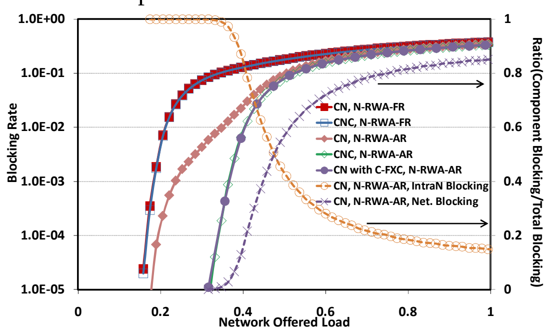

Figure 5: CORONET with N-RWA schemes.

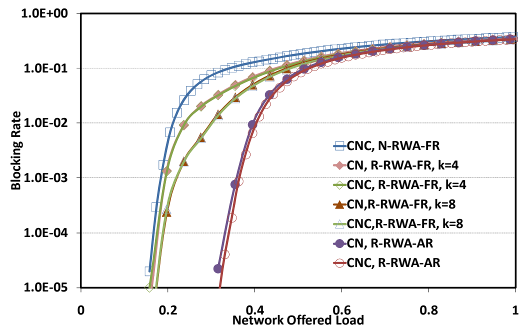

Figure 6: CORONET with R-RWA schemes.

Fig. 5 shows the blocking rate versus offered load for CORONET using N-RWA-FR and N-RWA-AR schemes. The blocking performance results show similar trends as that of NSFNET, except that the blocking due to wavelength contention in the network is much higher for a given load because the CORONET topology has higher average hop count of 6.88. For fixed routing, the blocking rate for CN-ROADM and CNC-ROADM are almost identical. When adaptive routing is used, the network blocking improves and the contribution of intra-node blocking in CN-ROADM becomes significant. With the addition of C-FXC to CN-ROADM, similar improvement in blocking performance as NSFNET is achieved. In Fig. 5, we also show the contribution of network blocking and intra-node blocking as a ratio of the total blocking for CN-ROADM with N-RWA-AR. The intra-node blocking (although it is small) is the main contributor at low loads, while the network blocking starts to dominate at higher loads.

Fig. 6 presents the results for CORONET using R-RWA-FR and R-RWA-AR schemes. For large networks such as CORONET, the difference in blocking rates between CN-ROADM and CNC-ROADM is negligible.

4. Conclusions

We have investigated the blocking performance of dynamic optical networks based on CN-ROADMs. We proposed two RWA methods of incorporating intra-node constraints. The simulation results clearly demonstrated that including intra-node constraints in routing and wavelength assignment is beneficial for deploying CN-ROADM networks. We confirmed that CN-ROADM with C-FXC can also lower blocking across the network. When using ROADM-aware RWA, the intra-node contention of CN-ROADMs has small to negligible impact (depending on the network size) on total blocking when compared to CNC-ROADMs. Thus, dynamic optical networks can be built with CN-ROADMs and enhanced RWA algorithms.

5. References

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