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LETTER

# A new integrated auxiliary graph based routing algorithm in waveband switching optical networks☆

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**Abstract**

In this letter, we propose a new routing algorithm based on integrated auxiliary graph (RA-IAG) to reduce switching ports in waveband switching optical networks. The IAG is compared of a single virtual topology layer (VTL) and multiple waveband-plane layers (WPLs). For each demand, RA-IAG first computes a single-hop or multi-hop route on VTL. If the route cannot be found on VTL, RA-IAG then computes a hybrid multi-hop route by jointing VTL and WPLs. Simulation results show that, compared with previous algorithm, RA-IAG can obtain better performance.


***Keywords:*** Waveband switching; Optical networks; Routing; Integrated auxiliary graph

## 1. Introduction

Since the number of wavelengths on fiber keeps increasing with the development of WDM technique, the size (i.e., the number of switching ports) and cost of conventional optical cross-connect (OXC) are enhanced greatly and the corresponding control and management become more and more complicated [1]. Therefore, in the recent years, the technique of waveband switching has been proposed to reduce the size of OXCs for saving cost. The main idea of waveband switching is to use the waveband grouping scheme to bind several lightpaths of wavelength level into one waveband which can be switched by only one port, so that the switches in conventional wavelength-routed networks can be reduced and the cost of OXCs can be saved.

In order to support waveband switching meanwhile provide efficiency for conventional wavelength switching; the authors in [1] proposed the structure of multi-granular OXC (MG-OXC) which includes multi-layer and single-layer models. Some papers [1–4] also proposed several waveband grouping schemes including same source-destination grouping, same source grouping, same destination grouping, and sub-path grouping, where the sub-path grouping scheme has the best performance for reducing switching ports. Based on MG-OXC and waveband grouping schemes, some papers investigated the waveband routing algorithms. Although the authors in [3,4] presented the integer-linear-programming (ILP) formulation for waveband routing and wavelength assignment to search the optimal or near-optimal result, they did not propose the efficient heuristic algorithm. In [5], the authors proposed a heuristic waveband routing algorithm based on generic auxiliary graph (RA-GAG). However, RA-GAG is based on the same source-destination waveband grouping scheme, so that the performance of reducing switching ports may not be good enough.

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In this letter, in order to well solve the routing and waveband assignment meanwhile further reducing switching ports, we propose a novel routing algorithm based on integrated auxiliary graph (RA-IAG). The IAG is compared to a single virtual topology layer (VTL) and multiple waveband-plane layers (WPLs), which are mapped based on the physical network topology. In RA-IAG, we use the waveband sub-path grouping scheme that has better performance than other waveband grouping schemes. For each demand, RA-IAG first computes a single-hop or multi-hop route on VTL. If the route cannot be found on VTL, RA-IAG then computes a hybrid multi-hop route by jointing VTL and WPLs. Compared with previous RA-GAG, RA-IAG obtains better performance.

## 2. Problem statement

The physical network is denoted as $G(N, L, B, W, T)$, where $N$, $L$, $B$, $W$ and $T$ represent the set of nodes that are equipped with MG-OXCs, set of links each of which is bidirectional and contains two unidirectional fibers with contrary direction, set of available wavebands on each fiber, set of available wavelengths on each fiber, and set of tunable transceivers that can tune the signal to any wavelength or waveband in fibers. We assume that each demand requires the bandwidth of one wavelength channel, and the waveband or wavelength assignment is the first-fit scheme. The shortest-path algorithm, i.e., Dijkstra's algorithm, is applied to compute the available routes. Some important notations are introduced as follows.

$D_n$: demand $n$; $WP_n$: working path from source node to destination node for $D_n$; $SWP_n(a, b)$: sub-working path from node $a$ and node $b$ on $WP_n$; $x$: physical node in physical network topology; $V_x$: virtual node in VTL corresponding to node $x$; $WRL(V_a, V_b)$: if there is a waveband route that has residual available wavelengths from node $a$ to node $b(a, b \in N, a \neq b)$, then there will be a waveband route link $WRL(V_a, V_b)$ between node $V_a$ and node $V_b$; $R\_WRL(V_a, V_b)$: number of residual available wavelengths on $WRL(V_a, V_b)$; $NT_x$: number of available transceivers in node $x$; $WPL_y$: WPL corresponding to waveband $B_y(1 \leqslant y \leqslant |B|)$; $B_y^x$: waveband node in $WPL_y$ corresponding to node $x$; $WPL_y(B_y^a, B_y^b)$: if there is a fiber connection between node $a$ and node $b$, and the waveband $B_y$ on this fiber is free, then there will be a waveband link $WPL_y(B_y^a, B_y^b)$ between node $B_y^a$ and node $B_y^b$; $VL(V_a, B_y^a)$: if the number of available transceivers on node $a$ is greater than 0, then there will be a virtual link $VL(V_a, B_y^a)$ between node $V_a$ and node $B_y^a(\forall y \in [1, |B|])$.

The IAG is composed of VTL, WPL and virtual link. The VTL is a single-layered graph and composed of waveband route links and virtual nodes. Although there may be multiple waveband routes between node $i$ and node $j$, there is only one waveband route link $WRL(V_i, V_j)$ between node $V_i$ and $V_j$ node while there will be multiple values of residual wavelengths on $WRL(V_i, V_j)$. In the end node of traffic, the waveband route can be de-multiplexed to wavelengths and be switched by wavelength-cross-connect (WXC) in MG-OXC. Since the demand can be allowed to reach the destination node by multi-hop waveband routes, if there is an out-of-local demand, it can be grouped into another waveband route link and transmitted forward together with the demands generated by this node. Therefore, each virtual node in VTL can be regarded as having wavelength or waveband conversion capacity. Also, new coming demand can use residual available wavelengths on all waveband route links to establish connection.

The WPL is a multi-layered graph and composed of free waveband links and waveband nodes. The WPL contains $|B|$ independent sub-graphs called WPL converting from physical network topology, and each waveband-plane layer $WPL_y$ corresponds to a waveband $B_y(1 \leqslant i \leqslant |B|)$. In WPL, each node in physical network topology will be copied $|B|$ times, and the free waveband $B_y$ between node $a$ and node $b$ will be mapped to the waveband link $WPL_y(B_y^a, B_y^b)$ on waveband-plane layer $WPL_y$. If we can find a route on some WPL, we can assign the corresponding waveband to this route. It is obvious that the routing and waveband assignment can be well solved based on WPL.

The IAG is an integrated graph by adding virtual links between corresponding nodes on VTL and WPL. If the number of available transceivers $NT_x = 0$, all virtual links connecting with node $V_x$ will be removed. Based on IAG, the routing computation can be performed to achieve hybrid multi-hop waveband route; that is, for each route from source node to destination node, some sub-paths may select the waveband route links with the residual available wavelengths on VTL, while other sub-paths may select new waveband links on WPL. It is obvious that the waveband grouping on IAG is equivalent to sub-path grouping that can save more ports than other schemes [1–4].

In order to well explain the routing and waveband assignment based on IAG, we give an example as shown in Fig. 1. The physical network topology is shown in Fig. 1(a), where each fiber link has 2 available wavebands, $B_1$ and $B_2$, each of which contains 4 available wavelengths. The initial IAG is shown in Fig. 1(b), where there are one VTL and two WPLs, and the number beside the virtual nodes denotes the number of available transceivers. Since there are no demands initially, there are no links between nodes on VTL. We assume that there are five demands, 4–3, 3–5, 4–3, 4–5, and 5–3, arriving at the network orderly. For each demand, we will first compute the route from the source node to destination node with single-hop or multi-hop on VTL. If the route cannot be found on VTL, we will perform the routing computation on the integrated IAG.

In Fig. 1(b), the first demand 4–3 will be assigned to the route $V_4$–$B_1^4$–$B_1^1$–$B_1^2$–$B_1^3$–$V_3$ and will consume the waveband links $WPL_1(B_1^4, B_1^1)$, $WPL_1(B_1^1, B_1^2)$ and $WPL_1(B_1^2, B_1^3)$ on $WPL_1$. The second demand 3–5 will be assigned to the