A New Waveband Switching Routing Algorithm in WDM Optical Networks

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Abstract — This paper investigates the technique of waveband switching and considers the problem of reducing the number of ports in optical cross-connects in WDM optical networks. Based on previous studies, this paper proposes a new heuristic, in which the k-shortest path algorithm and rerouting scheme are used to optimize the number of ports. Simulation results show that the performance of proposed scheme can be significantly improved.

Keywords — Waveband switching, optical networks, heuristic algorithm, optical cross-connects.

1. Introduction

With the development of WDM technology, the number of ports in Optical Cross-connects (OXC) keeps enlarging that result in the size and cost of OXCs enormously increased. In this situation, the technique of Waveband Switching (WBS) has been proposed to reduce the number of ports and save the costs of OXCs [1-3]. The main idea of WBS is to perform waveband grouping method 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 (WR) networks can be reduced and further the cost of OXCs can be saved. In order to support WBS and provide efficiency for conventional wavelength switching, the authors in [1] proposed the Multi-Granular OXCs (MG-OXCs) which includes multi-layer and single-layer models.

Although many researchers have investigated the problems in WR optical networks and the WR technique is also the foundation in design for WBS optical networks, the difference of motivations between WBS and WR is quite large. Generally, the motivation for designing WR optical networks is to reduce and optimize the number of consumed wavelength-links or wavelength-hops while the motivation for designing WBS optical networks is to reduce and optimize the number of consumed switching ports in MG-OXCs. Current research in [1] has indicated that, the method for minimizing the number of consumed wavelength-links or wavelength-hops cannot efficiently reduce the number of consumed switching ports in MG-OXCs, and even a simple WBS algorithm also cannot be obtained by slightly extending the conventional Routing and Wavelength Assignment (RWA) algorithm in WR optical networks. Therefore, the current opinion is that an efficient WBS algorithm can make a performance trade-offs between the number of consumed wavelength-links or wavelength-hops and the number of consumed switching ports, and generally the number of consumed switching ports can be significantly reduced by slightly increasing the number of consumed wavelength-links or wavelength-hops. Therefore, due to the difference of motivations between WBS and WR, the techniques that can be suitable for WR networks cannot be directly suitable for the design of WBS networks, such that the researchers on new and dedicated techniques for WBS, such as WBS routing algorithms, wavelength or waveband assignment methods, waveband grouping schemes, are quite necessary.

Previous papers in [3-5] proposed some waveband grouping schemes, e.g., same-source and same-destination scheme, same-source and different-destination scheme, different-source and same-destination scheme, and different-source and different-destination scheme, etc., for merging wavebands. Based on these schemes, the authors in [6, 7] proposed the WBS routing algorithms in which the aim is to compute the shortest lightpath with wavelength granularity for each request meanwhile try its best to merge the lightpaths from different connection requests into waveband granularity for saving the number of ports in OXCs. However, these algorithms in [6, 7] are called traditional WBS routing method that are just the simple shortest route algorithms. In traditional method, the paths computed by Dijkstra’s algorithm may not be optimal disposals for merging waveband, so that the number of ports may not be minimal.

In this paper, we propose a New WBS Routing (NWBSR) algorithm to further reduce the number of ports in OXCs. The proposed NWBSR is based on the k-shortest paths algorithm [8] and the rerouting method [9] so that it can optimize the result of number of ports. Compared with traditional algorithm which does not consider the WBS technique, the performance of proposed scheme can be significantly improved.

2. Problem Statement

2.1 Network model

The given WDM mesh networks is denoted as $G(N, L, W)$, where $N$ denotes the node set, $L$ denotes the link set, and $W$ denotes the wavelength set per fiber link. We assume each node has the wavelength conversion, there is only one connection request arrival at a time, and the bandwidth is one
wavelength channel for each connection request. Some important notations are defined as follows.

- $j$: Fiber link in WDM optical networks.
- $Cost_j$: Cost of link $j$, which is determined by the factors, such as physical length, constructing cost, and so on.
- $CW_j$: Consumed wavelengths on link $j$.
- $FW_j$: Free wavelengths on link $j$, where $CW_j + FW_j \leq W$ should be satisfied.
- $CR_n$: Connection request $n$.
- $CSP_n = (CSP_n^1, CSP_n^2, ..., CSP_n^K)$: Set of candidate shortest paths by the $k$-shortest path algorithm for $CR_n$, where $CSP_n^w (1 \leq w \leq K)$ denotes the $w$th shortest path in $CSP_n$.
- $WP_n$: Working path for $CR_n$, where $WP_n \in CSP_n$.
- $NOL(P_i, P_j)$: Number of overlapped links between paths $P_i$ and $P_j$.

2.2 Policy of merging waveband

In [3-5], the authors propose the schemes, e.g., same-source and same-destination scheme, same-source and different-destination scheme, different-source and same-destination scheme, and different-source and different-destination scheme, etc., for merging wavebands in these schemes, different-source and different-destination that is also called Sub-Path Merging (SPM) scheme has the best performance for saving the number of ports. We give an illustration in Figure 1.

![Figure 1. Merge waveband with SPM scheme](image)

In Figure 1, we assume there are three connection requests from source node A to destination node E, from source node F to destination node K, and from source node L to destination node O, respectively. In traditional method, the shortest paths for the three connection requests are A-B-C-D-E, F-I-J-K, and L-M-N-O, respectively, in Figure 1(a), where the number of ports consumed is 20. However, if we use the SPM scheme, as shown in Figure 1(b), the paths for the three connection requests can be A-B-C-D-E, F-B-C-D-K, and L-B-C-D-O, respectively, where the number of ports consumed is only 16 since the lightpaths with wavelengths can be merged in the wavebands on links B-C and C-D. It is obvious that the SPM scheme can save significant ports such that in this paper we use this scheme in our algorithm to reduce the number of ports consumed.

2.3 Heuristic algorithm

Based on SPM scheme, the process the proposed NWBSR algorithm is presented as follows.

**Input:** network information; matrix $MX$ with $Q$ connection requests; counter $CT$.

**Output:** number of ports $P$.

**Step 1:** Let $n \leftarrow 1$.

**Step 2:** For $CR_n \in MX$, compute $K$ shortest paths by the $k$-shortest path algorithm to obtain $CSP_n = (CSP_n^1, ..., CSP_n^K)$.

**Step 3:** Let $n \leftarrow n + 1$. If $n > Q$, set $c \leftarrow c + 1$, and go to step 4; otherwise, go back to step 2.

**Step 4:** If $c < CT$, rearrange the orders of $Q$ connection requests in $MX$ by the method of random numbers in [9], combine the new matrix $NMX$, and go to step 5; otherwise, go to step 7.

**Step 5:** For $CR_n \in NMX$, select the $CSP_n^1$ as the working path $WP_n$ and let $m \leftarrow m + 1$. If $m > Q$, set $m \leftarrow 1$, and go back to step 4; otherwise, go to step 6.

**Step 6:** For $CR_n \in NMX$, select $CSP_n^w (\forall w \in \{1, K\})$ as $WP_n$, where $NOL(CSP_n^w, WP_n) = \max\{NOL(CSP_n^w, WP_n) \mid \forall x, y \in \{1, K\}\}$ can be satisfied. Let $m \leftarrow m + 1$. If $m > Q$, calculate the number of ports $TP_e$ according to [1], let $m \leftarrow 1$, and go back to step 4; otherwise, go back to step 6.

**Step 7:** Let $P \leftarrow \min\{TP_e \mid \forall w \in \{1, CT\}\}$ and return $P$.

The time complexity of NWBSR mainly depends on the running times of $k$-shortest path algorithm in step 2 and the rerouting algorithm from step 4 to step 6. The time complexity of $k$-shortest path algorithm is $O(KN^2)$, then the time complexity in step 2 is approximately $O(QKN^2)$. In step 6, the complexity of finding $\min\{NOL(CSP_n^w, WP_n) \mid \forall x, y \in \{1, K\}\}$ is $O(LK^2)$, and then the complexity for reroute algorithm from step 4 to step 6 is $O(QCTL/K^2)$. Thus, the time complexity of NWBSR is approximately $O(QTK^3 + QCTL/K^2)$.

3. Simulations

In simulations, the test networks are shown in Figure 2 where each link contains 200 wavelengths. We compare the performance of number of ports consumed between NWBSR algorithm and Traditional Routing (TR) algorithm which does not consider the WBS technique.

We first test the performance of number of ports with considering different waveband granularity, which denotes the number of wavelengths contained in a waveband, in NWBSR algorithm. In Figure 3, we can see that with the waveband
granularity increasing, the number of ports decreases, which means that bigger waveband granularity can lead to fewer ports consumed. The reason for this is that, when the waveband granularity increases, more wavelengths can be merged in wavebands such that the number of ports can be saved. We can also see that, when the waveband granularity increases, the number of ports gradually closes to a constant.

In Figure 4, the G denotes the waveband granularity, i.e., each waveband contains G wavelengths. We can see that, the number of ports in NWBSR is much smaller than the TR, and the performance improvement ratio of NWBSR over TR is up to 300% which is significant and promising. The reason for this is that NWBSR can optimize the result of number of ports by k-shortest path algorithm and rerouting method but TR cannot. We can also see that, with the G increasing, the number of ports can be decreased further. The reason for this is that is same with the explanation for Figure 3.

4. Conclusion

In this paper, we have proposed a new heuristic algorithm called NWBSR in WBS optical networks. In NWBSR, we use the k-shortest path algorithm and rerouting method to optimize the number of ports. Compared with traditional algorithm, the performance of NWBSR can be significantly improved.

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REFERENCES


