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Minimum connection count wavelength assignment strategy for WDM optical networks

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Abstract

In this paper, we have proposed one wavelength assignment strategy for optical networks which assigns the wavelength according to minimum connection count. The performance of proposed strategy is compared with the most commonly used strategy among the existing strategies in terms of number of searches to find the wavelength for connection establishment. The searching takes the time and directly affects the connection establishment time. The simulation is done using different network models. The results show that the proposed strategy is much better than existing strategy in terms of number of searches required to find a wavelength for establishing the connection and hence connection establishment time reduces.
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Keywords: WDM; Wavelength assignment; Optical networks; Wavelength continuity constraint

1. Introduction

Optical networks employing wavelength division multiplexing (WDM) offer the promise of meeting the high bandwidth requirements of communication applications. It divides the huge transmission bandwidth of an optical fiber (∼50 terabits per second) into multiple communication channels with bandwidths (∼10 gigabits per second) compatible with the electronic processing speeds of the end users. In WDM optical networks, the lightpaths are the basic building block, so their effective establishment is crucial [1].

Given a network topology and a set of connection requests, determining a route and wavelength for each connection request is called routing and wavelength assignment (RWA) problem [2]. It is important because it provides a route for each connection request and assigns a wavelength on each of the links along this route among the possible choices so as to optimize a certain performance metric. Routing problem is to select an appropriate route from source to destination among all existing routes [3]. Generally, the shortest path routing approach is used. The shortest path for each source destination pair is computed off-line in advance using standard shortest-path algorithm, e.g., Dijkstra's algorithm or Bellman–Ford algorithm. Wavelength assignment problem is to assign the wavelength along the selected route on which data transmission can take place. The wavelengths assigned to different lightpaths should be such that no two lightpaths that share a physical link use the same wavelength on that link. In the absence of wavelength conversion, it is required that the lightpath occupy the same wavelength on all links it traverses. This requirement is referred to as the *wavelength continuity constraint*. A channel is a wavelength on a link and is reserved at any time for at most one lightpath [4].

The traffic assumptions generally have two categories: static or dynamic. In static models, it is assumed that the demand is fixed and known, i.e., all the connections that are to be set up in the network are known beforehand. The objective is typically to accommodate the demand while minimizing the connection establishment time. Connection establishment time is the time taken to establish the connection from source to destination.

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In dynamic, it is assumed that connection requests for source–destination pairs can arrive at any time.

In this paper, one wavelength assignment strategy has been proposed which reduces the number of searches to find the wavelength for connection establishment and hence reduces the connection establishment time. The performance of proposed strategy is compared with commonly used wavelength assignment strategy. The simulated results show that the proposed strategy is much better than the existing strategy. This paper is organized as follows. In Section 2, we explain system model. In Section 3, we present wavelength assignment strategies in WDM networks. Section 4 focuses on performance evaluation, which shows simulation results by taking examples of standard NJ LATA, COST239 and NSFNET networks. Conclusions are drawn in Section 5.

2. System model

Given is a network with physical topology represented by a graph $G(A, B, L)$. Here V is the set of vertices or nodes in the network. Total number of nodes in the network is $|A| = n$; they are numbered from 0 to $n - 1$. B is the set of links in the network. These are the physical edges connecting the vertices. Single fiber system is assumed, i.e., there is one fiber along any link. The edges are assumed to be undirected. L is the set of weights associated with the edges. These weights are used for computing the route with shortest path algorithm. The set of connection requests is C. $|C| = I$ indicates the total number of connection requests. These connection requests are numbered from 0 to $I - 1$. D represents the set of wavelengths. $|D| = N$ is the total number of wavelengths numbered from $W1$ to WN. Equal number of wavelengths per fiber has been assumed.

Notations

- p_{sd}: Total number of links along the route for s–d connection.
- s: The source for a connection.
- d: The destination for a connection.
- $sd[j]$: jth connection.
- R_{ij}: The route for the connection when $s = i$ and $d = j$.
- z_{ij}: The wavelength assigned to the connection when $s = i$ and $d = j$.

$$w_{ij}^{sd} = \begin{cases} 0, & \text{if } s\text{–}d \text{ connection does not use any wavelength on link } ij, \\ 1, & \text{otherwise.} \end{cases}$$

$$m_{ij,k}^{sd} = \begin{cases} 0, & \text{if } s\text{–}d \text{ connection does not use wavelength } k \text{ on link } ij, \\ 1, & \text{otherwise.} \end{cases}$$

$$Q_{sd}^{k} = \begin{cases} 1, & \text{if } s\text{–}d \text{ connection is established on wavelength } k, \\ 0, & \text{otherwise.} \end{cases}$$

Mathematical formulations

Total number of s–d pairs (I) (if s–d pairs when $(s = d)$ included), $\forall (s, d \in A)$

$$= \begin{cases} (n(n-1)/2) + n, & \text{if } (R_{ij} = R_{ji} \text{ and } z_{ij} = z_{ji})\ \forall i, j \in A, \\ n \times n, & \text{otherwise.} \end{cases}$$

Total number of s–d pairs (I) (if s–d pairs when $(s = d)$ excluded), $\forall (s, d \in A)$

$$= \begin{cases} n(n-1)/2, & \text{if } (R_{ij} = R_{ji} \text{ and } z_{ij} = z_{ji})\ \forall i, j \in A, \\ n(n-1), & \text{otherwise.} \end{cases}$$

Objective function = Minimize (number of searches) for fixed number of wavelengths.

Constraints

1. $\sum_{sd} w_{ij}^{sd} \leqslant N \quad \forall s, d \in C$ and $\forall i, j \in B$.
   Wavelengths assigned on a link for all the connections do not exceed N.
2. $\sum_{ij}^{sd} m_{ij,k} = \begin{cases} P_{sd}, & \text{if } Q_{sd}^{k} = 1, \\ 0, & \text{otherwise } \forall s, d \in C, \ \forall i, j \in B \text{ and } \forall k \in D. \end{cases}$
   For any wavelength k and for any connection request for s–d pair, left side of the equation represents the number of channels with wavelength k used by the lightpath. If the lightpath use wavelength k, then the total number of channels used will be equal to the total number of links along the route, i.e., P_{sd}. If the lightpath does not use the wavelength k then the number of channels (on wavelength k) used for the connection under consideration will be zero.
3. $m_{ij,k}^{sd} = \begin{cases} 1, & \text{if } w_{ij}^{sd} = 1 \text{ and } Q_{sd}^{k} = 1, \\ 0, & \text{otherwise } \forall s, d \in C,\ \forall i, j \in B \text{ and } \forall k \in D. \end{cases}$
   The left side of the equation shows whether the wavelength k on link ij is used by the connection for s–d pair or not. It will be 1, only if the lightpath for the s–d pair is using this channel, i.e., the lightpath uses the link ij and also the lightpath is established on wavelength k.
4. $m_{ij,k}^{sd} \times m_{yv,x}^{sd} = \begin{cases} 1, & \text{if } k = x,\ w_{ij}^{sd} = 1, \ w_{yv}^{sd} = 1 \text{ and } Q_{sd}^{k} = 1, \\ 0, & \text{otherwise.} \end{cases}$
   This constraint represents the wavelength continuity constraint.

3. Wavelength assignment strategies

Wavelength assignment deals with selecting a wavelength to establish the connection along a given route for the connection request. Whenever data is to be transmitted, a route is selected by using routing algorithm over which data transmission is done. The route gives the sequence of links starting from source node to destination node. A wavelength is required to be reserved over these links to carry the data. This wavelength is selected by the wavelength assignment strategy. As wavelength assignment deals with resource allocation and establishment of connections, it is critical issue and affects the performance of the network.

3.1. First-fit (FF) wavelength assignment strategy (existing strategy)

This strategy is implemented by predefining an order of the wavelengths. The wavelength search is made according to this order. The first free wavelength found on the links along the route is reserved for connection establishment. This wavelength assignment strategy does not take into consideration the usage factor of the wavelengths, i.e., how heavily loaded a wavelength is. The wavelengths are searched starting from the first wavelength for all the connections, so the wavelengths earlier in the list are tried before the wavelengths later in the list [5,6]. Algorithm for this strategy is presented in Appendix A.

3.2. Minimum connection count (MCC) wavelength assignment strategy (proposed strategy)

In this, whenever any connection request arrives, the wavelength which is used by minimum number of connections out of all the wavelengths is attempted for connection establishment. If this wavelength is free on all the links along the route for the *s–d* pair under consideration, it is reserved along the route for connection establishment. If wavelength is not free, then from the remaining wavelengths again the wavelength with minimum connection count is attempted and so on till the connection gets established or all the wavelengths are tried. If more than one wavelength has number of connections equal to minimum connection count then first fit is used to choose the wavelength out of all these.

Initially the number of searches will increase with the increase in total wavelengths. It is because the resources are very less and connection requests are more. Due to less resources than required, the connections will be attempted on mostly all the wavelengths including the added wavelengths resulting in increase in the number of searches. If number of wavelengths is further increased then as more resources become available, there is more connection establishment chances with the earlier attempted wavelengths as these are least loaded wavelengths. The number of wavelengths searched reduces as more resources are available. Even if all the connections get established and number of wavelengths is further increased, then the number of searches may decrease. For a connection request, chances of getting a free wavelength from the wavelengths attempted earlier are more as more resources lead to less load on wavelengths. Algorithm for this strategy is presented in Appendix B.

The disadvantage of first-fit strategy is that for every *s–d* pair, the search for free wavelength starts from the first wavelength in the index. Initially the lower indexed wavelengths may be available for connection establishment. But after some connections get established, the lower indexed wavelengths are more heavily used as compared to others because whenever a connection request arrives, wavelength search starts from lowest indexed wavelength. Lower indexed wavelengths are heavily used so there is less probability of connection establishment on these wavelengths. So number of searches to find wavelength for connection establishment increases leading to higher connection establishment time. In MCC, the wavelength which is tried first for any *s–d* pair is the wavelength which is used by minimum connections. So this wavelength is least loaded and the chance of getting the wavelength free on the links along the route is high. The wavelengths which will be tried earlier are freer, so there are more connection establishment chances on the earlier attempted wavelengths which directly reduce the number of searches and time to find a free wavelength.

4. Performance evaluation

In order to evaluate the performance of strategies, simulations are performed. Not able to find a suitable simulator that could support the strategies, we designed and developed a simulator for WDM optical networks for regular and irregular topologies. The simulator is developed in C++ language. It accepts input parameters such as the number of nodes in the network, link weight information, number of wavelengths per link, connection requests, etc. All these parameters can be initialized either before running the simulations to obtain results for a given selection of parameters or at the run time. Whenever any connection is to be established, a wavelength is required for the connection which is free on all the links along the route (in case of *wavelength continuity constraint*). The wavelengths are tried one by one for the connection establishment according to the wavelength assignment strategies discussed. The number of searches gives the information how many wavelengths have been tried. One output of the simulator is the number of searches for the specified parameters along with the detailed information of connections for the given resources. Extensive simulations are then carried out to get the results.

To determine the optimality of proposed strategy, we tested it on various standard networks. Figures 1, 2 and 3 show the NJ LATA [7,8], COST239 [5,9] and NSFNET [10,11] standard networks, respectively, taken as sample networks. The nodes are connected together with undirected links and the information on links can flow in both directions. Let t and u be two different nodes in the network. Due to undirected links, the routes for t (source) to u (destination) and u (source) to t (destination) will be same. Permutation routing has been taken for finding out the sample source destination pairs in which every node in the network acts as the source to every other node in the network simultaneously with unicasting approach. Total number of source destination pairs in permutation routing depends upon the number of nodes. It is assumed that if a node has to send some data to it, the data is sent internally and no external links are used for the transfer. So the *s–d* pairs, when $s = d$ are not included during the simulation as they do not require the wavelength and do not affect the number of searches. The weight taken for each link in the network is same. Shortest path algorithm is applied to find the route because it efficiently utilizes the resources. Equal number of wavelengths per fiber has

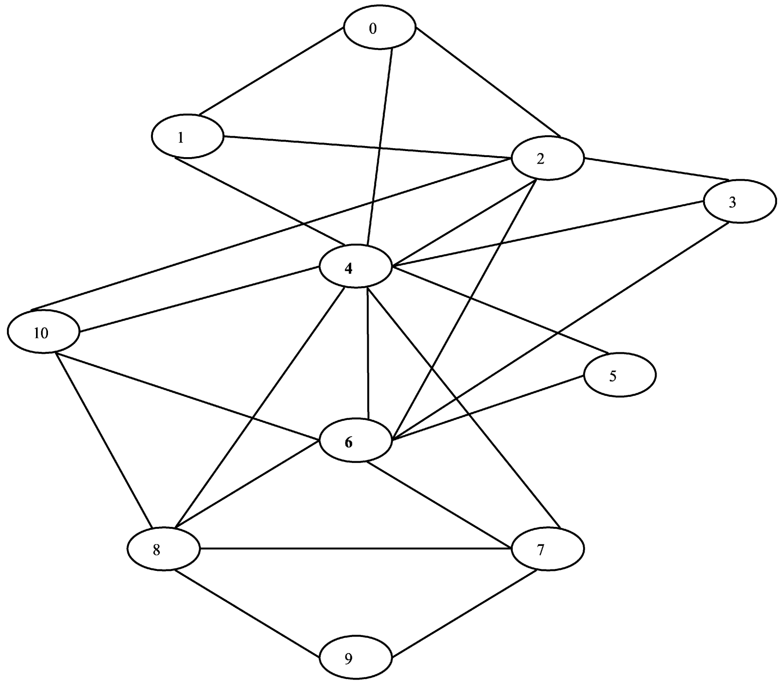

Fig. 1. NJ LATA (N: 11, L: 23) network topology.

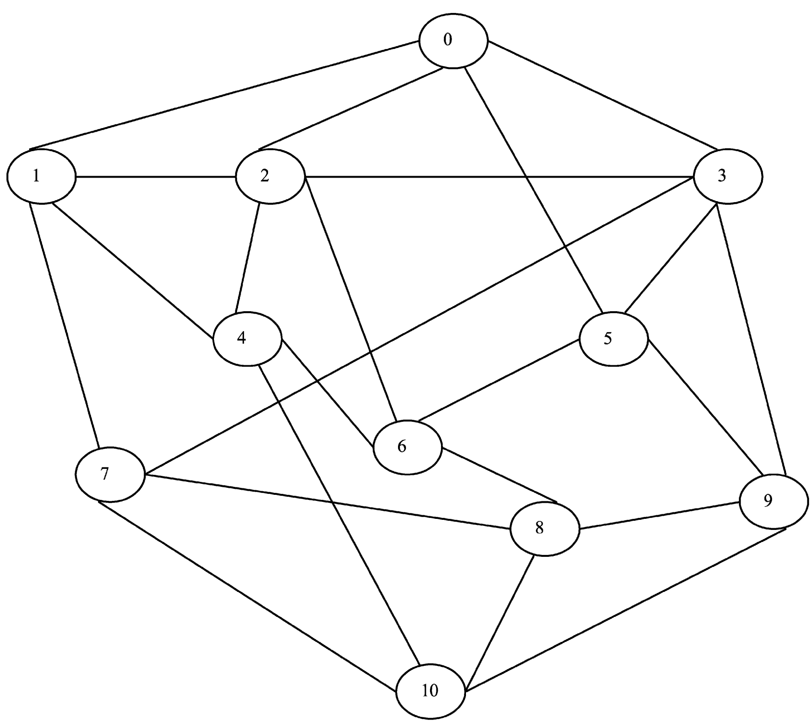

Fig. 2. COST239 (N: 11, L: 23) network topology.

been assumed. Wavelength continuity constraint is observed. Greedy approach is used while wavelength selection for a connection, i.e., the first free wavelength found along the route is reserved for the connection.

Figures 4, 5 and 6 show the comparison charts in terms of number of searches for FF and MCC wavelength assignment strategies when applied on NJ LATA, COST239 and NSFNET networks, respectively. The X-axis represents the number of wavelengths and Y-axis represents the number of searches done to find the free wavelength for the connection requests. Simulation results show that MCC strategy performs better than FF strategy because it tries the wavelengths according to their reservation for various connections. In MCC, the least loaded wavelength is tried first as there are more chances of connection establishment over it, leading to reduced number of searches and connection establishment time.

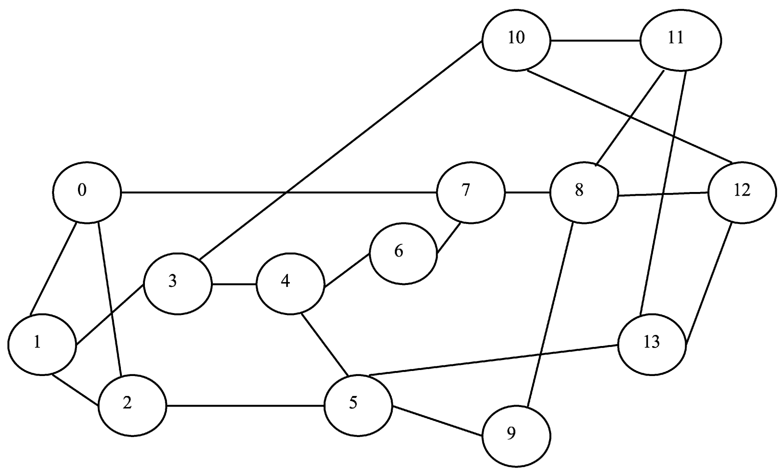

Fig. 3. NSFNET (N: 14, L: 21) network topology.

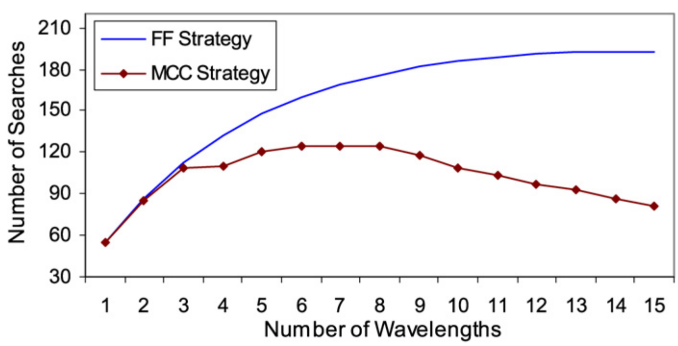

Fig. 4. Comparison chart for NJ LATA topology.

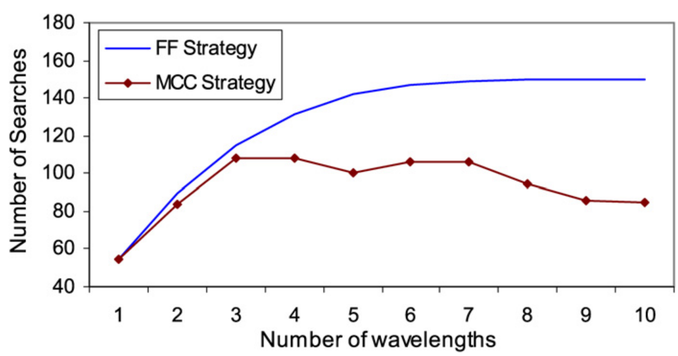

Fig. 5. Comparison chart for COST239 topology.

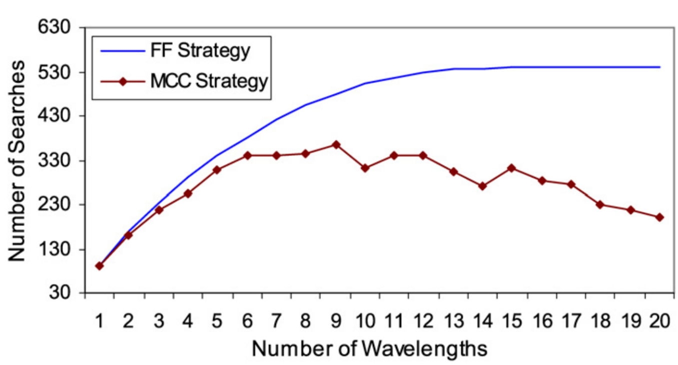

Fig. 6. Comparison chart for NSFNET.

5. Conclusions

In this paper, routing and wavelength assignment problem is discussed in WDM optical networks in general and wavelength assignment problem in specific. One wavelength assignment strategy has been proposed for optical networks which assigns the wavelengths according to minimum connection count. It reduces the number of searches to find the wavelength for connection establishment and hence reduces the connection establishment time. The performance of proposed (MCC) strategy is compared with the commonly used (FF) wavelength assignment strategy in terms of number of searches to find the free wavelength for connection establishment. The simulation is done using different network models. The simulated results show that the proposed strategy is much better than existing strategy in terms of number of searches required to find a wavelength for establishing the connection and hence connection establishment time reduces.

Appendix A. First-fit (FF) wavelength assignment strategy

For each s–d pair, do the following:

1. ptr1 $= W1$.
2. Take node pointer ptr2 initially pointing to s.
3. If wavelength ptr1 is not free on link from node pointed by ptr2 to next node on the route, then:
   (i) If ptr1 $= N$, then go to step 8;
   (ii) ptr1 $=$ ptr1 $+ 1$;
   (iii) Go to step 2.
4. Advance node pointer ptr2 to next node on the route.
5. If ptr2! $= d$, then go to step 3.
6. Reserve wavelength ptr1 on all the links on the route from s to d to establish the connection.
7. Go to step 9.
8. Reject the connection request.
9. End.

Appendix B. Minimum connection count (MCC) wavelength assignment strategy

For each s–d pairs, perform the following:

1. ptr1 = 1.
2. Find a wavelength from all the wavelengths in the list with minimum connection count. Let it be e.
3. Delete e from the list.
4. Take node pointer ptr2 initially pointing to s.
5. If wavelength e is not free on the link from node pointed by ptr2 to next node along the route, then:
   (i) If ptr1 = N, than go to step 11;
   (ii) ptr1 = ptr1 + 1;
   (iii) Go to step 2.
6. Advance node pointer ptr2 to next node on the route.
7. If ptr2! = d, then go to step 5.
8. Reserve wavelength e on all the links on the route from s to d to establish the connection.
9. Go to step 11.
10. Reject the connection request.
11. End.

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