# Performance optimization of wavelength conversion ADMH algorithm in WDM optical network

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**Abstract**

Aimed at the poor application performance issues of adaptive dynamic minimum hop routing algorithm (ADMH) in the wavelength conversion of WDM optical network, in this paper we present an improved ADMG algorithm based on ant colony algorithm. By using ant colony algorithm, we optimize the update rules of local and global link of ADMH algorithm when selecting route and obtain the global optimal value. Then, we set priority for links with different number of optical fibers. According to different number of available wavelengths, we calculate different selection probability and optimize the priority of wavelengths. Simulation results show that the performance of improved ADMH algorithm proposed in this paper based on ant colony algorithm is better than ADMG algorithm when the network traffic load is large.

*Keywords:* Improved ADMH algorithm, ant colony algorithm, rule optimization, wavelength priority optimization, WDM optical network

## 1 Introduction

With the rapid development of information society, humanity has met unprecedented opportunities and challenges, people hope that whenever, wherever and however it is easily to access the information needed, information explosion stimulates rapid growth of global communication services, there is a direct consequence of so-called "infinite desire" phenomenon to bandwidth standing for communication capacity [1]. When an electronic device gradually reaches its physical limits, optical wavelength division multiplexing (WDM) and optical switching technology demonstrate the great potential and bright future of direct interconnection through optical wavelength channels by its unique technological advantage and multi-wavelength characteristics [2]. The continuous progress of optical amplifier, WDM and other new technologies not only reinforces the importance of optical networking, but also gradually expands the optical domain to network edge [3]. In the WDM network, the number of available wavelengths restricts the connection number from the maximum end to end provided by the network, the wavelength channel interval, the tune ability of the optical transceiver and other physical constraints on the optical fiber link limit the number of available channels [4]. Furthermore, factors such as bandwidth requirements are not considered when allocating wavelength to each channel, so, bandwidth granularity also limits the bandwidth utilization rate of wavelength channels. Because of these limitation conditions of optical network, we must use Routing and Wavelength Assignment (RWA) algorithm [5] in order to optimize network performance. Picture coloring method is a static wavelength assignment algorithm whose optimization objective is to get the smallest requirement of the network wavelength [6]. First, mapping the network topology picture to the coloring assistant picture, i.e. optical channel is the vertex of the assistant picture, link segment shared by multiple optical channels is the undirected arc of the assistant picture, then colouring each vertex according to a certain order, so that the color between adjacent vertices is different. Wavelength assignment problem is put into channel coloring problem [7]. Total colors' number of the assistant picture is the wavelength requirement of the network. In the study of the problem of dynamic wavelength assignment, a series of wavelength assignment algorithms [8] appear. Without considering the network status, there are typical R (Random) algorithm, FF (First - Fit) algorithm [9]. With further research, researchers find that considering the network status when assigning wavelengths can greatly improve the performance of algorithms, such as MU (Most - Used) algorithm, LU (Least - Used ) algorithm, MS (Max-Sum) algorithm and LL (Least-Loaded) algorithm. Some new algorithms are proposed from the aspect of maximizing the number of relative free wavelengths, such as RCL (Relative capacity Loss) algorithm, RLI (Relative Lease Influence) algorithm, RCI (Relative Capacity Influence) algorithm, LI (Least-Influence) algorithm, LE (Load-Equalization) algorithm [10]. In addition, other algorithms have also been proposed from the perspective of supporting multiple priorities, such as dynamic threshold method based on

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RCL algorithm and the limited wavelength assignment algorithm for fair allocation.

Aimed at the existing issues of ADMG algorithm in the wavelength conversion application of WDM optical network, we present an improved ADMG algorithm based on ant colony algorithm in this paper, taking the application performance of ADMG algorithm as an example.

## 2 Adaptive routing algorithm for the minimum number of hops

### 2.1 ALGORITHM SET

The settings of ADMH to the network and connection are:

1) Connections are bidirectional, without considering unidirectional and radio connections. So we take a pair of optical fiber as the smallest unit (i.e. fiber pair).

2) There are enough transceivers for each node, establishing a connection will not be blocked because of insufficient transceivers.

3) It is the same that the number of multiplexed wavelengths in all fibers.

4) There is no wavelength converter.

Parameter symbols related to WDM optical network are defined as follows: $N$ is optical network node, node number is $0,1,2,...,(N-1)$ . $W$ is the number of multiplexed wavelengths. From small to large by wavelength values, the order number of wavelength is $0,1,2,...,(W-1)$.

The physical topology matrix of optical network is written as follows:

$$G=\{g_{ij},0\le i,j\le N-1\}, \tag{1}$$

where $g_{ij}$ represents the number of optical fiber pairs on the physical link between the node $i$ and the node $j$ , $L$ is links set of the network.

### 2.2 ALGORITHM DESCRIPTION

In order to achieve connection request, WDM optical network not only establishes a work optical channel, but also calculates a protective optical channel. What we consider here is a single link failure whose probability in the network is the greatest. Accordingly, the adopted protective way is a 1:1 shared path protection whose edges are disjoint, which is a protective manner with the most complex program logic. Protection can be further subdivided into two cases that work wavelength $\lambda_w$ and protective wavelength $\lambda_p$ are the same or different.

The link capacity matrix used by all the connected work routes in the $k$-th virtual optical network is as follows:

$$CWU_k=\{cwu_{ij}^k,0\le i,j\le N-1\}, \tag{2}$$

where $0\le k\le w-1$, $cwu_{ij}^k$ means the capacity occupied by all the work routes on the virtual link between node $i$ and node $j$ of the $k$-th virtual optical network.

The link capacity matrix used by the protective routes corresponding to a link failure in the $k$-th virtual optical network is as follows:

$$CPUL^{k,l}=\{cpul_{ij}^{k,l},0\le i,j\le N-1\}. \tag{3}$$

This matrix equals the sum of link capacity used by protective routes connected by all the work routes through link $l$ .

The link capacity matrix used by all the protective routes in the $k$-th virtual optical network is as follows:

$$CPU^k=\{cpu_{ij}^k,0\le i,j\le N-1\}, \tag{4}$$

where $0\le k\le w-1$, $cpu_{ij}^k$ means the capacity occupied by all the protective routes on the virtual link between node $i$ and node $j$ of the $k$-th virtual optical network.

$$CPU^k=\max\nolimits_{l\in L}(CPUL^{k,l}), \tag{5}$$

which represents the operation to take the maximum value of a plurality of matrix. Actually we take the maximum value of each element of the matrix respectively.

Aimed at the protective routes that connect $r$ and have built work route, the protective capacity matrix which can not be shared and has been used in the $k$-th virtual optical network is as follows:

$$CPUR^k(r)=\{cpur_{ij}^k(r),0\le i,j\le N-1\} \tag{6}$$

where $0\le k\le w-1$, $cpu_{ij}^k$ means the capacity occupied by the protective routes which can not be shared on the virtual link between node $i$ and node $j$ of the $k$-th virtual optical network.

$$CPUR^k(r)=\max\nolimits_{l\in r}(CPUL^{k,l}) \tag{7}$$

The free link capacity matrix available to be used by work route is as follows:

$$CWI^k=\{cwi_{ij}^k(r),0\le i,j\le N-1\} \tag{8}$$

where $0\le k\le w-1$,

$$CWI^k=G-CWU^k-CPU^k \tag{9}$$

Weight matrix used to calculate work route in the $k$-th virtual optical network is as follows:

$$EW^k=\{ew_{ij}^k,0\le i,j\le N-1\} \tag{10}$$

where $0\le k\le w-1$, $ew_{ij}^k$ means the weight of the virtual link between node $i$ and node $j$ in the $k$-th virtual optical network. If $cwi_{ij}^k\ne 0$ , then $ew_{ij}^k=(\sum g_{ij})-cwi_{ij}^k$ , otherwise $ew_{ij}^k=\infty$.

The free link capacity matrix which can be used by protective route connecting *r* is as follows:

$$CPI^k(r) = \{cpi_{ij}^k(r), 0 \le i, j \le N-1\}, \tag{11}$$

where $0 \le k \le w-1$,

$$CPI^k(r) = G - CWU^k - CPUR^k(r). \tag{12}$$

Weight matrix used to calculate protective route connecting *r* in the *k*-th virtual optical network is as follows:

$$EP^k(r) = \{ep_{ij}^k(r), 0 \le i, j \le N-1\}, \tag{13}$$

where $0 \le k \le w-1$, $ep_{ij}^k(r)$ means the weight of the virtual link between node $i$ and node *j* in the *k*-th virtual optical network. If $cpi_{ij}^k(r) \ne 0$, then $ep_{ij}^k(r) = (\sum g_{ij}) - cpi_{ij}^k(r)$, otherwise $ep_{ij}^k(r) = \infty$. In addition, in order to meet the condition that the edges of protective route and work route are disjoint, there should be $ep_{ij}^k(r) = \infty$ when the link $(i, j)$ is included in the work route connecting *r*. Finally, protective route should give preference to the protective capacity that can be shared and has been allocated for other protective routes, and try to avoid using the new protection capacity. That is, if $cpur_{ij}^k(r) < cpu_{ij}^k$, then $ep_{ij}^k(r) = 1$.

## 3 Improved ADMG algorithm based on ant colony algorithm

### 3.1 ANT COLONY ALGORITHM

Ant colony algorithm uses a simple individual-ant to iteratively construct the candidate solution of combinatorial optimization problem. The structure of ants' solution is guided by pheromone and heuristic information. In principle, ant colony algorithm can be used in various combination problems by defining the components of the solution. Firstly, one ant uses an empty solution; and then it repeatedly increases the components of the solution until producing a complete candidate solution, to construct candidate solutions. At each selection point, the ant must determine which component should be added to the solution of its current section. After completing the solution construction, the ants give positive feedback to the constructed solution, which are thrown in the components of the solution being used through pheromone.

The number of artificial ants is *m*, these artificial ants have a memory function. Each artificial ant has the following characteristics:

1) According to the pheromone density and heuristic information, select the next city by using the corresponding transition probability.

2) Put the traversed city into the memory table, the city in the memory table is no longer selected as the next one.

3) After one time round trip, release the corresponding pheromone and update pheromone on the travelled path.

The most important aspects of ant colony algorithm are the following:

1) The transition probability that the *k*-th ant in city $i$ selects the next city *j* at *t* moment is:

$$P_{ij}^k(t) = \begin{cases} \dfrac{\left[\tau_{ij}(t)\right]^\alpha \cdot \left[\eta_{ij}\right]^\beta}{\Sigma_{j \in N^k} \left[\tau_{ij}(t)\right]^\alpha \cdot \left[\eta_{ij}\right]^\beta}, \text{ if } j \notin N^k, \\ 0 \end{cases} \tag{14}$$

where $\tau_{ij}(t)$ is pheromone concentration on the edge $(i, j)$ at $t$ moment, $\eta_{ij} = 1/d_{ij}$ is the desired degree from city $i$ to city *j*, $N^k$ is the memory table placing the cities that the *k*-th ant has traversed, $\alpha$ and $\beta$ are respectively the interaction coefficients of the pheromone concentration $\tau_{ij}(t)$ and the desired degree $\eta_{ij}$.

2) The updated rule of pheromone $(\tau)$ is:

$$\tau_{ij}(t+1) = (1-\rho) \cdot \tau_{ij}(t) + \sum_{k=1}^{m} \Delta\tau_{ij}^k(t), \tag{15}$$

where, $\rho$ is the reserved proportion of pheromone, a constant varying from 0 and 1, 1-$\rho$ means the volatilization of pheromone. $\Delta\tau_{ij}^k(t)$ is the increased pheromone variable of ant $k$ on the edge $(i, j)$ between *t* moment and (*t*+1) moment. Its value is determined by the following equation:

$$\Delta\tau_{ij}^k(t) = \begin{cases} Q / L^k(t) & \text{if } (i, j) \text{ is used by ant } k \\ 0 & \text{others} \end{cases} \tag{16}$$

$L^k(t)$ is the length of one circle that ant *k* travels around at *t* moment, $Q$ is a constant.

### 3.2 RULE OPTIMIZATION BASED ON ANT COLONY ALGORITHM

The improved ADMG algorithm based on ant colony algorithm proposed in this paper meet the following rules:

#### *3.2.1 The update rule of local link*

When one ant chooses the best route at the time of the cycle, select the link the ant passing to update the network information.

$$\tau_{ij}(t+n) = \rho\tau_{ij}(t) + \Delta\tau_{ij} \tag{17}$$

where $\rho(\le \rho < 1)$ is the persistent factor of trajectory, $1-\rho$ means the evaporation coefficient of trajectory between $(t, t+n)$. $\Delta\tau_{ij} = \sum_{k=1}^{m} \Delta\tau_{ij}^k$, $\Delta\tau_{ij}$ is the number of unit trajectory pheromone ant $k$ leaving on the path $(i, j)$, $\Delta\tau_{ij} = \tau_{ij}$ is the initial pheromone concentration.

*3.2.2 The update rule of global link*

When all the ants successfully complete the cycle, we choose the best one overall.

$$\tau_{ij}(t+n) = (1-\alpha)\cdot\tau_{ij}(t) + \alpha\cdot\Delta\tau_{ij}\,, \tag{18}$$

where

$$\Delta\tau_{ij} = \begin{cases} (Q/L_{Best}), & if\,(i,j)\in best-tour \\ 0, & otherwise \end{cases} \tag{19}$$

The Equation is the relative importance of the trajectory. Furthermore, $\alpha = \rho$, $L_{Best}$ is the optimum value of the objective function; $best-tour$ is the route of the best ant; $Q$, a constant, adjusts pheromone concentration $\tau$.

## 3.3 PRIORITY OPTIMIZATION OF WAVELENGTHS

In this paper, load balance strategy is to set different priority for link with different number of optical fibers, i.e. to each link, calculate different selection probability depending on different number of available wavelengths. The more the number of available wavelengths is, the greater the probability of being selected.

Under the idea of load balance, links are divided into $m$ categories according to different numbers of wavelengths.

$p_{ij}(p)(p = 1,2,...,m)$ stands for each class, and is defined as follows:

$$p_{ij}(p) = \begin{cases} p, a^{p-1} < w \le a^p \\ 0, w = 0 \end{cases} \tag{20}$$

$a$ is the level parameter, in accordance with the size of $a$, the discrimination between grades can be changed, the greater $a$, the smaller the wavelength discrimination.

Links with different numbers of available wavelengths are divided into several categories. The larger the number of available wavelengths, the higher the level of links, and the greater the probability of being selected, then the transition probability is defined as follow:

$$P_2 = p_{ij} = p_{ij}(p)/|\,p_{\max}\,| \tag{21}$$

When $a$ increases, the link level discrimination will decrease. If $a$ is smaller, the link level discrimination will be better. For example, when $a = 2$, the number of available wavelengths on one link is 9, its probability of being selected is 100% according to load balance strategy. After a wavelength is used, its probability of being selected becomes 75%.

## 4 Example simulation

To validate the effectiveness of improved ADMG algorithm proposed in this paper based on ant colony algorithm, we make simulation experiment, and compare with ADMG algorithm. Parameter is set to: $\alpha=\rho=0.2$, $\beta = 0.7$, $Q = 1000$, $\tau_0 = 10$, count the congestion rate of the algorithm, the experimental results are shown as follows.

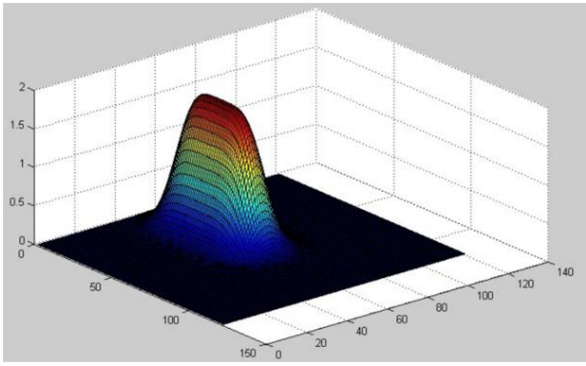


FIGURE 1 Congestion rate of admg algorithm

Through simulation, we can get the comparison chart of performance parameters. We can see that load balance of the network is greatly increased compared with ADMG algorithm. The graphs of Figure 1 and Figure 2 show that with the network traffic load increasing, the average link level decreases, the congestion rate increases. While, the increase of average congestion rate of improved ADMG is smaller, and the decrease of link level of improved ADMG is slower. It shows that the performance of improved ADMG algorithm is better than ADMG algorithm when the network traffic load is large.

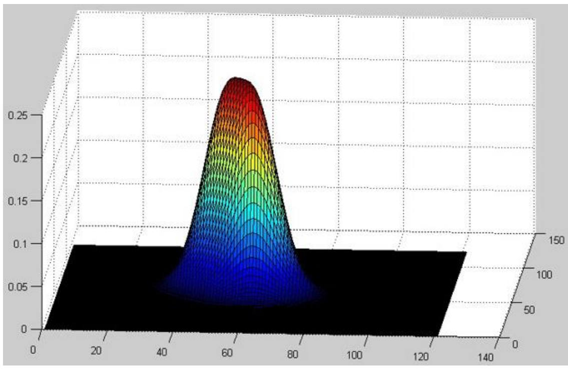


FIGURE 2 Congestion rate of improved ADMG algorithms

## 5 Conclusions

This paper presents an improved ADMG algorithm based on ant colony algorithm, optimizes the performance of wavelength conversion of ADMG algorithm in WDM optical network. As can be seen from the simulation results, the performance of improved ADMG algorithm is better than ADMG algorithm. With the rapid development of optical communication technology, optical fiber communication has gradually evolved as an important networking tool from simple transmission technology. Optical network design based on wavelength route has a crucial significance to improve equipment utilization and reduce the cost of network construction.

## References


[1] Chen Y, Hua N 2013 Dynamic routing mechanism considering port connectivity constraints in WDM optical network *Chinese Laser* **4** 134-40

[2] Wang R 2011 Research on survivable mesh WDM optical networks using load-balancing mechanism *Journal on Communications* **32** 1-9

[3] Liu Y 2011 Strictly Non-blocking Clos-type Wavelength-division-multiplexing Optical Permutation Network *Mini-micro Systems* **32** 450-4

[4] Guan A 2009 Experimental study of four-wave mixing influence in WDM optical networks *Laser Technology* **33** 5-7

[5] Wang T, Qiang L 2008 Research on protection method of dynamic shared path in WDM optical network *Computer Applications and Software* **25** 219-20

[6] Yu H, Gu C 2008 Dynamic wave band exchange algorithm considering transmission impairment in WDM mesh network *Optical Communication Technology* **32** 34-7

[7] Bai J 2008 A novel alternate routing algorithm for WDM optical networks *Study on Optical Communications* **2** 1-3

[8] Yu Hua, Gu Chen 2008 Dynamic wave band exchange algorithm based on load balance in WDM mesh network *Dalian Maritime University Natural Science* **34** 78-82

[9] Shi G 2014 WDM optical transmission network with fault tolerance strategy *Optical Communication Technology* **29** 24-6

[10] Jiang P 2005 Route supporting QoS and wavelength assignment algorithm in WDM network *Optical Communication Research* **1** 6-8


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