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Dynamic Routing and Resource Assignment Algorithm in Sloted Optical Networks

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Abstract

All-optical wavelength division multiplexing networks are the most promising candidate for the next generation wideband backbone networks. To improve the utilization of wavelength, time division multiplexing technology is introduced. The routing, wavelength and time-slots assignment problem was studied in such time-space switched networks. Two new dynamic algorithms were proposed which distribute slots of the session request on multiple different wavelengths of single fiber separately based on fixed alternate routing and adaptive routing policy. Especially in LLR-MWLB algorithm, network link weights adjust adaptively with the available time slots of each link and load balancing strategy is adopted. The effectiveness of the proposed algorithms is demonstrated by simulations and results show the better performance.

Keywords: *WDM-TDM network, RWTA algorithm, load balancing*

1. Introduction

Wavelength-division multiplexing (WDM) [1] in optical networks is a preferred technology to exploit the enormous bandwidth of optical fiber and it offers the capability of building very large wide-area networks with throughputs of the order of gigabits per sec for each node [2, 3]. In traditional WDM networks, when a new session request arrives, a lightpath is established between the source and the destination which occupies the whole bandwidth of one wavelength. However, with the rapid progress in optical transmission technology, the bandwidth of a single wavelength has reached 40Gbps which far exceeds the capacity requirement of most applications request. For example, HDTV works well with only 20Mbps.

As wavelengths are key resources in WDM networks, it's important to better utilize the huge bandwidth per wavelength. In order to increase the utilization of fiber bandwidth, TDM (Time Division Multiplexing) technology is introduced into WDM networks [4] and such a network is called *WDM-TDM network* or *WDM grooming network* which further divides the bandwidth of each wavelength into fixed-length time-slots. In this way, more than one successful connection request are capable of sharing one wavelength and blocking probability will decrease. WDM-TDM networks can be classified into two types-(i) dedicated-wavelength TDM networks and (ii) shared-wavelength TDM networks [5]. In the former, entire wavelength are dedicated to connection requests between specific source-destination pairs. Connection requests between other source-destination pairs cannot use these dedicated resources and switching is not performed in the time domain at the intermediate nodes along the routing path. In the later, time-slots within a wavelength, rather than the entire wavelength, are dedicated to specific source-destination pairs. Various other connection requests can share the same wavelength on a link by using different time-slots for information transmission. The bandwidth available in such networks is used more efficiently than in networks which dedicate entire wavelengths between specific source-destination pairs. In this paper, we only consider the shared-wavelength TDM networks.

In WDM-TDM optical networks, the granularity of bandwidth allocation is in terms of time-slots instead of the entire wavelength bandwidth. Hence, time-slots assignment has to be determined for a connection request, in addition to the route and wavelength. It is called routing, wavelength and time-slots assignment (RWTA) problem. Like the routing and wavelength assignment (RWA) problem, RWTA problem can be classified as static or dynamic [6] according

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to the traffic models. In the former, all the traffic requests are known advance and the RWTA decision is made offline. In the later, the problem is to determine routes, assign wavelength and time-slots for a set of dynamic traffic request given the current state of time-slot allocation in the network. The dynamic version is well accordant with the most practical data services in WDM-TDM optical networks.

For dynamic RWTA problem, designing a good and appropriate dynamic RWTA algorithm is critically important to improve the network performance. The design objective of the algorithm is to minimize the blocking probability while maximizing the bandwidth utilization. When designing the algorithm, two principles must be abided by which called *wavelength continuity constraint* and *time-slot continuity constraint*. For wavelength continuity constraint, a connection between two endpoints can be only setup on one wavelength, and wavelength conversion is not allowed at the intermediate nodes along the routing path. For time-slot continuity constraint, slot interchanging is not allowed at the intermediate nodes along the routing path.

In this paper, we will concentrate on the RWTA problem. The network manager runs the RWTA algorithm to establish a lightpath for session requests. If a lightpath can not be established, the request is blocked or rejected. Compared to the RWTA problem, the RWA problem has been well addressed in wavelength-routed (WR) optical networks. Reference [7] comprehensively reviewed the proposed RWA approaches. Despite of that, some researches have been conducted in the area of finding efficient algorithms for RWTA problem. In 2002, Bo Wen and Krishna M. Sivalingam first presented RWTA concept and proposed a scheme to divide RWTA problem into three sub problems which are routing problem, wavelength assignment problem and slots allocation problem [6]. Then they improved the scheme for routing problem in multiple fiber optical networks and proposed two wavelength and slot assignment policies [8]. In the same year, several adaptive routing and resources assignment algorithms were discussed [9] which used multi paths for one session request. These algorithms above all are based on multi fibers optical networks. In [10], the authors report a dynamic RWTA algorithm with complete switching capability in time domain. But for recent WDM-TDM networks the routing nodes without wavelength converters and time slots interchangers may be more applicable. In literature [11, 12], dynamic RWTA schemes have been proposed for ring networks, though there is need to research the RWTA problem in the mesh WDM-TDM optical networks. Reference [13] has proposed dynamic Most-used Based (MUB) and enhanced MUB (EMUB) algorithms to address RWTA issue in mesh WDM-TDM optical network, but assigned slots are only distributed on one single wavelength. Different from the objective of minimizing the blocking probability above, reference [14] has proposed a RWTA reassignment algorithm with the purpose of maximizing the time of first blocking.

In this paper, we proposed two new dynamic RWTA algorithms to minimize the blocking probability. Based on mesh WDM-TDM optical networks with single fiber and abided by wavelength and time-slot continuity constraint, these two algorithms adopt multiple wavelength distributed slot assignment policy. In the fist algorithm, fixed alternate routing policy is used. We called it as MUMD (Most Used based and Multi-wavelength Distributed based) algorithm. In the second algorithms, least loaded (means most available slots) routing policy is used and assigns slots with load balancing. We called it as LLR-MWLB (Least Loaded Routed, Multiple Wavelengths distributed with Load Balancing based) algorithm. The experimental results showed that the two algorithms outperform the existing algorithms — RANDOM, FIRST-FIT, EMUB in terms of blocking probability. And LLR-MWLB algorithm has the best performance.

2. Definitions

In this section, network model and traffic model are defined. We also give some mathematic definitions.

2.1. Network Model

The network topology is represented as an undirected graph *G (V, E)*, consisting of $|V|=n$ nodes and $|E|=m$ links interconnecting the nodes. We consider a single fiber network consisting of $|W|$ wavelengths where $W= \{w_1, w_2, \ldots w_{|W|}\}$. Each wavelength is divided into fixed-length TDM frames composed of a fixed number of time slots which are denoted by $T= \{t_1, t_2, \ldots t_{|T|}\}$ and $|T|$ represents the number of time slots of each wavelength capacity. When a session arrives, one route will be selected and some slots will be assigned for the session to establish a lightpath. If enough resources were not available, the session is blocked.

2.2. Traffic Model

Several traffic models have been considered for the RWA problem. Typically, three types of session requests are applied which are static traffic, dynamic traffic and incremental traffic. All session requests are known in advance for static traffic. For incremental traffic model, the session requests arrive sequentially, and established lightpath will remains indefinitely in the network. For dynamic traffic model, the session arrives at a random time and lasts for a finite random time.

In our algorithm, we consider the dynamic random traffic model. A connection request r_i is represented by a tuple $(s_i, d_i, t_i, \Delta_i, D_i)$, where $s_i \in V$ is the source, $d_i \in V$ is the destination, t_i is the arriving time, Δ_i is the holding time and D_i is required bandwidth represented as the number of time-slots. We use the assumptions followed for the dynamic traffic model:

(i). Session requests arrive according to the *Possion* process with the rate λ. The holding time of each session request obeys a negative exponential distribution with a mean $1/\mu$. The holding time is independent of each other and the arrival time. The network load is defined as λ/μ (erlang).

(ii). The required bandwidth of each session is uniformly random distributed in [*1, |T|*], so we consider multi-rate session.

(iii). If lightpath can not be established for a session, the session is blocked and discarded from the network.

2.3. Mathematic Definitions

Similar to the RWA problem, approaches to address RWTA problem can be classified in to two categories: combined approaches and disjoint approaches. Disjoint approaches are popular in the literatures. Usually disjoint approaches are to divide the RWTA problem into three subproblems: routing subproblem, wavelength assignment subproblem and timeslot assignment subproblem.

For routing subproblem, we choose *K* shortest routing policy and network weights change adaptively with the total number of available time-slots on the links. To detail the link weight function, we state the following mathematic descriptions.

Define $S(l,w,t)$ as the state of the slot *t* in wavelength *w* on link *l*. $S(l,w,t)=1$ means slot is available and $S(l,w,t)=0$ means slot is occupied.

Define $S(p,w,t)$ as the combined state of the slot *t* in wavelength *w* along path *p*. $S(p,w,t)=1$ means slot is available and $S(p,w,t)=0$ means slot is occupied. $S(p,w,t)$ is given by Equation (1).

$$S(p,w,t) = S(l_1,w,t) \wedge S(l_2,w,t) \wedge \cdots \wedge S(l_{|p|},w,t) \quad (1)$$

Define $C(l,w)=\sum_t S(l,w,t)$ as the total number of the available slots for wavelength *w* on link *l*.

Define $C(p,w)=\sum_t S(p,w,t)$ as the total number of the available slots for wavelength *w* along path *p*.

The link weight function is given by Equation (2):

$$C(l) = \frac{|T| \times |W|}{\sum_w C(l,w)} \quad (2)$$

Where |*T*| denotes the number of time-slots for each wavelength and |W| denotes the number of wavelengths.

The choice of weight function makes a significant difference in the calculation of the optimal path. These links with more available time-slots always have more probability to be selected into the route. Thus the new session request tends to avoid the busier links. As a result, the load of the whole network is balanced and the probability of blocking decreases.

3. Research Method

In this paper, two dynamic RWTA algorithms called MUMD and LLR-MWLB are proposed, which have the same idea that time slots may be distributed on multiple different wavelengths.

3.1. MUMD Algorithm.

In the MUMD algorithm, we choose the fixed alternate routing for routing subproblem. For wavelength assignment subproblem, the algorithm may select multiple different wavelengths based on most used approach. And slots may also be distributed on different wavelengths based on most used approach.

The pseudo-code of MUMD algorithm is shown in Figure 1, mainly including the following steps:

```
p=NULL; setW=NULL; setT=NULL; w=NULL; t=NULL;  % initialization
for k=1 to K
     for i = 1 to |W|
           if C ( p_k, w_i ) >= D   % D is the number of requested slots
                p=p_k;    %choose p_k as the selected route
                break;
           end if
      end for
end for
if p ≠ NULL
      for i=1 to |W|
           if C(p,w_i)>0
                 setW=setW ∪ {w_i}; %put w_i to the available wavelength set
           end if
      end for
      if setW ≠ NULL
            Rank setW according to the UR_W descending;
            for i=1 to |setW|
                    for j=1 to |T|
                          if t_j is available on w_i along the route p
                          then setT=setT ∪ { t_j };
                          end if
                     end for
                     Tp=length (setT);
                     Rank setT according to the UR_T descending;
                     if Tp >= D
                          Choose the first n slots in setT to t;
                          w=w  ∪ { w_i } ;
                           break;
                     else
                          Choose all the slots in setT to t;
                          w=w  ∪ { w_i } ;
                          n=n-length ( setT );
                     end if
            end for
            if ( w= = NULL or t = = NULL)
                   The session is blocked;
            End if
      else
            The session is blocked;
      end if
else
      The session is blocked;
end if
```

Figure 1. Pseudo Code of MUMD Algorithm

Step one: Select the route. Check the route from the first available route of the *K* alternate routes set. If $C(p^i, w) \geq n$, choose p^i as p and go to the next step. Or the session is blocked.

Step two: Look for the available wavelength of *p*. If $C(p,w)>0$, put *w* to the *setW* and sort *setW* according to *UR_W* in descending order where *UR_W* denotes the use-rate of wavelengths. If *setW* is empty, the session is blocked. *setW* represents the available wavelengths set.

Step three: Assign wavelength and time-slot. Choose wavelength from *setW* sequentially. Add the available slots to *setT* and sort *setT* in descending order according to *UR_T* where *UR_T* denote the use-rate of time-slots. If the number of available slots is more than *n*, select the first *n* slots in *setT* and assignment has been finished. Otherwise, choose all the slots in *setT* and go to next wavelength in *setW*.

Step four: If the number of assigned slots is less than *n* after checked the entire wavelength in *setW*, the session is blocked. Otherwise, lightpath is successfully established.

3.2. LLR-MWLB Algorithm

The pseudo-code of LLR-MWLB algorithm is shown in Figure 2. and Figure 3. Figure 2 shows the pseudo-code of routing policy and Figure 3 shows the pseudo-code of the assignment policy of wavelength and slots. The following steps can be abstracted:

Step one: Update all link weights of the network according to the formula *1*. Find *K* alternate routes set $P=\{p^1, p^2, \ldots, p^K\}$ based on the *K* shortest routing policy and sort them ascendingly by $C(p^i)$ where $C(p^i)=\sum_l C(l)$ denotes the total weight of path p^i.

Step two: Decide the route. From the first available route of set *P*, where current route is p^i, search *setW* based on the wavelength continuity constraint. Then search available time-slots sets in *setW* and calculate the amount of the total available slots in *setW* which is T_p. If $T_p \geq D$, choose p^i as p and go to the next step. Or analyze the next route in set *P* until find an available route. If no available route in *P*, the session is blocked.

```
p=NULL; setW=NULL; setT=NULL; TA=NULL; % initialization
for k=1 to K
     for i=1 to |W|
          if C(pk,wi)>0  then  %C(p,wi) denotes the amount of available slots on wi
along pk
                setW=setW∪{wi}; %put wi to the available wavelength set
          end if
     end for
     if setW ≠ NULL then
          for i=1 to |setW|
                setTi=NULL;
                for j=1 to |T|
                     if tj is available on wi along all links of pk
                     then setTi=setTi ∪ {tj};
                     end if
                end for
                setT=setT ∪ setTi;
                 TA=TA ∪ |setTi|;
          end for
          Tp= sum (TA);
            if Tp ≥ D then
                 p=pk;
                 break;
           end if
     end if
end for
```

Figure 2. Pseudo-code of Routing Policy for LLR-MWLB Algorithm

```
if p ≠ NULL
      Rank setW  descendingly by |setTi|;
      Delete wavelengths with zero slots;
      if Tp = = D then
            Assign all available slots in setW for the session;
       end if
       if Tp >D and Tp ≤ 2*D then
            for i = 1 to |setW|
                 if Di ≥ D then
                        Assign D slots of setW(wi) for the session;
                        break;
                 else
                        Assign Di slots of setW(wi) for the session;
                        D=D-Di;
                 end if
            end for
        end if
        if Tp > α*D then
            Dp = [D1/β];
            if Dp ≥ D then
                    Assign D slots to the session;
            else
                     if Tp - D1 < D – Dp then
                        The session is blocked;
                     else
                        Assign Dp slots to the session;
                         D = D-Dp;
                        for i = 2 to |setW|
                                if Di ≥ D then
                                      Assign D slots of setW(wi) for the session;
                                       break;
                                 else
                                      Assign Di slots of setW(wi) for the session;
                                      D=D-Di;
                                 end if
                          end for
                     end if
            end if
        end if
else
        Route is not available and the session is blocked;
end if
```

Figure 3. Pseudo-code of Slots Assignment Policy for LLR-MWLB Algorithm

Step three: Assign wavelengths and time slots combinedly. Path *p* has been selected in step two. Available wavelength set *setW* and available time-slots set *{setTi}* have been calculated. Now rank *setW* descendingly by the amount of available slots and delete wavelengths with zero available slots. Define *m*=|*setW*| which denotes the amount of available wavelengths in path *p*. Then *{setTi}* where *i=1~m* denotes the available time-slots set and define D_i where *i=1~m* as available slots for each available wavelength. (i) If $T_p = D$, assign all available slots in *setW* for the session request; (ii) If $T_p > D$ and $T_p \leq \alpha\ D$, where α is a constant, assign the first D slots in *{setTi}* to the session request; (iii) If $T_p > \alpha\ D$, define $D_1^{'} = [\frac{D_1}{\beta}]$ where β is a constant, and [•] calculates a integer not more than the number filling in the brackets. Choose *D* slots in the first wavelength of *setW* for the session if $D_1^{'} \geq D$; Or choose $D_1^{'}$ slots in the first wavelength of *setW* for the session and assign slots from the next wavelength in *setW* sequentially. In this case, the session is blocked if $\sum_{i=2}^{m} D_i < D - D_1^{'}$.

Step four: Update the network states and wait a new session request.

3.3. An Example for the Proposed Algorithms

Give a network with 5 nodes and 6 links. Give 3 session requests from node 1 to node 5: Session A needs 2 slots, session B needs 3 slots and session C needs 4 slots. The sessions arrived at node 1 sequentially. Given an assumption of |*W*| =2, |*T*| =4, *K=1*.

Figure 4 shows the result of slots assignment by MUMD algorithm. It shows that, the same route (1, 3, 5) is selected for all three sessions and session C is blocked.

Figure 5 shows the result of routing and slots assignment by LLR-MWLB algorithm. It shows that, the same route (1, 3, 5) is selected for sessions A and B and route (1, 2, 4, 5) for session C because of the variable link weight.

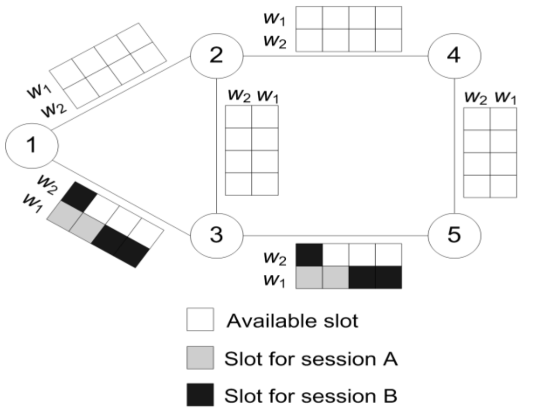

Figure 4. An Example of MUMD Algorithm

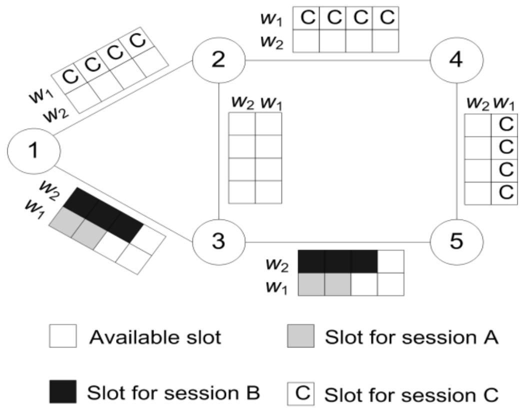

Figure 5. An Example of LLR-MWLB Algorithm

4. Results and Analysis

Simulations have been performed on NSFNET with 14-nodes and 21-links. And we assume that in the network each link is consisting of a pair of an opposite one-way fiber and has the same capacity. In the simulations, session requests arrive at the network according to Poisson process with rate λ and the holding time of a session is exponentially distributed with mean $1/\mu$. And *K*-shortest path algorithm is used to calculate alternate paths, where *K* is 2.

4.1. Optimal Combination of *α* and *β*

We have performed a simulation to find the optimal combination of α and β. Figure 6 shows the blocking probability under the case of |*W*|=16 and |*T*|=16, and network load is 100 in erlangs. We find the best performance while α= 2 and β= 1.

4.2. Performance of Algorithms

We evaluate the performances of MUMD and LLR-MWLB algorithm in terms of the overall average blocking probability which is defined as a ratio of the number of blocked sessions to the number of total arrived sessions. We compare our algorithms with RANDOM, FIRST-FIT, EMUB algorithm.

Figure 7 plots the average blocking probability under the case of |*W*|=16 and |*T*|=16. Simulation results show that the MUMD and LLR-MWLB policies perform much better than the other three policies and the later has the best performance that increases by 1 to 3 orders of magnitude. Two reasons contribute to the good results. First, *K*-shortest alternate routing policy based on adaptive link weights tends to conduce that sessions are routed to those path with more available time-slots. Thus session loads will be well-proportionally distributed in the links of the network and a new session will have more chance to be transferred successfully. Second, slots in multiple different wavelengths are assigned to the session and the assigning algorithm is adaptive with the remainder resources of the network. Therefore, the capacity of wavelengths is fully utilized, which tends to leave more available wavelengths and slots to accept the subsequent session requests.

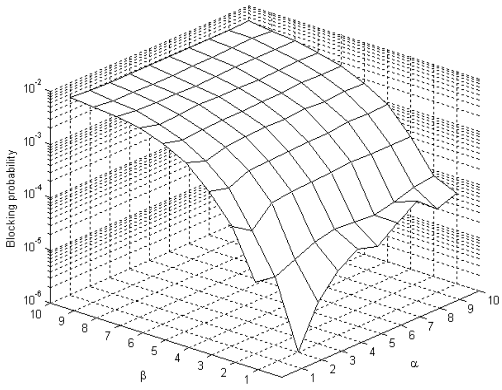

Figure 6. Optimal Combination of *α* and *β*

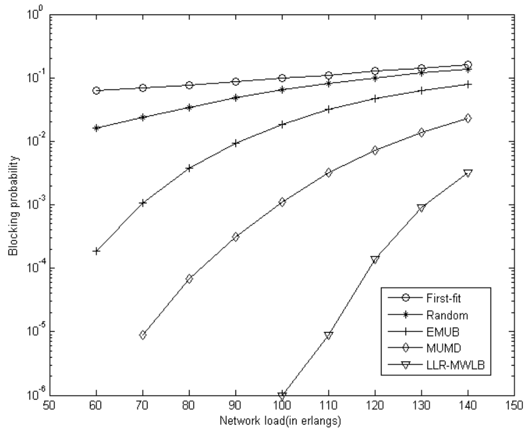

Figure 7. The Blocking Probability Versus the Network Load (In erlangs)

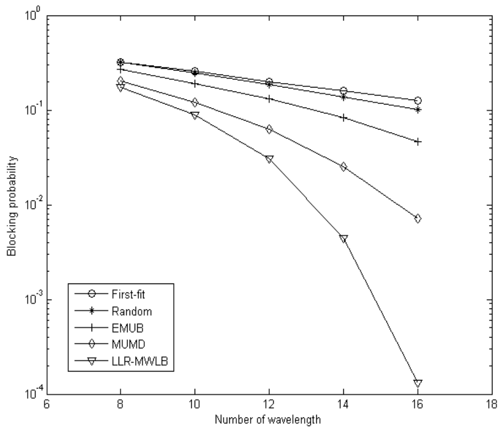

Figure 8. The Blocking Probability Versus the Number of Wavelength

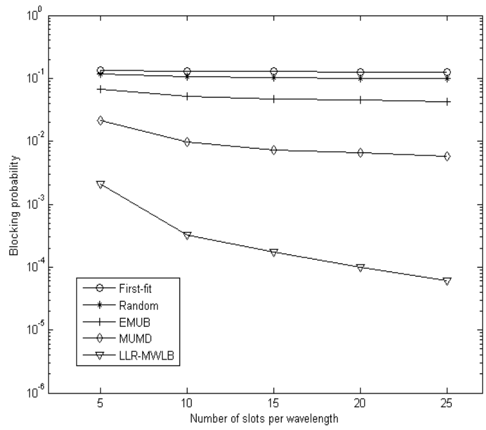

Figure 9. The Blocking Probability Versus the Number of Time-slots per Wavelength

The simulation also performs the impact of $|W|$ on the network blocking probability. Figure 8 shows the blocking probability of the four RWTA algorithms versus |W|, when the network load is fixed at 120 and $|T|$ is 16. The results show that with the increasing of $|W|$, the blocking performance of both five algorithms is enhanced. This is because the capacity of network enlarges with the increasing of $|W|$. Clearly, our algorithms perform much better than other algorithms and LLR-MWLB algorithm does the best.

The impact of $|T|$ on the network blocking probability is shown in Figure 9. When network load is fixed at 120 and $|W|$ is 16, the blocking performance is slightly improved with the increasing of $|T|$. As the rate of sessions is uniformly random distributed in [1, $|T|$], the average rate of sessions increases when $|T|$ increases. So the performance is not obviously improved. Clearly, our algorithms also perform the best.

5. Conclusion

TDM technology is considered to improve the wavelength capacity utilization of All-optical WDM networks. In this paper, we study the routing, wavelength and time-slots assignment problem in such time-space switched networks. Two new dynamic algorithms called MUMD and LLR-MWLB are proposed which can distribute slots of the session request on multiple different wavelengths. In MUMD algorithm, fixed alternate routing policy is used. In

LLR-MWLB algorithm, network link weights vary adaptively with the number of available slots on the link and this policy distributes slots of the session request on multiple different wavelengths adaptively with the remainder resource of the network. Simulation results show that the performances of our algorithms are much better than RANDOM, FIRST-FIT, EMUB algorithm and LLR-MWLB performs the best.

Acknowledgements

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