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Performance Assessment of Fuzzy Logic Control Routing Algorithm with Different Wavelength Assignments in DWDM Networks

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Abstract

DWDM (Dense Wavelength Division Multiplexing) is an effective technique to make use of the large amount of bandwidth in optical fibers to meet the broadband requirement of multimedia applications. The routing and wavelength assignment (RWA) algorithm efficiently manages optical network resources and separated from the optical topology. This paper proposes a dynamic LLR algorithm using fuzzy logic control (FLC LLR) with different wavelength assignments. The unexpected traffic load is increased when the traffic load is high and lightpath is long for the LLR routing algorithm. How to balance the traffic loads of each link and minimize the hop counts for each path is considered in this paper and the fuzzy logic control in FLC LLR algorithm is based on the traffic load and hop counts to determine the lightpath can be established or not. The simulation results show that the FLC LLR algorithm has better system performance than LLR algorithm in terms of connections setup, blocking probability, and channel utilization, especially for the traffic load is high. The number of conversions is compared as three wavelength assignments are embedded in FLC LLR algorithm when the converters are considered.

Key words: DWDM, RWA, FLC LLR algorithm, System performance.

1. Introduction

DWDM (Dense Wavelength Division Multiplex) [1,2], is an efficacious technology to carry different wavelengths into one optical fiber, has been an indispensable communication technique on the Internet broadband and high speed transmission systems. The networks with the development of optical cross-connects and WDM technology, are referred to as wavelength routed networks. In the DWDM network, a lightpath can be established by the same or different wavelengths available on all links between the source node to the destination node. The routing and wavelength assignment (RWA) problem [3,4] is to select possible path and wavelength for each connection given a set of connection requests. Two network traffic patterns are discussed, static traffic [5,6,7] and dynamic traffic [8,9,10]. Most works focus on the dynamic traffic case, which the connection requests arrive in random and lightpaths are setup on demand. Many studies showed that the RWA problem with/without converters is known to be or near NP-complete [5]. As a result, one of good dynamic wavelength routing algorithms, Least Loaded Routing (LLR) Algorithm [10], is proposed to increase the network throughput by balancing the traffic load among the alternate paths without loading any of them into congestion. LLR algorithm is an adaptive routing and an application of the shortest path algorithm (*DijkStra's algorithm*). It is different from hop by hop routing algorithm that uniforms to use the minimum traffic load of links as cost function [10,11], instead of hop counts, to reduce the blocking probability of connection establishments. Unfortunately, the hop counts based on LLR algorithm is still high and causes some unexpected traffic load produced to offset the merits of the LLR algorithm. So, how to balance the traffic load of each link and minimize the hop counts for each path is considered in this paper.

The scenario of this paper is categorized into two parts. For the first part, the LLR algorithm with fuzzy logic control (LLR FLC) is proposed to mitigate the problem of unexpected traffic load of the LLR algorithm during the lightpath connections. The membership functions of the LLR FLC use fuzzy sets based on the traffic load of each link and the hop counts of the routing path, and then applies the fuzzy rules to determine the lightpath can be established or not. Then the system performance of three wavelength assignment algorithms (First-Fit, Random [8,10] with/without converters and Least converter count [3,5] with converters) with the LLR FLC are evaluated and compared. First-Fit algorithm assigns the number to the index of each wavelength, and chooses the wavelength with the sorting result. When the indexes of wavelengths are sorted in increasing order, the selected wavelengths center on smaller wavelength numbers that causes the utilization and assignment of wavelength unbalanced. As for Random algorithm, it selects the wavelength arbitrarily and judges whether it can meet the routing requests or not. Due to the random style, the wavelength assignment is more uniform than sorting algorithm. Both random and first-fit algorithms have high number of wavelength conversion and increase the end-to-end delay time. Another better algorithm, called Least converter count, takes the wavelength conversion times into consideration. It checks any available wavelengths in source node, and then adds one to the conversion times if no channel is available. After collecting all information, the path with least wavelength conversions from the source node to destination node is selected to decrease the blocking probability and improve the end-to-end delay time.

The rest of the paper is organized as follows. Section II describes the proposed LLR FLC algorithm. Section III evaluates system performance with/without converters using computer simulation in terms of connections setup, blocking probability and channel utilization. The conclusion is summarized in section IV.

2. FLC LLR Algorithm

The FLC LLR algorithm is used to decrease the block probability and minimizes the hop counts for each lightpath. LLR algorithm selects the route-wavelength pair for each connection based on the current network's state and the fuzzy logic control routing algorithm is used to evaluate the relation between load of each link and hop count during selecting lightpaths.

A. The model assumptions and cost function

The model assumptions and definitions of cost function are described as follows:

1. The topology is a mesh network.
2. All control information is obtained by central management.
3. There are L links in the network. Each link L_j only holds one fiber, j=1,…,n, and there are W_i channels in each fiber, i=1,…,m, respectively. If W_i is used on the certain link, then the indicator UM_i is equal to 1; otherwise 0.
4. The traffic load on the certain link is expressed as follows:

$$L_i = \sum_{i=1}^{m} UM_i \Big/ m \quad . \qquad (1)$$

5. Each node has converter that can convert all different channels.

B. Fuzzy set and membership function of traffic load

Membership degree	Traffic load
LVS (Load Very Small)	0% to 20%
LS (Load Small)	10% to 50%
LM (Load Middle)	30% to 70%
LH (Load High)	60% to 90%
LVH (Load Very High)	80% to 100%

Table 1 Membership degree of traffic loads.

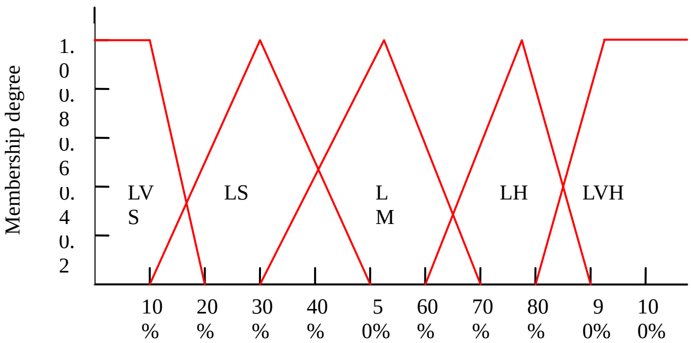

Fig. 1 Membership function of traffic load.

The membership functions based on fuzzy sets depend on the traffic load and hop counts. The ratio of traffic load is defined in (1) and the ratio of hop count is defined by the hop counts to all links of the network. The Membership degree vs. traffic load is defined in table 1 and the membership function of traffic load is shown in Fig. 1.

C. Fuzzy set and membership function of hop count

The membership degree vs. hop counts is defined in table 2 and the membership function of hop count is defined in Fig. 2.

Membership degrees	Hop counts
HVS (Hop Very Small)	0% to 20%
HS (Hop Small)	10% to 30%
HM (Hop Middle)	20% to 50%
HH (Hop High)	35% to 75%
HVH (Hop Very High)	70% to 100%

Table 2 Membership degree of hop counts

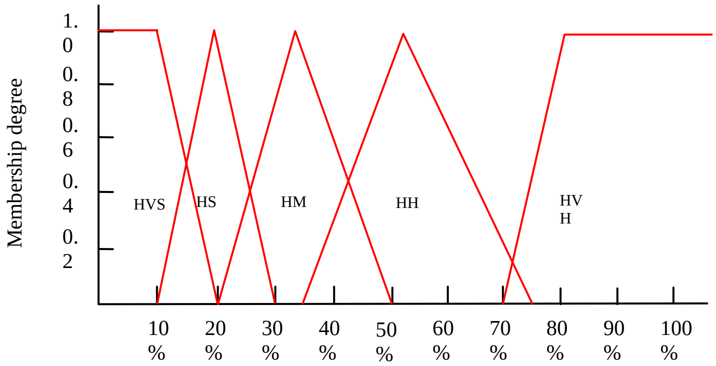

Fig. 2 Membership function of hop counts

D. Fuzzy rules

Table 3 shows the fuzzy rules of lifetime for each connection, $R^{(g)}$(g=1,2,…,14), using if-then rules constructed by fuzzy sets {LVS, LS, LM, LH, LVH} in the membership function of traffic load and {HVS, HS, HM, HH, HVH} in the membership function of hop count as it's universal set.

Fuzzy rules		Traffic Load		Hop count		Connection
$R^{(1)}$	If	LVS	and	HVS	then	1
$R^{(2)}$	If	LVS	and	HS	then	1
$R^{(3)}$	If	LVS	and	HM	then	1
$R^{(4)}$	If	LVS	and	HH	then	1
$R^{(5)}$	If	LVS	and	HVH	then	0
$R^{(6)}$	If	LS	and	HVS	then	1
$R^{(7)}$	If	LS	and	HS	then	1
$R^{(8)}$	If	LS	and	HM	then	1
$R^{(9)}$	If	LS	and	HH	then	1
$R^{(10)}$	If	LS	and	HVH	then	0
$R^{(11)}$	If	LM	and	HVS	then	1
$R^{(12)}$	If	LM	and	HS	then	1
$R^{(13)}$	If	LM	and	HM	then	1
$R^{(14)}$	If	LM	and	HH	then	0

Table 3 Fuzzy rules.

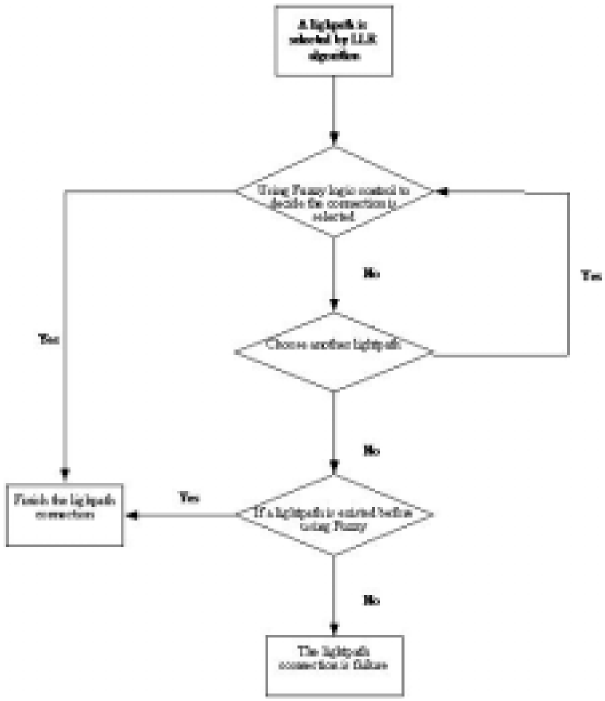

Fig. 3 FLC LLR algorithm flowchart.

The defuzzification method is based on Center of Gravity Defuzzification and setting the appropriate parameter of fuzzy limit. If the value after defuzzification is greater than the fuzzy limit, the connection request succeeds; otherwise, the connection request fails. While connection request fails, the selected path may be too long or the mean traffic load may be too heavy. The flowchart of FLC LLR algorithm is shown in Fig. 3.

3. Simulation Results

The simulation environment is based on the NSFNet that is constructed by 16 nodes and 21 links and the number of channels is 8 or 16, shown in Fig. 4. The traffic load is dynamic. The system performance of three algorithms without converters, LLR, hop by hop and FLC LLR, are compared in terms of the number of successful connections, blocking probability and channel utilization in first-fit and random wavelength assignment algorithms. Furthermore, the blocking probability with/without converters and the number of conversions are evaluated for three wavelength assignment algorithms, first-fit, random and least converter count with converters embedded in the FLC LLR. The membership functions and fuzzy rules are defined in Section 2 and the fuzzy limit is set 0.8 or 0.9 based on the simulation results [12]. The saturation time T is the duration time when the channel utilization is 100% by LLR algorithm.

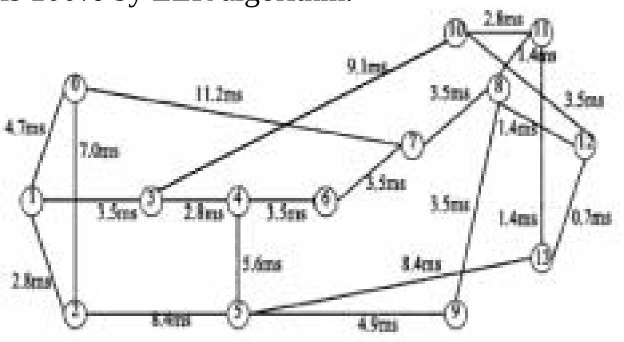

Fig. 4 NSFNet

A. Connections setup

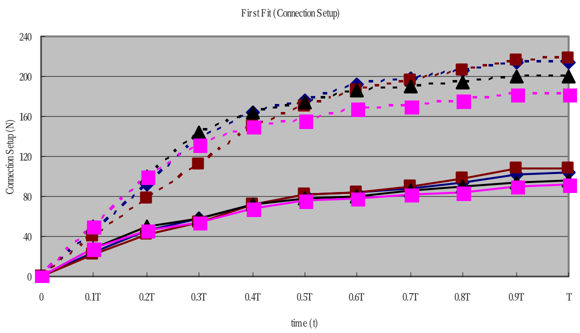

Fig. 5(a) connections setup for FLC LLR, LLR, and Hop by Hop algorithm with first-fit wavelength assignment.

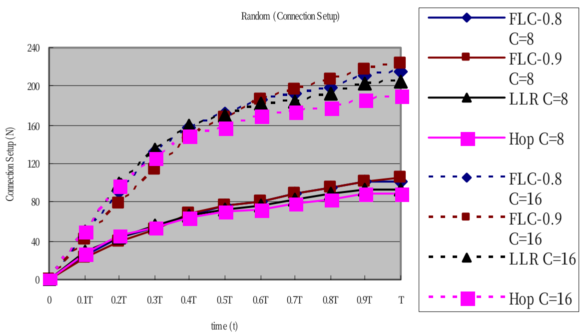

Fig. 5(b) connections setup for FLC LLR, LLR, and Hop by Hop algorithm with random wavelength assignment.

Figure 5(a) shows simulation results of the number of successful connections setup for three routing algorithms, FLC LLR, LLR and Hop by Hop algorithms without converters using first-fit wavelength assignment algorithm. It is interesting to notice that the number of successful connections for different three algorithms is LLR>FLC LLR>Hop by Hop when the time is below 0.3T. The reason is that the unexpected traffic load with LLR algorithm is low when the traffic load is below 0.3T. But when the time is more than 0.4T, the number of successful connections for different three algorithms is FLC LLR>LLR>Hop by Hop. The unexpected traffic load with LLR algorithm is high when the connections of paths are longer after the traffic load is getting heavy and the defuzzification with FLC LLR algorithm can alleviate the problem when the traffic load is high. The same simulation result for random wavelength assignment algorithm is shown in Fig. 5(b). Overall, the simulation result shows that the performance of first-fit algorithm performs better than that of random algorithm.

B. Blocking probability

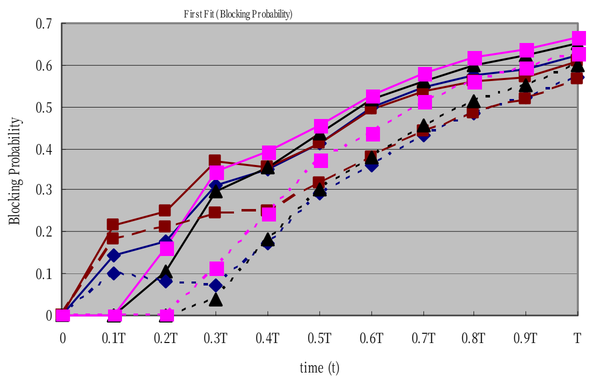

Fig. 6(a) blocking probabilities for FLC LLR, LLR, and Hop by Hop algorithm with the first fit wavelength assignment.

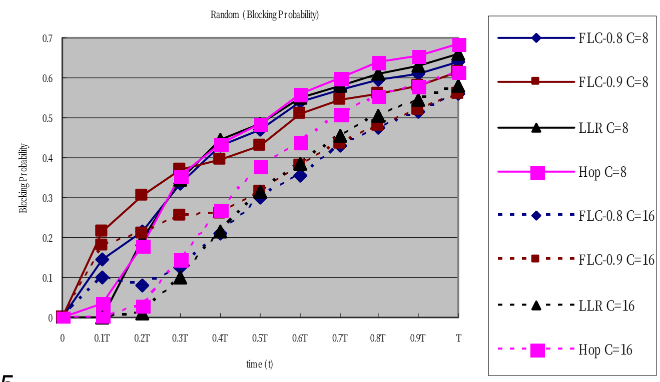

Fig. 6(b) blocking probabilities for FLC LLR, LLR, and Hop by Hop algorithm with the random wavelength assignment.

Fig. 6(a) and Fig. 6(b) show the blocking probabilities for three routing algorithms with two wavelength assignment algorithms. The simulation shows that the LLR algorithm performs better than the FLC LLR algorithm when the time is below 0.4T. The possible reason is that the FLC LLR algorithm rejects the connection when the hop count is high and the value after defuzzification is smaller than the fuzzy limit. Another reason is that the unexpected traffic load generated by LLR algorithm is tolerable when the traffic load is low. But, the side effect of the unexpected traffic load generated by LLR algorithm shows up when the traffic is high and blocking probability with FLC LLR algorithm is improved when the time is more than 0.5T.

C. Channel utilization

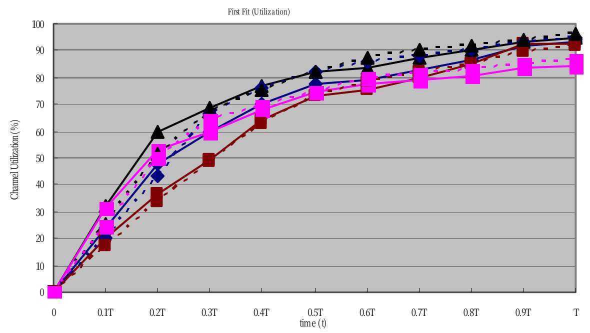

Fig. 7(a) channel utilizations for FLC LLR, LLR, and Hop by Hop algorithm with the first fit wavelength assignment.

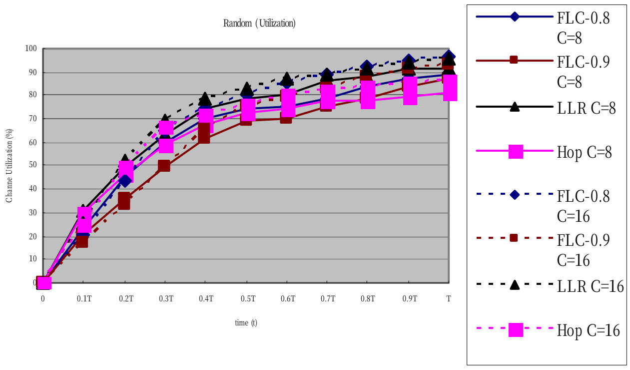

Fig. 7(b) channel utilizations for FLC LLR, LLR, and Hop by Hop algorithm with the random wavelength assignment.

Fig. 7(a) and Fig. 7(b) compare the channel utilizations for three routing algorithms with two wavelength assignment algorithms, first-fit and random when the number of channel is 8 or 16. The traffic load and hop count are balanced when the number of channel is high for LLR algorithm and FLC LLR algorithm. But, the FLC LLR algorithm, which reduces the unexpected traffic load when the traffic load is high, has better performance than LLR algorithm.

D. Blocking probability with/without wavelength converters

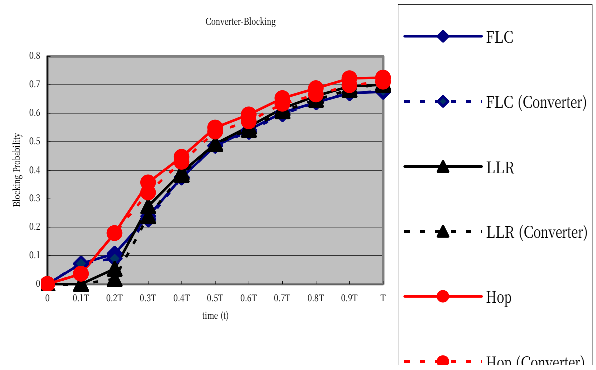

Fig. 8 blocking probabilities for FLC LLR, LLR and Hop by Hop algorithm with wavelength converter using first fit wavelength assignment.

Figure 8 shows the blocking probabilities for three routing algorithms, FLC LLR, LLR and Hop by Hop algorithm with/without wavelength converters using first fit wavelength algorithm. The blocking probabilities are improved when the converters are used for three different routing algorithms.

E. Number of conversions needed with wavelength converters

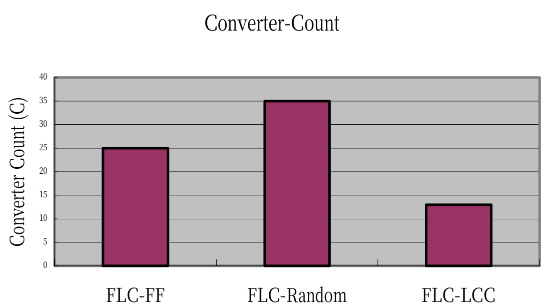

Fig. 9 average number of conversions needed for first fit, random and least converter count wavelength assignment algorithms embedded in FLC LLR when the time is 0.7T.

The advantage of DWDM network with

wavelength converters is that the wavelength continuity constraint can be ignored. But the cost of wavelength converter and delay time of the number of conversions are needed to be considered to enhance the system performance. Figure 9 shows the average number of conversions needed for first fit (FLC-FF), random (FLC-Random) and least converter count (FLC-LCC) wavelength assignment algorithms embedded in FLC LLR. The simulation shows that the FLC-LCC outperforms the FLC-Random and better than the FLC-FF when the time is 0.7T.

4. Conclusion

This paper proposed the dynamic FLC LLR algorithm to balance the traffic load of each link and minimize the hop count for each path. Due to unexpected traffic load with LLR algorithm is generated when the length of lightpath is long and the traffic load is high, the fuzzy logic control based on traffic load and length of lightpath is used to determine the connections can be established or not. The simulation results show that FLC LLR algorithm without converters using appropriate fuzzy limit has better system performance than LLR algorithm in terms of connections setup, blocking probability and channel utilization when the traffic load is high. Furthermore, when the cost of wavelength converter and delay time of the number of conversions are considered, three RWA algorithms with converters are compared and the simulation shows that the FLC-LCC outperforms the FLC-Random and better than the FLC-FF.

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