บทความวิจัย

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PERFORMANCE ANALYSIS OF WAVELENGTH ASSIGNMENT IN WDM OPTICAL NETWORK

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บทคัดย่อ

วิธีการจัดสรรความยาวคลื่นนั้นเป็น ปัญหาสำคัญของการออกแบบการส่งผ่านเส้นทางเดินแสงในโครงข่ายมัลติเพลกซ์แบบแบ่งความยาวคลื่น เพื่อที่จะออกแบบให้โครงข่ายมัลติเพล็กซ์แบบแบ่งความยาวคลื่นส่งผ่านข้อมูลได้รวดเร็วมีประสิทธิภาพสูงสุด บทความนี้จึงได้นำเสนอแบบจำลองเชิงคณิตศาสตร์สำหรับการออกแบบเส้นทางเดินแสงของโครงข่ายมัลติเพล็กซ์เชิงแสงแบบแปลงความยาวคลื่นด้วยวิธีการของมาคอฟโปรเซสสำหรับการจัดสรรเส้นทางและความยาวคลื่น ในการหาค่าความน่าจะเป็นที่จะเลือกความยาวคลื่นเพื่อที่จะใช้งานในการเชื่อมต่อเส้นทางเดินแสงสำหรับโหนดในมัลติเพล็กซ์เชิงแสง บนโครงสร้างของโครงข่ายแบบวงแหวน จากผลการทดสอบด้วยวิธีการเชิงตัวเลขนั้น วิธีการที่ได้นำเสนอสามารถให้ค่าความน่าจะเป็นในการสกัดกั้นทราฟฟิก ได้ดีกว่าวิธีการจัดสรรความยาวคลื่นแบบเฟิร์สฟิต, แรนดอม, โมสยูส อีกทั้งวิธีการดังกล่าวสามารถออกแบบเส้นทางเดินแสงโดยประยุกต์ใช้งานเข้ากับวิธีการหาเส้นทางแบบเผื่อเลือก ในโครงข่ายมัลติเพล็กซ์เชิงแสงแบบวงแหวน ได้อย่างมีประสิทธิภาพ

คำสำคัญ : วิธีการจัดสรรความยาวคลื่น โครงข่ายมัลติเพล็ซ์แบบแบ่งความยาวคลื่น มาคอฟโปรเซสสำหรับการจัดสรรความยาวคลื่น การแปลงความยาวคลื่น

ABSTRACT

Wavelength Assignment (WA) is an important issue of the WDM (Wavelength Division Multiplexing) network light path transmitting designation for the purpose of designing the WDM network with high speed data transmission and high quality. This article proposes a mathematical model for the light path designation of WDM wavelength conversion with Markov process method for wavelength assignment (MPM-WA). Finding the probability for choosing the suitable wavelength is used for light path connection of WDM with wavelength conversion nodes on a ring network system. From the numerical experiment results, the proposed method can give the blocking probability better than First-Fit WA, Random WA, and Most-Used WA wavelength assignment methods. Moreover, the proposed method can create light paths by applying the Fixed-Alternate path routing method for WDM ring network efficient usage.

KEYWORDS : Routing and Wavelength Assignment, Wavelength Division Multiplexing, Markov process method for wavelength assignment, Wavelength Conversion

Introduction

Recently, optical networks have been wildly used in high speed communication work. This is because the system transmits the data via light waves. This wave is an informational medium which has the advantage of a wide bandwidth and high speed transmission in the light path transmission calls routing and wavelength assignment. The signal transmissive process can be explained through Fig. 1. When there are 2 light path requests, light path 1 requests a connection from A node to D node and light path 2 requests a connection from A node to C node, the path finding process will assign the light paths in each rout by having optic fiber as a medium between nodes, also known as links. After the light path has been laid, the second step in the process is finding the wavelength for light path assignment. There are two types of wavelength assignment; wavelength conversion and without wavelength conversion Mukherjee, B. et al. (2006). For the optical transmission without wavelength conversion, optical signal will use a single wavelength through the whole route from the source node to the destination node. This problem sometime is called wavelength continuity constraint Ramaswami, R. et al. (2010). However, the wavelength continuity constraint will likely block the traffic. The wavelength continuity constraint's problem can be solved by using the converted wavelength transmission. This system will add optical wavelength conversion tool into the system's nodes in order to convert the light signal from one wavelength to another.

The conversion is done so that the available wavelengths can be adaptably used for light paths. Therefore light paths can connect with signal continuously as shows in Fig. 1. When the Light Path 1 is assigned (A-B-C-D) a wavelength assignment under the wavelength continuity constraint, then it will use λ_1 for connection all the way. Light Path 2 (A-B-C) with the wavelength conversion type, the wavelengths for connections can vary. This article has used λ_2 for A-B link connection and λ_3 for B-C link connection respectively.

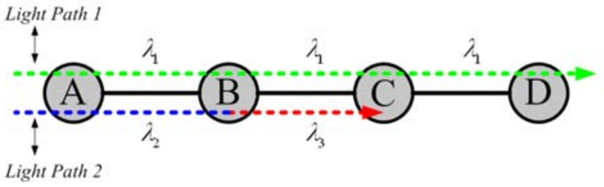

Fig.1 Light Path Transmitting with Wavelength Conversion Type and without Wavelength Conversion Type.

WDM network will use a fixed wavelength converter as an important part of nodes in order to solve the problem of the wavelength continuity constrain. The wavelength conversion will be based on the wavelength converter's system ZHENG J. et al. (2003) as explained in Fig. 2.

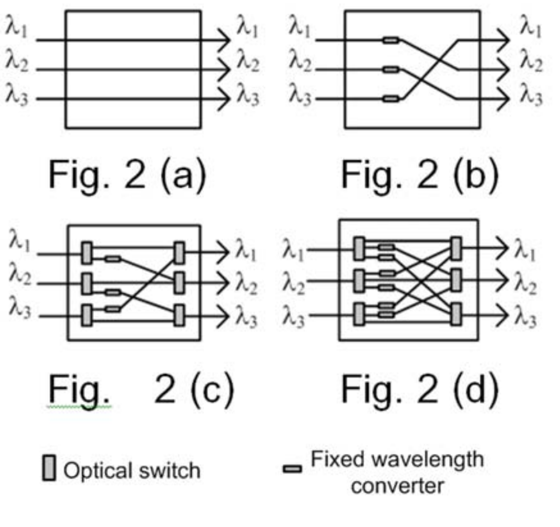

Fig. 2 Wavelength Transmitting Patterns in Optical Multiplex Nodes

Fig. 2 (a) is a wavelength transmission without wavelength conversion. The output light wave has the same wavelength as the input one. Fig. 2 (b) is a transmission with fixed wavelength conversion: F-WC. It will fix the input wavelength pattern to have one wavelength. From the figure, it is clear that

- If the input wavelength is λ_1 the output is λ_2
- If the input wavelength is λ_2 the output is λ_3
- If the input wavelength is λ_3 the output is λ_1

Fig. 2 (c) is a transmission with limited wavelength conversion: L-WC. It will fix the output wavelength pattern to have more than one wavelength, but the number will not be equal to the used waves; for example,

- If the input wavelength is λ_1 the output is λ_1 or λ_2
- If the input wavelength is λ_2 the output is λ_2 or λ_3
- If the input wavelength is λ_3 the output is λ_1 or λ_3

Fig. 2 (d) is the transmission with full wavelength conversion: Full-WC. It has the ability to choosing output wavelength to use, depending on the available maximum wavelength number.

Previous research has proposed an approach to analyze an optical multiplex network's performance. It aims to offer an idea for improving the network's data transmission to have a better capacity. One example is the mathematical model for probability analysis in blocking an optical multiplex generating network's traffic. The experiment is a simple model with fast calculation by comparing the probabilities of traffic blocking on a route length parameter, and the number of free wavelength Wason, A. et al. (2010). Furthermore, there is a model proposed to analyze the wavelength assignment problem for the optical multiplex network's performance evaluation Wason A. et al. (2011). The author proposed a mathematical model called the Most-used wavelength conversion (MUWC) algorithm, aimed to improve the network's traffic blocking probability by referring to the number of used links. Singh, H. et al. (2010) proposed a mathematical model on OBS wavelength assignment. The proposed model is simple and takes a short time in calculation. He, M. et al. (2011) analyzed traffic blocking probability of First-fit algorithms wavelength assignment for traffic transmission. Randhawa, R. et al. (2013), the author evaluated the wavelength assignment's performance on the optical multiplex ring network. The algorithm can give better traffic blocking probability than other algorithms in comparison. Randhawaa, R. et al. (2010) 's author proposed Best-Fit Sparse-Wavelength Conversion Algorithm Mathematical Model which analyzed the network's traffic blocking probability. The proposed model was tested under optical wavelength conversion and without optical wavelength conversion. Sudhir, K. (2013),(2014) improved the general extreme value for link's length analysis in an optical network. The link's length would be improved to have better capacity. The model could be adjustably used in optical network designation and installment. Fang, W. et al. (2015) worked on the joint defragmentation (DF) problem for spectrum and IT resources in elastic optical datacenter-interconnection (EO-DIC). The analysis was done by adjusting the usage into the mixed integer linear programming type. The experiment showed that the DF algorithm could reduce the traffic blocking probability in EO-DIC.

This article offers MPM-WA model for the adaptation with wavelength conversion optical multiplex nodes on ring network architectural connection. The model can be used to design a suitable wavelength for light paths under the lowest traffic blocking probability condition. It can also be used as important parameter of alternative light path designation, which will improve the light path transmitting capacity in optical multiplex networks. Section 2 of this article explains wavelength assignment models. Section 3 presents details of analyzed model case studies and an explanation of the numerical experiment results. Section 4 is the article's conclusion and discussion.

2. Introduction Routing and Wavelength Assignment Method on WDM Ring Network.

Wavelength assignment is important to optical data transmission because it will select wavelengths for light paths. There are many types of wavelength assignment. For examples, random one chooses wavelengths that work by randomly choosing available wavelength from each link and selecting them for use. First-Fit chooses wavelengths by order. Least-Used one chooses the least used wavelength to use. Most-Used one chooses the most used availability wavelength to use. Fig.3 explains the working process of the network.

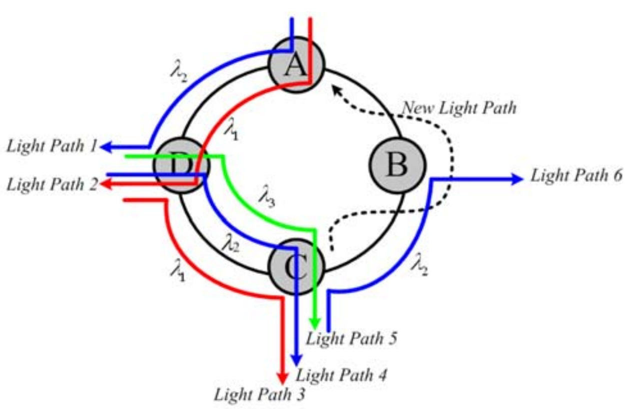

Fig.3 Light Path Transmission in WDM Ring Network

From Fig. 3 is a structure of WDM ring network that has 4 nodes, or 4 links on a ring network architectural connection. It assumes that connecting links have 4 used wavelengths in the network, which are ($\lambda_1, \lambda_2, \lambda_3$, and λ_4). These wavelengths are under the connection of 7 light paths which work by

- Light Path 1 connects A-D route with λ_2
- Light Path 2 connects A-D route with λ_1
- Light Path 3 connects D-C route with λ_1
- Light Path 4 connects D-C route with λ_2
- Light Path 5 connects D-C route with λ_3
- Light Path 6 connects C-B route with λ_2

Usage Summary

- λ_1 is used in 2 links which are A-D and D-C.
- λ_2 is used in 3 links which are A-D, D-C and C-B.
- λ_3 is used in 1 link which is D-C.
- λ_4 has no usage.

Considering the wavelength usage above when there is a new light route request which is C-B-A, the wavelength assignment for the route will depend on each algorithm's properties.

1. Random algorithm chooses wavelength using order random procedure which has 4 wavelengths. Assuming all 4 are ($\lambda_2, \lambda_3, \lambda_1$ and λ_4). λ_2 is used here because it is the first one that will be assigned randomly.

2. First-Fit algorithm assigns wavelengths by orders which are ($\lambda_1, \lambda_2, \lambda_3$ and λ_4). Wavelength λ_1 is chosen to use here because it is the first one that will be assigned.

3. Least-Used algorithm chooses the least used wavelength to sort out into ascending order. The order goes ($\lambda_4, \lambda_3, \lambda_1$ and λ_2). Wavelength λ_4 is chosen to use here because it is the least used one.

4. Most-Used algorithm works opposite to Least-Used algorithm by putting the chosen most used

wavelengths into descending order. The order goes ($\lambda_2, \lambda_1, \lambda_3$ and λ_4). Wavelength λ_2 is chosen to use here because it is the most used one.

Each wavelength assignment procedure will choose wavelengths according to Table 1.

Table 1 The New Assigned Wavelengths in the New Optical Route

Route	WA Algorithm	Wavelength
C-B-A	Random	λ_2
	First-Fit	λ_1
	Least-Used	λ_4
	Most-Used	λ_2

This article applies the work of wavelength assignment condition in optical multiplex nodes by applying MPM-WA with the available and not available wavelength's probabilities. This application is for selecting used wavelengths while multiple routes traffic receiving node chooses many wavelengths based on the amount of input traffic in WDM network, which can be explained below.

1.) When the most used wavelength equal λ_N each used wavelength will have probability's condition for wavelength usage as available and not available which are written down as follow.

$$P_{ro}(\lambda_N) = \begin{cases} 0; \textit{free} \\ 1; \textit{busy} \end{cases}$$

2.) State Diagram

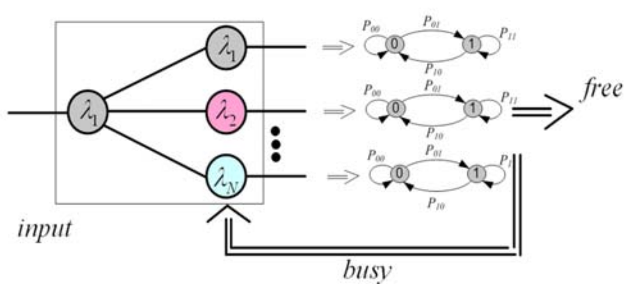

Fig. 4 Wavelength Usage Change Condition

Fig. 4 is a state diagram of a wavelength transmitting condition. The transmission depends on the transmitting structure in Fig.2. When there is a request to use a processing wavelength, it will lead to a wavelength choice based on whether the used wavelength condition is available or not. Fig.4 can also be written down in matraix as follow.

$$\overline{P} = P_{\lambda_{ij}} = \begin{bmatrix} P_{00} & P_{01} \\ P_{10} & P_{11} \end{bmatrix} \quad (1)$$

When P_{00} and P_{11} are confined to be zero because it is a constaint condition.

P_{01} is changing condition from available to not available.

P_{10} is changing condition from not available to available.

$P_{\lambda_{ij}}$ is changing wavelength usage conditions in nodes which has 2 conditions of available and not available.

An equation for wavelength usage prediction state in (2)

$$\pi_{\lambda_j}^{(k+1)} = \sum_{k=0}^{\infty} \pi_{\lambda_i}^{k} P_{\lambda_{ij}} \quad (2)$$

When π is the probability that it will use wavelength from (2). The mean can be written down as follows.

$$\overline{\pi}_{\lambda_j}^{(k+1)} = \overline{\pi}_{\lambda_j}^{(k)} \overline{P} \quad (3)$$

When k is the amount of input traffic in nodes per cycle.

$\overline{\pi}^{(k)}$ is the probability that it will use wavelength in nodes, which receive the amount of traffic under condition k.

$\overline{\pi}_{\lambda_j}^{(k+1)}$ is the probability that it will use wavelength in nodes, which receive the amount of traffic under condition of $k+1$.

Later when using the results find the used wavelength in each structure, it can be written as the equation (4).

$$P_{used_{\lambda j}}^{(k+1)} = \overline{\pi}_{\lambda_j}^{(k+1)}.P_{con} \quad (4)$$

P_{con} = The probability in wavelength transmission of each structure

$P_{used_{\lambda j}}^{(k+1)}$ = The probability of wavelength usage in each traffic's structure under the $k+1$ condition.

Therefore when more cycles of traffic usage are added, the equation will be able to find a suitable wavelength for light path designation under the lowest traffic blocked probability. The wavelength becomes an important parameter in selecting light path of alternative light path finding process. The working process runs as follow in Fig.5.

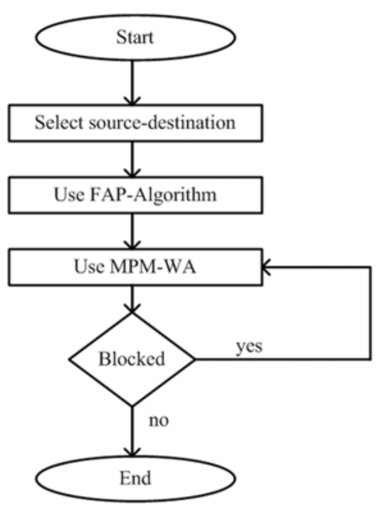

Fig.5 Working Process of MPM-WA.

3. Case Studies and Results.

The experiment was done on 3 wavelengths converted structures of a WDM node. The wavelength conversion was done on architectural ring network that has 4 nodes and 4 links by confining the used wavelength as 4. The matrix equation could be written down as follows.

3.1 Fixed Wavelength Conversion (FWC)

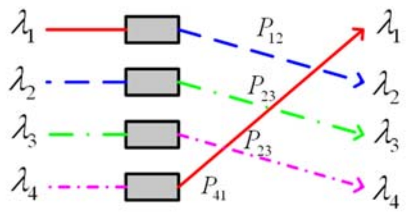

Fig.6 The Within Node Transmission of Fixed Wavelength Conversion.

$$p_{f_{ij}} = \begin{bmatrix} 0 & p_{12} & 0 & 0 \\ 0 & 0 & p_{23} & 0 \\ 0 & 0 & 0 & p_{34} \\ p_{41} & 0 & 0 & 0 \end{bmatrix} \quad (5)$$

3.2 Limited Wavelength Conversion (LWC)

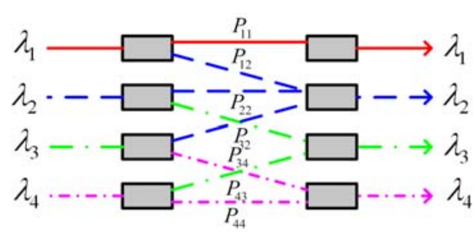

Fig. 7 The Within Node Transmission of Limited Wavelength Conversion.

$$p_{L_{ij}} = \begin{bmatrix} p_{11} & p_{12} & 0 & 0 \\ 0 & p_{22} & p_{23} & 0 \\ 0 & 0 & p_{32} & p_{34} \\ 0 & 0 & p_{43} & p_{44} \end{bmatrix} \quad (6)$$

3.3 Full Wavelength Conversion (Full-WC)

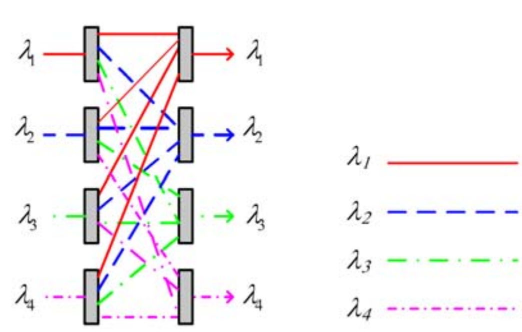

Fig. 8 The Within Node Transmission of Full Wavelength Conversion.

$$p_{Full_{ij}} = \begin{bmatrix} p_{11} & p_{12} & p_{13} & p_{14} \\ p_{21} & p_{22} & p_{23} & p_{24} \\ p_{31} & p_{32} & p_{33} & p_{34} \\ p_{41} & p_{42} & p_{43} & p_{44} \end{bmatrix} \qquad (7)$$

The wavelength conversion structures in Figs (6),(7) and (8) could be written down in matrix form following the equations (5),(6) and (7).The 3 equations above were brought to represent in the variable P_{con} of equation (4) for a randomly chosen number of cycles from MATLAB 7.0 program. The choosing was done under the probability's condition of optical wavelength usage in order that network analysis, in predicting the probability of choosing optical wavelength, could be done. The chosen optical wavelength would be applied to use in WDM network designation.

The experiment from 3 structures of wavelength conversion within nodes in 3.1, 3.2 and 3.3 was done by MATLAB R2015a program on the computer that has Intel (R) Core(TM) i5, RAM 4 GB. The experiment used

- 4 wavelengths in used nodes
- 50 erlang traffic
- 0.9999 probability of available wavelength and 0.1111 probability of not available wavelength (Network's initial condition has more available wavelength probability than highly used wavelength probability)
- $\pi_{\lambda_i}^{k}$ is randomly selected from the program under initial condition.

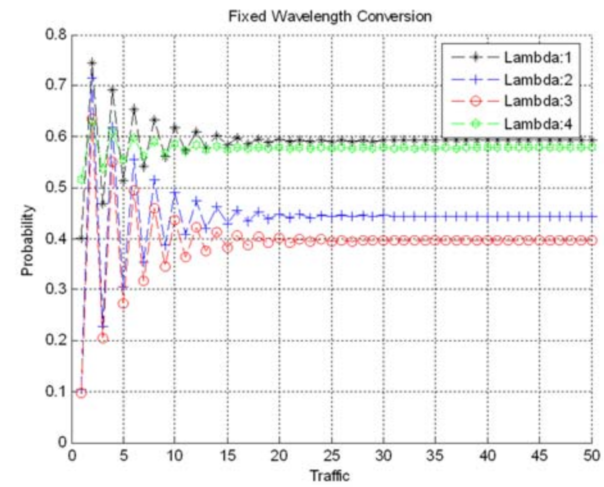

Fig. 9(a)

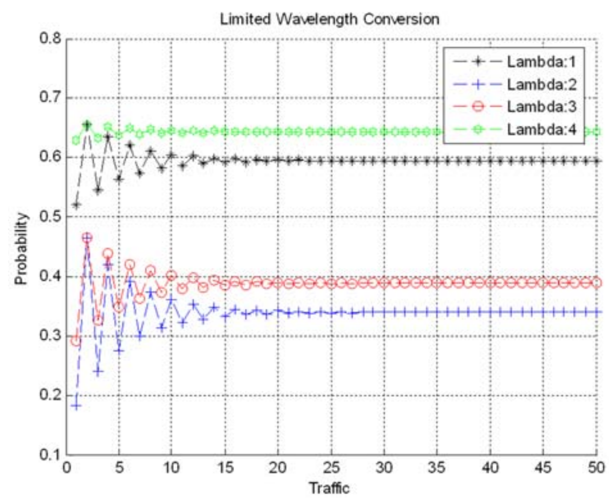

Fig. 9(b)

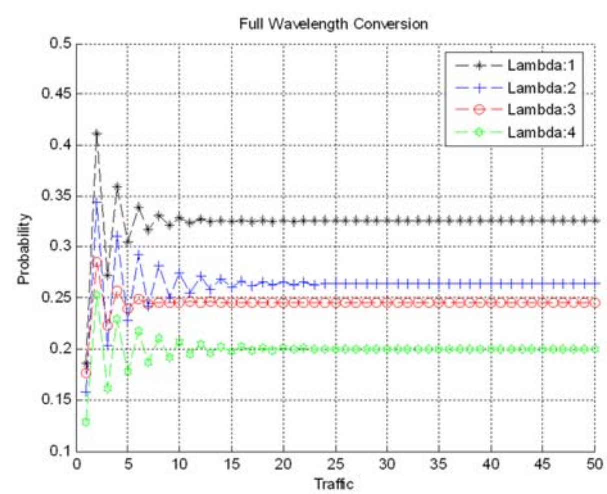

Fig. 9(c)

Fig. 9(a), 9(b) and 9(c) Wavelength Conversion in FWC,LWC and FuWC

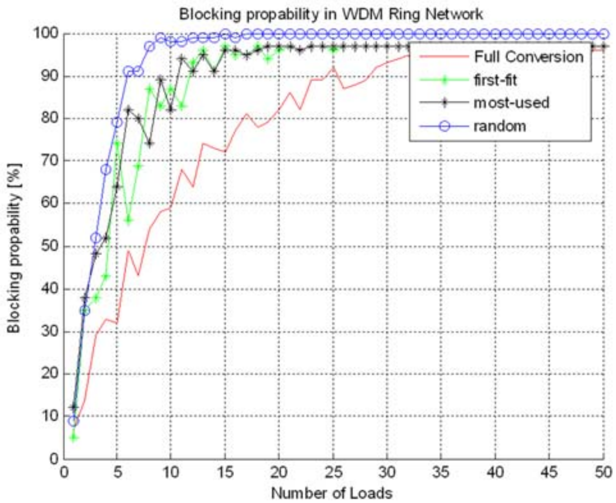

Fig. 10 Comparing Experiments between First-Fit, Most-used Random and MPM-WA

The result in Fig. 9 (a,b,c) shows that each structure had low used wavelength probability. FWC used λ_3 with a 0.402 probability. LWC used λ_2 with a 0.347 probability. FuWC used λ_4 with a 0.202 probability. FWC used the highest used wavelength. Followed up with LWC and then is FuWC. With the outstanding ability of wavelength conversion, these models could be brought to design the node for suitable wavelength usage evaluation.

Fig. 10 is a result of a usage comparison between First-Fit ,Most-used and Random methods. When confining the number of used wavelengths to 4 and the loaded traffic number to 20, MPM-WA model gave out the best blocking probability. The result of applying MPM-WA with FAP-Routing for light path designation in WDM ring network as in Fig. 3 by imitating the data transmission from A node to C node, are shown below in Table 2 .

Table 2 The experimental result that will be used in WDM Ring Network designation.

S-D Pairs	Path Length	Wave length	Route Length	Blocking Probability
A-D	A-D	λ_2	1	0.0123
	A-B-C-D	$\lambda_4, \lambda_1, \lambda_2$	3	0.0432
B-C	B-C	λ_1	1	0.0184
	B-C-D-A	$\lambda_2, \lambda_3, \lambda_1$	3	0.0526
C-D	C-D	λ_4	1	0.0218
	C-B-A-D	$\lambda_3, \lambda_1, \lambda_4$	3	0.0471

Table 2 the results of a WDM network designation on ring network architectural connection as in Fig. 2. The structure has 4 connecting links and 4 used nodes in the network. The experiment was done by assuming there were a Poisson distribution of input traffics, exponential traffic rate usage, 100 average cycles, 50 Erlang traffic load and 4 used wavelengths. The experiment used the MPM-RW algorithm of wavelength assignment and Fixed-Alternate Path Routing method for route selection. The network's cost function was calculated along with the traffic blocked probability of the network. This calculation depended on the selection of used wavelengths. The results show that when there is a low Route Length number, the probability of traffic blocking will be low as well, which means it can be used as the main route. Also when Route Length number is high, the traffic blocked probability will be high. This is because the optical route will require many used wavelengths, hence the probability of traffic blockage rises up accordingly. Disadvantage that we found, by the method of MPM-WA, Its test result, the process is more complicated than the 3 methods mentioned above which is only conducted on ring network. This research hasn't taken the other network types into consideration such as star network, mesh network. However, the test result is better than the results of those 3 methods.

4. **Conclusion and Discussion**

This article is to find suitable wavelengths by using MPM-WA method of wavelength assignment's problem in WDM ring network. The wavelengths will be used in optical routes on FWC, LWC, FuWC structures of wavelength conversion. This research focuses on simulating the light path of wavelength division multiplexing on ring network is for its more speed and efficiency. They can also apply to a light path finding method called fixed alternate path routing in order to design optical routes on a optical multiplex Ring network architectural connection. The result showed that MPM-WA method gave better traffic blocked probability than First-Fit WA,Most-Used WA and Random WA methods. It can also be used effectively in light path designation on a ring network with the condition of the smallest traffic blocking probability.

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ปัจจุบันดำรงตำแหน่งอาจารย์ประจำสาขาวิชาวิศวกรรมสารสนเทศและการสื่อสาร คณะเทคโนโลยีอุตสาหกรรม มหาวิทยาลัยราชภัฏเพชรบุรี