

A FUZZY CHANNEL ALLOCATION SCHEME FOR THE WDM HIERARCHICAL ALL-OPTICAL NETWORK

Elok Robert Tee

Mohd. Yazid Md. Saman and A. K. Ramani

Jabatan Sains Komputer
Universiti Putra Malaysia
43400 UPM Serdang
email: robert@fsas.upm.edu.my

V. Prakash

Fakulti Kejuruteraan
Jabatan Komunikasi
Universiti Putra Malaysia
43400 UPM Serdang
email: prakash@eng.upm.edu.my

ABSTRACT

The fuzzy means of allocating WDM channels in a hierarchical all-optical network (AON) for the modified token medium access protocol is addressed. The goal is to minimise the average delay of local subnet and global bound traffic, and to maximise the number of nodes that can be supported by the network. This is achieved by allotting a minimum number of spatially-reuse channels to the subnets, which can accommodate a certain maximum number of nodes. Actually the minimum number of nodes that are sought for each subnet in terms of cost. By working out the maximum number of nodes for each subnet and the total subnets that can be supported, the optimum number of global channels and the overall total number of nodes for the entire network, can hence be determined. The packet generation rate and average delay in slot time are used to gauge the performance of the fuzzy channel allocation model.

Keywords: Hierarchical, All-optical network (AON), Wavelength division multiplexing (WDM), Fuzzy control, WDM channel allocation, Modified token-passing protocol

1.0 INTRODUCTION

Medium access control (MAC) procedures have been extensively studied on its role in arbitrating access to achieve higher throughput and network support for more nodes. The modified token-passing is a fair round-robin scheme for WDM that is not time-synchronous, yet able to provide a guaranteed access latency. This is achieved by limiting the packet size and restricting the time a node can hold the token. The token is passed along continuously in a logical manner. Data is transmitted after the token, and both are sent on randomly sensed (or the first few sensed available) free channels [1-7].

Channel reservation, broadcast and multicast are possible with the modified token-passing protocol. When reserving a channel, the node selects a free channel and announces its reservation. A reserved channel can be made available for two or more nodes, and communications among these nodes may be regulated by

other means, e.g. a dedicated token, time slotted or transmission by collision sensed. Broadcast and multicast are achieved as determined by the destination address identifier on the token. The node can receive from all the available channels.

An array type receiver is implemented at the node, while the transmitter can be wavelength tuneable. The array types are more expensive, and theoretically feasible for very high numbers of WDM channels. The array receiver that monitors all the channels for the token will read only the channel(s) with transmission directed for the node, by referring to the destination address on the token. Since the node can receive simultaneously from all channels, some forms of input buffering and multitasking processing capabilities are inadvertently required. The typical operation of the node and its receiver, however is not within the present scope of this study. The wavelength tuneable transmitter will sense all channels in sequence for inactivity when it has a token with or without data to transmit.

In AON, complete lightform transmission from source to destination in a single-hop is possible, i.e. no intermediate intervention or signal regeneration [8]. The hierarchical AON is constructed with an optical coupler for subnet interconnection, and the wavelength partitioner (WP) at the subnet level for channel allocation to the nodes. The physical topology resembles a star with WPs for nodes at the branch ends. Spatial channel reuse is filtered for the nodes at the subnets. For a model with C WDM channels, $C = \{\lambda_1, \lambda_2, \dots, \lambda_n\}$, the subnets may be allotted local channels, $C_L = \{\lambda_1, \lambda_2, \lambda_3, \dots, \lambda_m\}$. Communications among the nodes of a subnet will utilise only the C_L channels. The remaining global channels, $C_G = C - C_L$, $C_G = \{\lambda_{m+1}, \lambda_{m+2}, \lambda_{m+3}, \dots, \lambda_n\}$ are accessible by all nodes on the network, and are used for communications among the subnets. The channels that are allotted to every subnet may be different sets depending on the resource demands. A symmetrical model where each subnet has the same configuration is used, i.e., similar numbers of nodes and channel allocation [9, 10]. The AON model forms a double-layered hierarchy.

1.1 Channel Resource Allocation

The problem of this paper lies in deciding optimal channel allocation, to provide sufficient channel resources which contribute to the delay in transmission (medium access). With fewer channel resources, packet generation may be blocked and buffered packets may have to wait for busy channels to clear. Channel reservation for private use can compound the problem as channels can be hogged up way in advance. As with all network designs, the primary goal is to support as large as possible the number of nodes (or network resources). This in effect also contributes to the delay in transmission. With token-passing, increasing the number of nodes will add to the latency of the token cycle. As described, the double-layered hierarchical network architecture serves to dissipate the token cycle latency by grouping nodes that intercommunicate frequently into subnets. Leaving an upper layer for intercommunication among subnets (of nodes within). The assumption being the traffic load between two nodes of different subnets, will be at least less than 50% of the average load, of two nodes of a same subnet. The number of channels that are allotted to the subnet determines the number of nodes that can be supported by the subnet [11-14].

1.2 Scope of the Problem

Thus, the scope of the problem focuses on achieving a tolerable delay in transmission for the node. This is the average delay experienced by a packet in waiting for its turn for transmission. The scope includes the goal of the AON to support a large number of nodes. The resolution objective is the allocation of channels, for the upper or global layer and to the subnets or local layer.

The token MAC scheme eliminates the need for universal clocking of transmission as implemented for the slotted transmission schemes that are time synchronous [2, 3, 4]. While the AON architecture easily permits the MAC protocol to transmit a local bound packet using the global channels. Another contribution of this work is the fuzzy definition for channel allocation, which can accommodate compromise from varying channel demands of different subnets.

This paper is organised as follows. The objectives of the fuzzy model are described in detail in the next section. In Section 3, the fuzzy set solution method is described. The results from the tests are presented in Section 4 and the summary of this work is discussed in the last Section 5.

2.0 THE OBJECTIVES

In resolving the channel allocation for the double-layered hierarchical AON model, either set of the global channels or the local channels may be considered. By limiting the total channels available for use C , given a particular set, C_y the other set may be deduced $C_x = C - C_y$. The channel allocation functions referring to the global average delay and the highest number of nodes that can possibly be supported by a subnet, are defined as $D(C_y)$ and $N(C_y)$ respectively. The function on (C_y) being the allocation of global channels, since the local channels can be deduced. And because the global channels carry traffic for all nodes on the network, the global average delay that is suffered as the packet generation rate is increased, is much greater than the local average delay. The effect is illustrated as Fig. 1 comparing the global bound traffic performance of 144 nodes with the subnet traffic of 4 nodes.

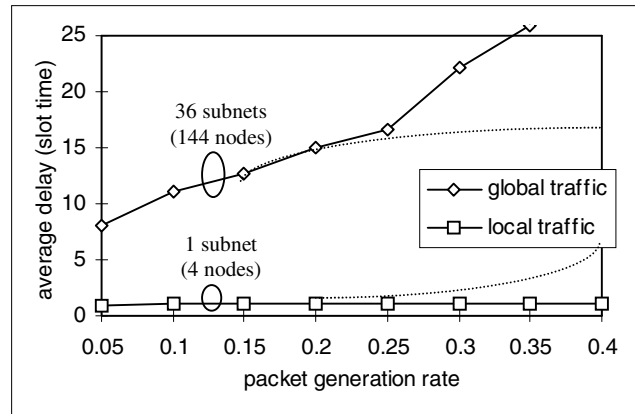


Fig. 1: Performance of a 4 nodes by 36 subnets model.
 $C=24$, $C_G=22$, $C_L=2$

Fig. 1 shows the degrading performance of the transmitter in sending global bound packets as the packet generation rate is gradually increased. Local bound traffic remained constant in the example, as the two C_L channels allotted served only a single communicating pair of nodes each. The dotted lines show the desired performance, the local increase is a compromise with less channel resources.

In reducing the global average delay, more channels must be allotted for global bound traffic. Remaining channels will be allotted to the subnets for local bound traffic. The number of channels allotted to a subnet will determine how many nodes the subnet can support. The goal of the subnets however is to support as many nodes as possible given the remaining channels. Increasing the number of nodes will also increase the local bound traffic. The objectives are now conflicting, i.e. to minimise global average delay by global channel allocation and to

maximise the number of nodes (in a subnet) given the global channel allocation (by the remaining channels). The conditions thus are expressed as

$$\begin{aligned} &\text{Minimise } D(C_y) \\ &\text{Subject to } N(C_y) \leq N_{\max} \end{aligned}$$

N_{\max} being the maximum number of nodes that can be supported by a subnet. The objective being to minimise the allocation of global channels:

$$\begin{aligned} &\text{Minimise } \left(\begin{array}{c} D(C_y) \\ N(C_y) \end{array} \right) \\ &\text{Subject to } c_x \leq C_y \leq (C - 1) \end{aligned} \quad (1)$$

where c_x denotes the minimum number of remaining channels allotted to the subnet, and $(C - 1)$ denotes at least one channel must be allotted to the subnet. Note that c_x can be $c_x \leq C_x$.

2.1 Fuzzy Sets from Performance Model

The conflicting objectives represent a multi-objective decision environment [14], each goal can be represented by a fuzzy set. The fuzzy sets are associated real-value measures as defined, i.e. $D(C)$ and $N(C)$ [15-17]. These are obtained from performance analysis of the semi-Markov probabilistic model [1, 9, 10]. The global average delay is the sojourn time calculated from the probabilities a data packet traversed and waited in the semi-Markov transition states, using Little's Law. A full description of the general SMP model can be found in [9].

3.0 FUZZY SOLUTION

The fuzzy set theory deals with properties that are loosely defined where no clear boundaries exist to which to associate them. In working with fuzzy properties, fuzzy sets are defined with membership functions to indicate the likelihood that, x belongs to the set. The multi-objective decision can be defined as fuzzy sets and resolved through finding a compromise among the alternatives [13-18].

The membership functions of the fuzzy sets associated to the global average delay and subnet nodes are defined as $\mu_D(D)$ and $\mu_N(N)$ respectively. Another for the fuzzy sets associated to the global bound traffic and the local bound traffic are defined as $\mu_G(C_y)$ and $\mu_L(C_y)$ respectively. The first sets are used to indicate to the channel allocation controller the degree of acceptability with the measures of D and N . While the second sets are to indicate the degree

of acceptability with the performance goal on the traffic types that the controller perceives for the allocation of C_y [14]:

$$\mu_G(C_y)(\mu_L(C_y))$$

For each goal, the relationship between the membership functions is represented by:

$$\left. \begin{array}{l} \mu_G(C_y) = \mu_D(D(C_y)) \\ \mu_L(C_y) = \mu_N(N(C_y)) \end{array} \right\} \quad \text{for all } C_y$$

The compromise decision is defined as the highest value that is return from the allocation of global channels. The membership function on the allocation of global channels is thus to minimise the fuzzy sets:

$$\mu_{\text{alloc}}(C_y) = \min(\mu_G(C_y), \mu_L(C_y))$$

Although $\min(\mu_L(C_y))$ seems conflicting with the goal of the subnet (to support as many nodes as possible), it seeks to keep the numbers small, but exploits the maximum that can be supported without jeopardising local performance.

3.1 Fuzzy Optimisation

Optimisation involves lowering the global average delay and defining the number of nodes in a subnet, to which the membership functions are mapped between the closed interval values of $[0, 1]$. The lower bound denotes the most desirable outcome while the upper bound is otherwise:

$$\begin{aligned} 1 &- \text{lower bound, desired outcome} \\ 0 &- \text{upper bound, less desired} \end{aligned}$$

Let the following denote the solutions to minimise $D(C_y)$ and $N(C_y)$, the number of channels that may be allotted:

$$\begin{aligned} C_y^D &= C_1 \dots C_{G-1} \\ C_y^N &= c_1 \dots c_L \end{aligned}$$

also define

$$\begin{aligned} D^0 &= D(C_y^D) \\ D^m &= D(C_y^N) \dots \text{max. delay, higher } c \\ N^0 &= N(C_y^N) \\ N^m &= N(C_y^D) \dots \text{min. nodes, max. } C \end{aligned}$$

(e.g. where D^0 - lower bound, D^m - upper bound, to define the tolerance intervals $[D^0, D^m]$)

and

$$\begin{aligned} d^D &= D^m - D^0 \\ d^N &= N^m - N^0 \end{aligned}$$

The membership function defined for variables D and N representing the global average delay and subnet nodes, as functions of C:

$$\mu_D(D) \begin{cases} 0, & \text{subject to } D \geq D^m \\ (D^m - D)/d^D, & D^m \geq D \geq D^0 \\ 1, & D^0 \geq D \end{cases}$$

$$\mu_N(N) \begin{cases} 0, & N \geq N^m \\ (N^m - N)/d^N, & N^m \geq N \geq N^0 \\ 1, & N^0 \geq N \end{cases}$$

3.2 Solution Method

A certain value of the functions μ_G and μ_L is assumed, i.e. μ . This is the value where the functions cross each other, which may provide the optimal (fuzzy) solution for C_y . From $\mu_G(C_y)(\mu_L(C_y))$, the solution which is a decreasing (increasing) operation from 1 (0) at c to 0 (1) at C in C_y on $[c, C]$.

$$\begin{aligned} &\text{Maximise } \mu_L(C_y), \\ &\text{Subject to } \mu_G(C_y) \geq \mu \\ &\quad c_x \leq C_y \leq C \end{aligned}$$

The membership functions of $\mu_G(C_y)$ and $\mu_L(C_y)$ can be defined for each channel allocation or as a closed formula that encompasses the necessary input parameters [9, 10] to compute the approximate number of channels. The latter would produce rigid fuzzy sets as the values will not be reflective of real values. For operation, it is envisaged that the fuzzy set membership will be altered regularly to reflect the actual demands. This set will be the probable demand levels for the next run. In this model, the number of nodes is prefixed before commencing trail. As such, the only the global channels (and the remaining that is allotted spatially to the subnets), are manipulated depending on the global average delay that is achieved at higher packet generation rates. The model operation begins with a fixed number of nodes and c_x channels, the (increasing) global average delay is observed and (more) global channels may be allotted. Note that there may also be free channels from $(C_x - c_x)$ which can be allotted to the subnets. The test is repeated for different node configuration of subnets.

4.0 SOME RESULTS

The results from probability performance models [9,10] are used for the fuzzy sets. The fuzzy allocation scheme is incorporated into the models to step-vary the number of global channels. Global bound traffic may include some of the local bound traffic which may occur if the global token arrives before the local token, and no global bound data is awaiting transmission. *Other conditions apply to transmit over the global channels, e.g. local congestion.* The fuzzy scheme is applied to the double-layered AON,

the performance indicators which are the average delay in normalised slot time on increasing packet generation rates γ (e.g. Fig. 1). Table 1 exemplifies the global average delay of the model configuration of 8 nodes by 18 subnets varying $C_G = \{18, 20, 22, 24\}$ and $\gamma = \{0.35, 0.4\}$.

Table 1: Sample of results from varying global channels

global delay (slot time) of 144 nodes		global channels, C_G
$\gamma=0.35$	$\gamma=0.40$	
100+	100+	18
36.763	100+	20
27.158	86.482	22
26.095	34.175	24

Subnet performance with $\{4, 6, 8\}$ nodes and $c_x = \{1, 2\}$ at $\gamma=0.4$ are exemplified as Table 2. These are approximate results from the probabilistic model.

Table 2: Sample of results from varying nodes of a subnet

number of nodes in each subnet	local channels, C_L	local delay
4	1	4.392
4	2	2.295
6	1	13.371
6	2	13.171
8	1	35.29
8	2	15.0

Fig. 2 plots the performance of a model with 16 subnets, and 9 nodes for each subnet. The global average delay in slot time is plotted for the global channels and that of the subnet as the packet generation rate is gradually increased. From the graph it is observed that by varying the global channels between $\{22, 23\}$ and reducing the local channels to 1, the global average delay is kept below 25 slot time at $\gamma=0.4$ when compared to Fig. 3. The local average delay increased sharply as the nodes now have only one channel to content with. Fig. 3 plots the performance of different node by subnet configurations, i.e. 8x18, 6x24 and 4x36. The global average for 144 nodes is shown only for 8x18 as results from the other configurations resemble closely of the performance curve. The bottom lines (Fig. 3) show the local average delays of the subnets with $\{4, 6, 8\}$ nodes respectively.

As aforementioned, it is possible to reduce the local average delay by permitting the local bound packets to access local nodes through the global channels. Fig. 4 and Fig. 5 illustrate the performance of the 8x18 model with the local average delay maintained due to the alternative path available. The local channels are tested for $C_L = \{2, 1\}$ while $C_G = 22$. The results indicated that a single channel is sufficient to support the configuration.

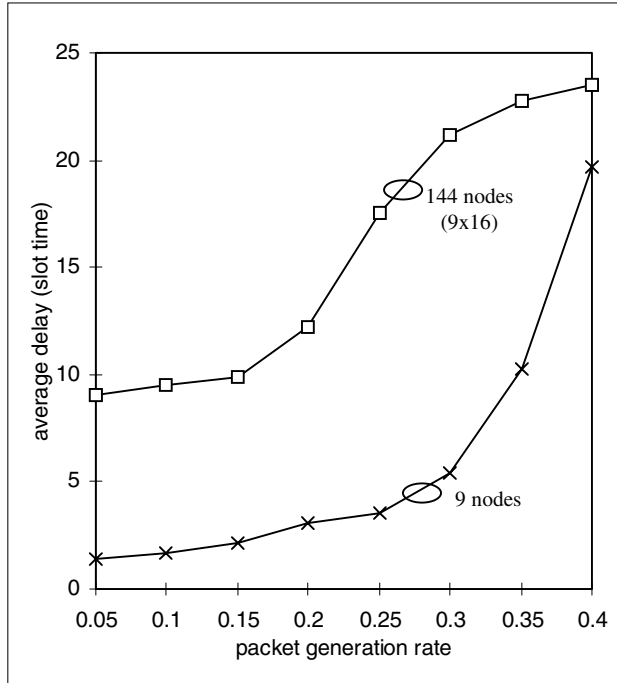


Fig. 2: Performance of 9 nodes x 16 subnets with fuzzy channel allocation, i.e. $C_G + C_L$ varied between 24. $C=24$, $C_G=\{22,23\}$ $C_L=\{2,1\}$

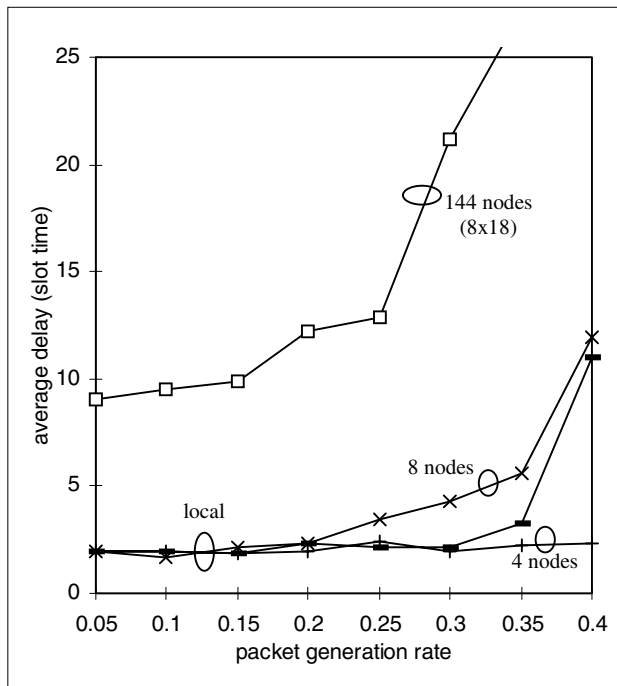


Fig. 3: Performance of 8 nodes x 18 subnets. $C=24$, $C_G=22$, $C_L=1$

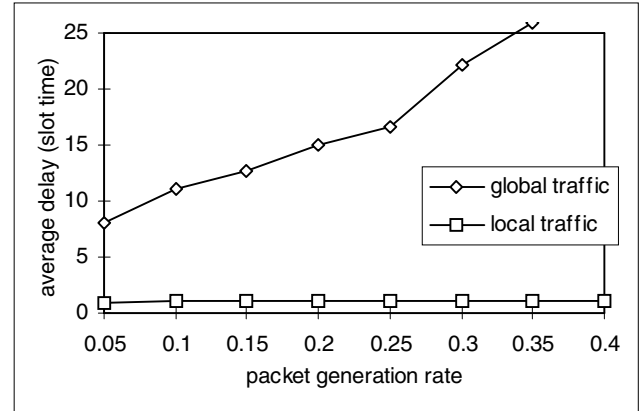


Fig. 4: Performance of 8 nodes x 18 subnets with global channels accessible to local traffic with fuzzy channel allocation. $C=24$, $C_G=22$, $C_L=2$

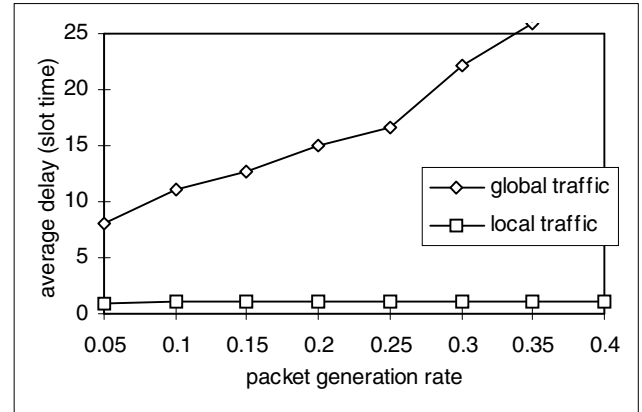


Fig. 5: Performance of 8 nodes x 18 subnets, with global channels accessible to local traffic. $C=24$, $C_G=22$, $C_L=1$ (1 channel not used)

5.0 DISCUSSIONS AND SUMMARY

This paper has shown a possible approach to optimise the allocation of channels, for a double-layered hierarchical AON in performance modelling. The idea is simple in that it provides leeway in catering for other input parameters, e.g. channel utilisation instead of number of nodes. The definitions for both μ_G and μ_L can be defined otherwise, as actual traffic loads, along with their membership function declaration. These are used by the controller to determine the conditions, such as traffic load, on the global and local channels which are directly affected by (associated to) the global average delay and the subnet configuration. The fuzzy optimising solution that is devised, may not be effective enough to produce the desired levels of outcome from the approximated fuzzy sets. The values which are likely to be taken from aggregation of past runs, and may not accommodate to real-time fluctuating differences in channel demands. The

fuzzy set scheme may not respond efficiently too, to dynamically fluctuating demands as it is dependent on lookup to the sets, and updating them. Thus, for this work an alternative to the fuzzy set approach should be considered [15-17]. Future work may include the study on the effects of the mixed traffic (level) types on the global channels, and perhaps on non-symmetrical subnet configurations.

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BIOGRAPHY

Elok Robert Tee is currently a Ph.D. candidate at Universiti Putra Malaysia. He received his B.Sc.(Hons) in Computing Science from Staffordshire University, and M.Comp.Sc. from the University of Malaya. His research interests include biometrics verification systems, massive systems integration, fiber optic communications and the impact of IT.

Md. Yazid Mohd. Saman received his Ph.D. in Computer Science from Loughborough University of Technology, his Masters from Universiti Teknologi Malaysia and B.Sc. from Essex University. His field of research interests include parallel processing, networking, simulation and modelling.

A. K. Ramani received his B.E. in electronics, M.E. in digital techniques and instrumentation, and Ph.D. from the Devi Ahilya University, where he is currently on leave as Associate Professor at Universiti Putra Malaysia. His research interests are in high performance computing, networks, distributed systems, fault-tolerant computing and operating systems.

Veeraraghavan Prakash is working as a Lecturer in the Department of Computer and Communication System Engg. He has obtained his Ph.D from Indian Institute of Technology, Madras, India. His field of research includes Graph Theory and Combinatorial Optimization, VLSI Design, Image compression, Computer security and Distributed networking.